RESEARCH

Social and economic flows across multimodal transportation networks in the Greater Tokyo Area: Supplementary Materials

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Data Details

Table 1 Summary of the population and employment data used in our analysis. After adjusting each hex's population aged 15-64 by the population adjustment factor and adjust for fractional people we confirm that the total population of the hexes does indeed equal the total number of jobs.

Number of Hexes	244,721
Total Number of Companies	1,417,979
Largest Company Count	831
Total Number of Jobs	16,614,941
Largest Job Count	15,665
Total Population Aged 15-64	22,743,338
Population Adjustment Factor	0.73054
Total Rounded Adjusted Working Population	16,613,199
Total Adjusted Working Population	16,614,941
Highest Population	2,024
Highest Net Demand	15,665
Highest Net Supply	−1,506

Road Network Details

Table 2 Default speed limits and assumed driving speeds in kph by road type when data was unavailable in [1]. We use the driving speeds and assumptions on lanes to calculate capacity [2, 3, 4]. The number of lanes in refers to the value for one-lane traffic. We use the driving speeds and Haversine distance between endpoint nodes to calculate traversal times.

Road Type	Speed Limit	Driving Speed	Number of Lanes Each Way	Road Link Capacity Vehicles per Hour
Motorway	80	70	3	6000
Motorway Link	60	40	1	2000
Trunk	60	30	2	4000
Trunk Link	50	30	1	2000
Primary	50	30	2	2000
Primary Link	50	30	1	1000
Secondary	40	30	1	1000
Secondary Link	40	30	1	1000
Tertiary	30	30	1	1000
Tertiary Link	30	30	1	1000
Road (undefined)	30	25	1	500

Network Structure Summary

Table 3 Summary of basic network features by transportation mode. Train and bus networks are bi-directional, but the timeWeights of access edges are asymmetric. The road network includes 23.1% one-way links, often representing each side of a divided two-road. The hex network as well as the intermode walking links are fully symmetrically bi-directional. Train station and bus stop edge counts include both transfer and access links.

Transportation Mode	Node Count	Directed Edge Count
Train Stations	1,546	46,028
Train Lines	5,179	10,536
Bus Stops	32,901	710,432
Bus Routes	93,086	181,574
Road Network	58,012	113,582
Hex Network	244,721	1,459,096
Intermode "Glue" Links	0	434,892
Integrated Network	435,445	2,921,886

Analysis Details

Table 4 The greatest net demand equals the highest value for jobs, indicating the population is zero there. The greatest supply (negative demand) is 518 less than the greatest population, indicating that there are at least 519 jobs (actually it's 808 jobs) in that hex. The hex with a supply of 1,506 has an adjusted working population of 1,638.

Highest Net Demand	15,665
Highest Net Supply	1,506

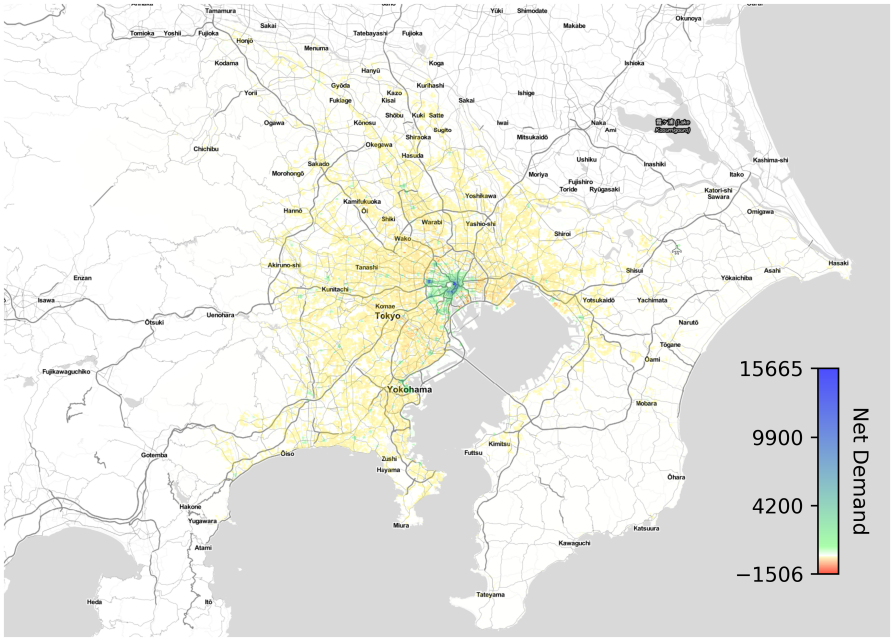

Figure 1 A map of the Tokyo area showing the net demand for workers (number of jobs minus the adjusted working population) for each hex. Map tiles by Stamen Design[5], map data by OpenStreetMap[1].

Results Details

Table 5 Total usage frequency of each link mode used for three generated flow datasets. The number of times an edge is used is less informative than the distance traveled and time spent on each edge modality, but is still informative for certain usage statistics such as transfers and access links.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	683,871	466,386	466,431
walk	1,852,251	2,123,304	2,121,659
train	1,157,548	1,887,936	1,889,764
trainTransfer	52,778	221,755	221,233
trainAccess	407,128	553,800	553,802
bus	66,912	65,757	65,735
busAccess	35,280	30,900	30,898
busTransfer	480	1,744	1,744
road	2,431,690	3,972,597	3,972,191

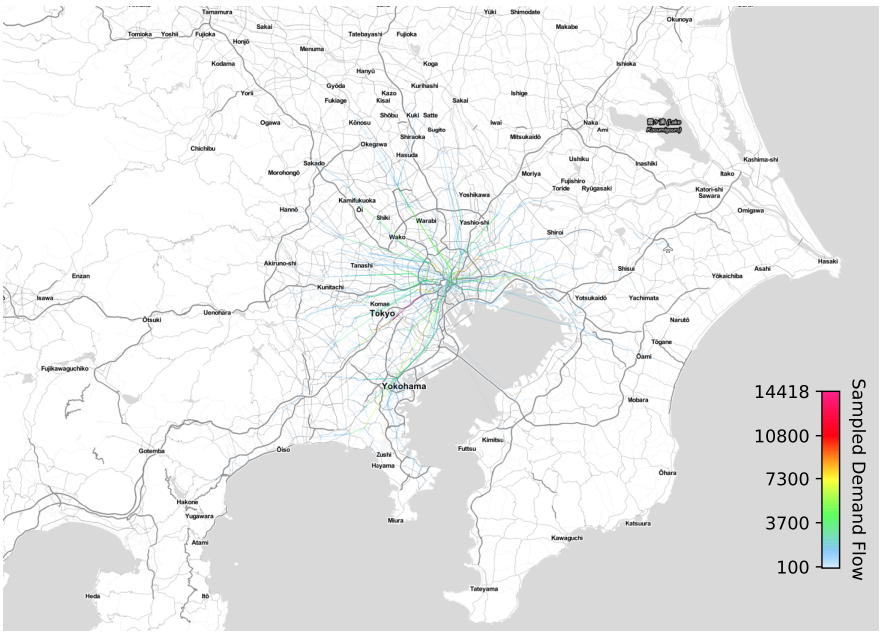

Figure 2 A map of the Tokyo area showing the flow solution found by the simplex algorithm using a sample of one million people/jobs. Map tiles by Stamen Design[5], map data by OpenStreetMap[1].

Table 6 Percent of the usage frequency of links by modality for three generated flow datasets.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	10.225	5.002	5.003
walk	27.695	22.772	22.756
train	17.308	20.248	20.269
trainTransfer	0.789	2.378	2.373
trainAccess	6.087	5.939	5.94
bus	1.0	0.705	0.705
busAccess	0.528	0.331	0.331
busTransfer	0.007	0.019	0.019
road	36.359	42.605	42.604

Table 7 The total amount of time used by each link modality for three generated flow datasets.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	2,051,579.26	1,399,160.0	1,399,294.57
walk	1,700,939.41	1,970,929.0	1,970,769.13
train	5,258,420.73	9,181,407.0	9,184,124.36
trainTransfer	263,890.0	1,108,775.0	1,106,165.0
trainAccess	1,221,384.0	1,661,400.0	1,661,406.0
bus	242,072.0	297,467.0	297,479.0
busAccess	105,840.0	92,700.0	92,694.0
busTransfer	2,400.0	8,720.0	8,720.0
road	206,6997.7	349,6978.0	349,6883.4

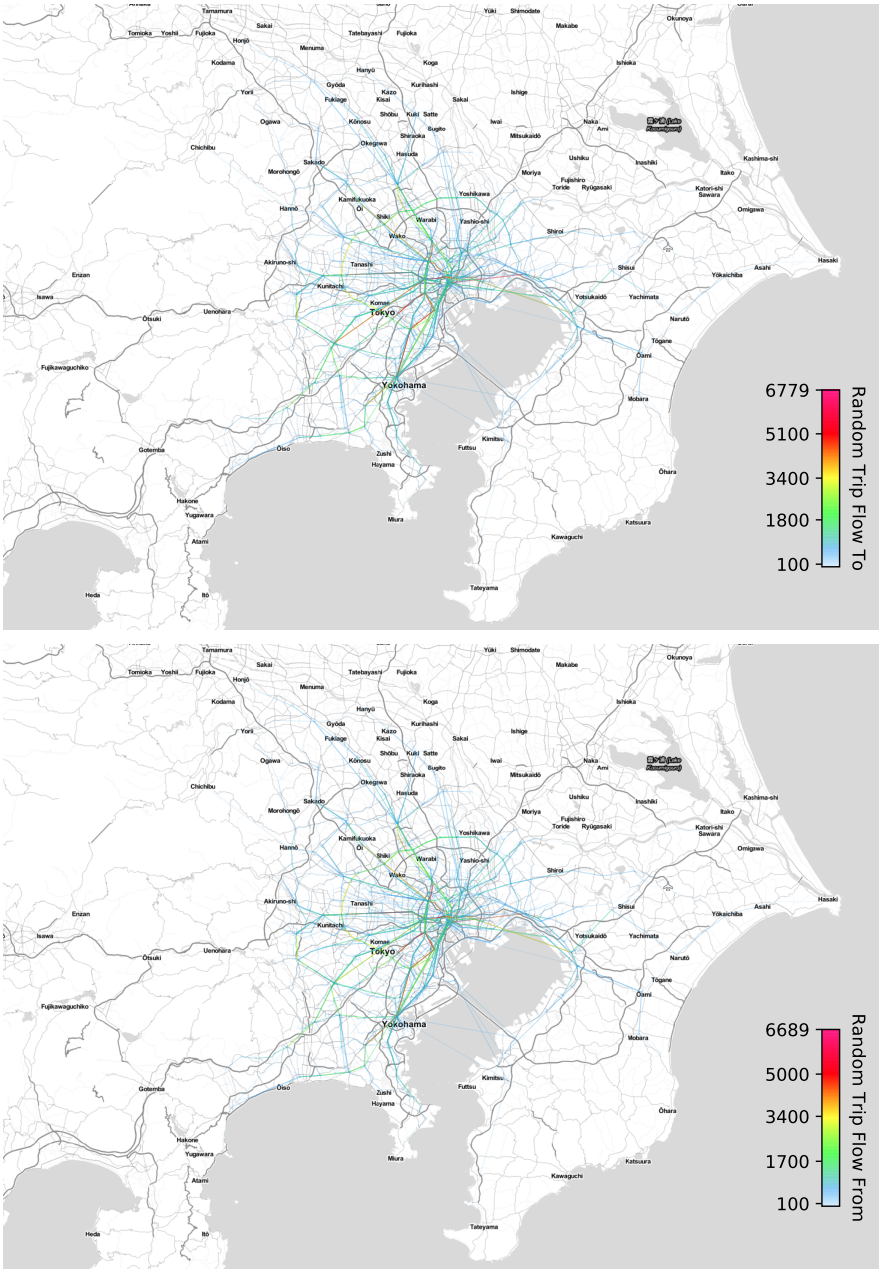

Figure 3 A map of the Tokyo area showing the edge-use frequency among 300,000 random trip to-work; i.e., from a hex chosen from the population distribution to a hex chosen from the distirbution of jobs at top and the opposite direction ("from work") at bottom. To focus attention on the heavily used corridors, we filtered edges with fewer than 100 trips in these diagrams (but not in our analysis). Note that edges going in each direction for each pair of nodes overlap, and even at 0.3 opacity some of the difference in color may be due to the z-order. Map tiles by Stamen Design[5], map data by OpenStreetMap[1].

Table 8 The percent of total travel time used by each link modality for three generated flow datasets.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	15.887	7.281	7.281
walk	13.172	10.256	10.255
train	40.72	47.776	47.79
trainTransfer	2.044	5.77	5.756
trainAccess	9.458	8.645	8.645
bus	1.875	1.548	1.548
busAccess	0.82	0.482	0.482
busTransfer	0.019	0.045	0.045
road	16.006	18.197	18.196

Table 9 The total distance traveled via each link modality for three generated flow datasets.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	170,964,938	116,596,626	11,660,7881
walk	141,762,124	164,283,266	164,269,961
train	4,594,523,349	8,191,513,698	8,191,803,582
trainTransfer	4,380,574	18,405,665	18,362,339
trainAccess	33,791,624	45,965,400	45,965,566
bus	171,822,488	203,399,144	203,401,724
busAccess	2,928,240	2,564,700	2,564,534
busTransfer	39,840	144,752	144,752
road	1,037,008,963	1,753,357,535	1,753,316,536

Table 10 The percent of total travel distance used by each link modality for three generated flow datasets.

Modularity	Simplex Algorithm 1,000,000 Demand	Random Trips 300,000 To Work	Random Trips 300,000 From Work
hex	2.777	1.111	1.111
walk	2.302	1.565	1.565
train	74.62	78.042	78.044
trainTransfer	0.071	0.175	0.175
trainAccess	0.549	0.438	0.438
bus	2.791	1.938	1.938
busAccess	0.048	0.024	0.024
busTransfer	0.001	0.001	0.001
road	16.842	16.705	16.704

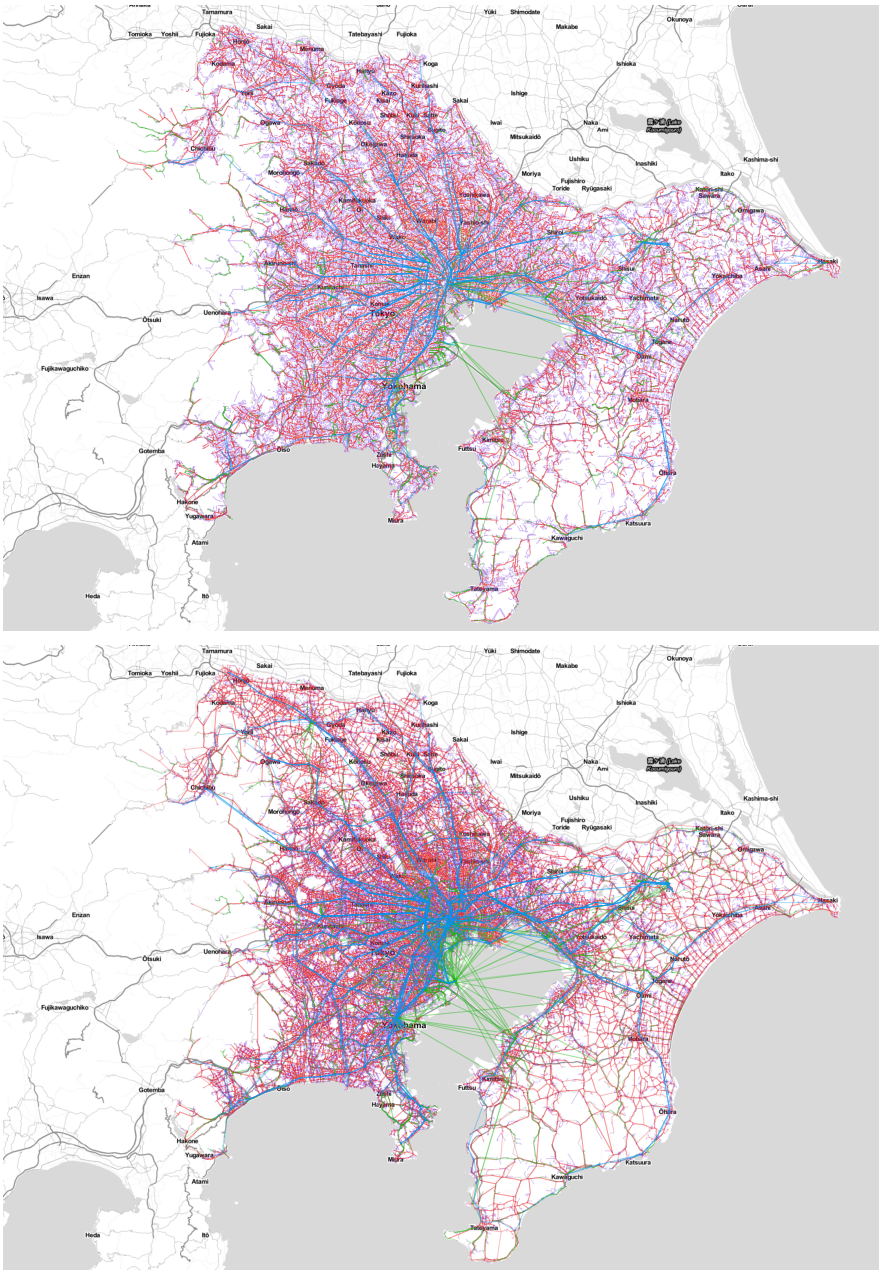

Figure 4 A map of the Tokyo area showing the links used by mode for the simplex algorithm (top) and random trips to-work (bottom) isalated to links with more than 10 traversals. Blue lines are trains, green are buses, red are roads, purple are interhex links, and connecting walking links are orange. Map tiles by Stamen Design[5], map data by OpenStreetMap[1].

Availability of Data and Material

As described in the text, the population/employment/mesh data and road network data are openly available from the citations provided. The train and bus network data come from third-party sources (Ekitan). Additional output data and/or plots of data generated are available upon request.

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References

1. OpenStreetMap Contributors: Planet dump retrieved from https://planet.osm.org (2019). https://www.openstreetmap.org
2. Japan Traffic Safety Association: Rules of the Road. Japan Automobile Federation (2017)
3. Polus, A., Craus, J., Livneh, M.: Flow and capacity characteristics on two-lane rural highways. Transportation Research Record (1320) (1991)
4. Highway Capacity Manual: Highway capacity manual. Washington, DC **2** (2000)
5. Stamen Design: Map Tiles (2019). {http://maps.stamen.com}