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Visualizing Road Network Congestion to Inform Regional Planning in Southern Maine

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Abstract

This work presents a model by which road network congestion (traffic congestion) may be analyzed at spatial units other than the road segments themselves. Using Geographic Information Systems (GIS), I present a method for apportioning road segments and aggregating the characteristics of the segments – namely, an index of the potential for congestion to occur at various times of day – to any polygon containing them. The present work uses U.S. Census Block Groups as the unit of analysis; however, any areal unit can be used, including traffic analysis zones (TAZs), zoning zones, or even entire municipalities. The method of aggregating characteristics to larger areal units allows for easier analysis in combination with other data sources. To increase the usefulness of the method, aggregation is completed using several different methods. In this analysis, road traffic volumes and capacity estimates are used in conjunction with population data and population change forecasts to visualize the potential for congestion at present, and to project the potential for congestion in 2030. The areas most and least at risk of congestion are identified, so as to inform thought and effort around planning on a regional scale in southern Maine. The area of study includes large portions of York and Cumberland Counties, as well as a small portion of Androscoggin County, in the Greater Portland region.

Acknowledgements

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Table of Contents

"Traffic congestion is a waste of time, and often a miserable waste of time.
It is certainly one of the curses of modern life" (Arnott, 2005, p. 1).

Introduction

In 2010, an advanced land use modeling seminar at the Muskie School examined issues surrounding data collection and planning at a regional level in Southern Maine. One facet of the seminar work was a preliminary analysis of the potential for congestion in the region. The seminar work was a precursor to the Sustain Southern Maine effort, a partnership to address issues of economy, transportation, public health, land conservation, among others, on a regional scale (Sustain Southern Maine, 2012). The present work continues to consider the same metropolitan study area, with congestion as its main focus.

The Importance of Regional Planning

Writers over the years have waxed and waned on the merits of regionalism. Rexford G. Tugwell, the New Deal-era planner, argued that planning would "necessarily become a function of the federal government" (1932, pp. 88–89). This federal function, organized as a "central board," would coordinate the top-level activities of industry – any activities that could impact the entire economy – while leaving operational details to localized (non-federal) boards positioned within specific industries (Sternsher, 1964, p. 98).

Since that era and World War II, the federal government has provided support for regional planning through programs such as the section 701 program administered by the Department of Housing and Urban Development (HUD), emphasizing local government cooperation in regional planning (Weiner, 2008, pp. 43–44). In addition, the Federal-Aid Highway Act of 1962 restricted the use of certain funds to planning activities at the regional level, rather than at the city level (Weiner, 2008, p. 33). However, though there is support among the public for regional solutions to problems, there is also a hesitance to embrace anything that undermines the independence of local government. And so it is that we see a more grassroots approach: the building of formal organizations might even take a back seat to the process of networking (Porter & Wallis, 2002, p. 29).

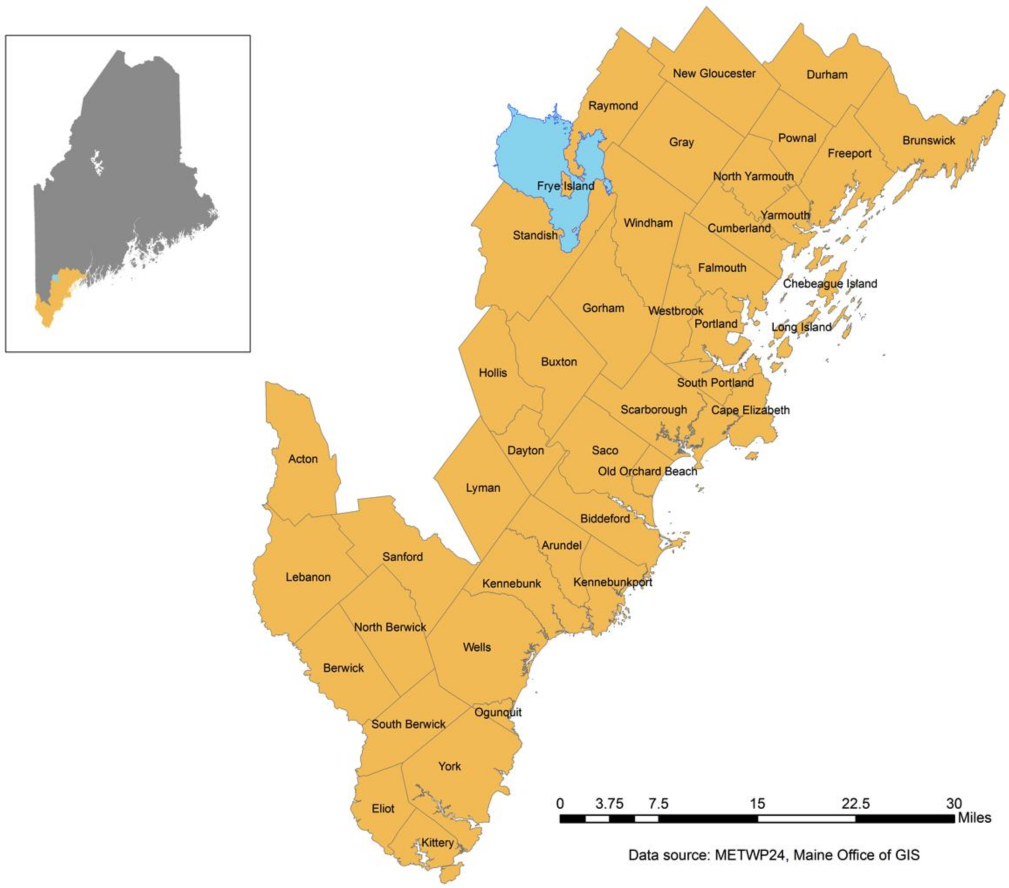

Figure 1: The study area

The problems facing our communities – water quality, equity and congestion among them – are not limited in scope to local jurisdictions. Clearly, then, there is a need for planning on a regional scale (Seltzer & Carbonell, 2011, pp. 3–4). The jurisdictions charged with legal authority – the nation, state, town or even county in some cases – rarely coincide neatly with the region or scope of a given issue and “local leaders tend to hold authority dearly and cede it sparingly” (Foster, 2011, p. 56). As Carol Whiteside, of the Great Valley Center in central California, notes: “there are win-win opportunities that you can achieve at the regional scale, that you can’t achieve community-by-community” (Whiteside, as cited in Porter & Wallis, 2002, p. 23).

GIS in Planning

Today, of course, Geographic Information Systems (GIS) are highly automated and integral to many disciplines and industries, from defense, to natural resources conservation, to logistics, public health and planning, just to name a few (ESRI, 2012). But it was actually the planning field where GIS originated, in the 1960s and 1970s. Early approaches, led by Carl Steinitz and Ian McHarg, dealt primarily with suitability analysis and were fully manual processes (Kwartler & Longo, 2008, p. 7).

McHarg’s *Design with Nature*, published in 1969, outlined the method used to determine the most suitable alignment for a new highway in Richmond, New York. McHarg prepared a set of transparencies mapping the area, one for each dimension to be considered in the analysis. There were transparencies for physical characteristics, such as slope, drainage, and soils. Other transparencies covered social and ecological values: recreation value, wildlife value, scenic value, and so on. The transparencies were then colored: darker areas indicated areas less suitable for a highway alignment, and lighter areas indicated areas more suitable. When stacked on a light table, the valuations combined to indicate an overall most suitable alignment, highlighted by the lightest areas of the transparency stack (McHarg, 1971, pp. 35–41). This method, now in digital form, is the same method often used in modern GIS.

A Model for Visualizing Road Network Congestion

This is not a traditional transportation analysis model *per se*. Comprehensive planning models require teams of people, and "considerable resources," to implement properly (Timmermans, 2008, p. 41). Such plans are based strictly on traffic analysis zones (TAZs), which are areas of relatively homogeneous uses (with regard to trip origin or destination) defined at the metropolitan level for the purpose of transportation modeling. Such analysis is purely technical, and can concentrate authority in the hands of technical experts (Forester, 1982, pp. 68–69). In addition, traditional transportation modeling is concerned with one thing: the most efficient movement of motor vehicles. The traditional assumption is that congestion is best addressed by adding capacity, not by examining inefficient land use patterns.

The method developed here does not seek to identify particular road segments or intersections of concern; rather, it seeks to identify more general zones of congestion at any areal unit. This method will allow for congestion and volume data – which are traditionally the province of transportation engineers – to be combined with any other spatial data commonly used by and readily available to planners: population density, housing stock, land use, and land cover, just to name a few.

This study uses Census block groups as the areal unit because of the ready availability needed of data at that level. However, with the method proposed here, any other areal unit could be used, including TAZs, other Census geometries, and zoning districts.

Despite the fair amount of complexity required in obtaining the transportation network data, translating it to meet various technical requirements, and running it through several layers and iterations of analyses, this is, at its core, a fairly simple model. Klosterman (2007, pp. 200–201) suggests that in planning, models are best kept simple, and that their assumptions and methods must be documented clearly and fully. I have kept these recommendations in mind, and attempt here to describe a model in sufficient detail so as to allow others to use it as-is or adapt it for their own needs.

Data

Multiple data sources were used in this model. Some of the data were publicly available, published and regularly updated. Other data were somewhat less readily available. Road capacity data, for instance, are not published, but were available on request directly from Maine Department of Transportation (MaineDOT) staff. Each major data source is described here.

Data on the road network in Maine are available from the Maine Office of GIS in a spatial layer titled MEDOTPUBRDS, which covers the entire state. This layer contains geometry for road centerlines and other relevant data fields: Annual Average Daily Traffic in vehicles per day (AADT), Federal Functional Classification, or FFC (interstate, arterial, collector, local road, etc.), and speed limit, among others. Depending on changes in the road's alignment, width, number of lanes, and intersections with other roads, a given road is broken up into individual segments in the dataset, each with its own data characteristics. There are over 200,000 segments in the road network data available in Maine (Maine Department of Transportation, 2015).

Geometric data from the 2010 decennial census were obtained from the United States Census Bureau. In order to allow for maximal interoperability with various data sources, the block group is chosen here as the areal unit of analysis. Block groups are defined in such a way as to contain between 600 and 3,000 people, and may span across municipality boundaries. There are over 1,000 block groups defined in the state of Maine (US Census Bureau, n.d.), and 344 in the current study area. In addition, total population data at the block group level were also obtained from the United States Census Bureau Summary File 1 (US Census Bureau, 2011).

Municipality-by-municipality population projections were obtained from the Maine Office of Policy and Management. These analyses start with the 2010 decennial Census and calculate projected populations for 2030, at the municipality, county and state levels (Maine Office of Policy and Management, 2013).

Several other pieces of data were necessary to calculate the likelihood of congestion on a given road segment. AADT and FFC are available in the public dataset distributed by the Maine Office of GIS. In 2010, we had received a table of default segment capacities from MaineDOT. These values are shown in Table 1 and have not changed as of this writing (Hanscom, 2015).

In order to calculate capacity, three additional pieces of data were required. First was the number of through lanes of the segment. Second, its access control characteristics: interstates, for instance, have fully controlled access (entrance and exit are allowed only at designated ramps), whereas local roads may have no access control whatsoever (the road may be broken repeatedly by entrances for parking lots, streets and driveways). The level of access control affects a road segment's capacity. The last determinant of a segment's default capacity is its rural or urban setting.

Upon request, MaineDOT offered to provide these additional data points. MaineDOT was provided with a working version of MEDOTPUBRDS, and they joined additional columns to the data. These included the number of through lanes per segment, its access control status, and its rural/urban setting (Beckwith, 2015).

The Maine Office of Policy and Management publishes projections of population change within the state. From their office, I have used population projections at the city and town level. These publications use the 2010 population as a starting point. From there, they estimate births, in- and out-migration, and deaths. These variables allow for the projection of population in 2030 (Maine Office of Policy and Management, 2013).

Table 1: Default Segment Capacities (MaineDOT)

Default Link Capacities for TINIS/Tide Mobility Applications (in vehicles per hour)

Federal Functional Class	Number of Thru Lanes (segment)	Area Type (State of Maine urban and rural definitions)					
		Rural			Urban (Compact)		
		Access Control			Access Control		
		Full	Partial	None	Full	Partial	None
Interstate (including Turnpike)	1	1700	1700	1700	1800	1800	1800
	2	3700	3700	3700	3800	3800	3800
	3	5800	5800	5800	6000	6000	6000
	4	7700	7700	7700	8000	8000	8000
Other Freeway and Expressway	1	1700	1700	1700	1800	1300	1300
	2	3700	3100	3100	3700	2300	2300
	3	5700	4900	4900	5500	2800	2800
	4	7600	6500	6500	7300	3700	3700
Other Principal Arterial	1	1700	1700	1200	1180	1180	1160
	2	3400	3400	2400	2360	2360	2320
	3	4800	4800	4200	3120	3120	3060
	4	6200	6200	6000	3880	3880	3800
Minor Arterial	1	1700	1700	1200	980	980	960
	2	3400	3400	2400	1960	1960	1920
	3	4700	4700	4100	2540	2540	2480
	4	6000	6000	5800	3120	3120	3040
Major Collectors (includes all federal urban collectors)	1	900	900	900	720	720	700
	2	1800	1800	1800	1440	1440	1400
	3	3400	3400	3400	1760	1760	1700
	4	5000	5000	5000	2080	2080	2000
Minor Collectors	1	800	800	800	520	520	520
	2	1600	1600	1600	1040	1040	1040
	3	2400	2400	2400	1360	1360	1360
	4	3200	3200	3200	1680	1680	1680
Local	1	500	500	500	500	500	500
	2	1000	1000	1000	1000	1000	1000
	3	1300	1300	1300	1300	1300	1300
	4	1600	1600	1600	1600	1600	1600

For numbers of lanes greater than 4, capacity = (number of lanes / 4) * (capacity of 4 lanes)

Finally, I obtained zoning data covering a large portion – though not all – of the area of interest. As part of the Sustain Southern Maine project and the Muskie School's

Sustainable Urban Regions project (part of a statewide NSF/EPSCoR project), the Muskie School's Eric Larsson examined many of the zoning ordinances in southern Maine, and gathered spatial zoning data from the individual municipalities. From these data, he created a single, unified zoning layer (Larsson, 2015). Because there is no inventory of land use for this region, the unified zoning layer can serve as a proxy of sorts for land use.

Methods

At its core, this is a fairly simple model. The roads layer is intersected along census block group boundaries, and then joined spatially to the block groups. From this join, the segments pick up population data and projections. Susceptibility to congestion at present is calculated, and projected to 2030. The intersected road segments are then rejoined to the block groups, which pick up congestion data. The full results are presented as a quintile (top 20%, next 20%, and so on) classification range for 2015 and 2030, and the top 20 block groups most and least likely to experience congestion are identified for 2015 and 2030. Finally, zoning areas intersecting the top block groups are selected out for further analysis. Unless otherwise specified, all manipulations are conducted using Esri ArcGIS 10.2.2.

Defining the Area of Interest

The area of interest was defined as the Sustain Southern Maine region. Individual municipalities were selected interactively from METWP24, a political boundaries layer for the state of Maine (Maine Office of GIS, 2014). A subset of features was then selected only if LAND was equal to "y". This ensured that only land, and not water, territory was included. The resulting selection was then exported and saved as the area of interest.

Before beginning the analysis, the MEDOTPUBRDS layer and the Census block groups layer were both clipped to the extent of the area of interest (unless otherwise noted, all operations were done on clipped layers). This cut down on processing overhead by reducing the number of features to be analyzed and drawn on the working map. The clip operation reduced the number of road segments from over 200,000 to less than 53,000, and reduced the number of block groups from over 1,000 to less than 400. Finally, as they would be unlikely to be the focus of regional development efforts, any block groups consisting solely of island territory were manually removed from the layer.

AADT and FAADT

The central calculation in the model is annual average daily traffic (AADT) divided by capacity, or AADT/C. This calculation results in a value ranging from slightly above 0 to higher than 12. A higher value of AADT/C does not mean that a segment is perpetually congested, but a score of 9 or higher indicates likelihood of the segment reaching full capacity – with backups as a result – at certain hours of the year (Hanscom, 2011).

MaineDOT conducts traffic counts on roughly 4,000 road segments per year. In the southern portion of the state, which contains the area of interest, counts are conducted every other year. These actual counts are used to estimate volume on every segment in the area. This is the AADT measurement. MaineDOT also maintains a number of permanent count stations. The permanent count stations cover a representative sample of federal functional classes. During off years, AADT is adjusted based on the change in previous and current year counts from the permanent monitoring stations. This measure is known as factored annual average daily traffic, or FAADT (Morgan, 2011). In order to make use of the most current available information, this study uses FAADT.

Capacity

Capacity is determined by the segment's federal functional class (FFC), its urban/rural setting, number of through lanes, and level of access control. The matrix used by MaineDOT was shown previously in Table 1 (page 11). In order to use the capacity data in conjunction with MEDOTPUBRDS, those data needed to be transposed from the matrix shown above in Table 1 (page 11) into a format where one capacity was represented per row. After accounting for the possibility of 5 through lanes of traffic per segment, there were 210 unique combinations of the four variables listed above. Table 2 (below) shows a sample of the capacity table in its transposed format.

Table 2: Capacities in transposed format (sample)

THRU_LANES	FED_FC	RURAL_URB	ACCESS_CONTROL	CAPACITY
1	0	Rural	Full	500
2	0	Rural	Full	1000
3	0	Rural	Full	1300
4	0	Rural	Full	1600

Joining Roads and Capacity

The standard MEDOTPUBRDS layer was augmented on request by MaineDOT to include capacity-related variables. Federal functional class (FFC) is included in the standard roads layer published by the Maine Office of GIS. MaineDOT added the rural/urban setting of the segment, its number of through lanes, and its access control status. These fields were formatted similarly to those found in the capacities table (Table 2, above).

Because ArcGIS does not allow for multiple-key joins, a join key was added to both the capacity table and to MEDOTPUBRDS[1]. The join key was calculated using the field

[1] In order to be permanent, joined tables need to be exported into new feature classes or shapefiles. This process is omitted here for the sake of clarity. The usual practice is to take the new feature class (which

calculator. It had the format FED_FC – RURAL_URB – ACCESS_CONTROL – THRU_LANES. This resulted in the 210 rows having 210 unique join keys. This allowed for a capacity to be matched to each segment in MEDOTPUBRDS. When creating the join key, the numeric equivalent of the FFC was used. This decreased the chance of mismatches due to variations in coding or spelling of the classification descriptions. Table 3 (below) and Table 4 (below) show the numeric equivalents of the federal functional class and a sample of the join key as implemented.

Table 3: Federal functional classes

Numeric	Description
0	Local
1	Interstate (including Turnpike)
2	Other Freeway and Expressway
3	Other Principal Arterial
4	Minor Arterial
5	Major Collectors (includes all federal urban collectors)
6	Minor Collectors

Table 4: Capacities table with join key (sample)

JOIN_KEY	FED_FC	RURAL_URB	ACCESS_CONTROL	THRU_LANES	CAPACITY
0-Rural-None-1	0	Rural	None	1	500
6-Rural-Full-5	6	Rural	Full	5	4000
1-Urban-Full-5	1	Urban	Full	5	10000
2-Urban-Partial-3	2	Urban	Partial	3	2800

Present Susceptibility to Congestion

With capacity now specified for each road segment, it is possible to calculate the present congestion index. A new field FAADT_C was added to the dataset, and was calculated as FAADT divided by CAPACITY, using the field calculator. Sample results are shown in Table 5 (below) and see also Appendix A: MaineDOT Level of Service (LOS) Assumptions.

contains all of the fields that had been in the old feature class, plus the new fields currently being joined in), use it to replace the old feature class, and continue to the next step in the process.

Table 5: MEDOTPUBRDS with capacity and FAADT/C (sample; some field names edited for clarity)

SEGMENT	FED_FC	FAADT	TOWN_NAME	STATE_URB	ACCESS	LANES	STREET_NAM	JOIN_KEY	CAPACITY	FAADT_C
1239552	4	7778	Scarborough	Rural	Partial	2	HAIGIS PKY	4-Rural-Partial-2	3400	2.288
1114688	1	36305	Kittery	Urban	Full	3	I 95	1-Urban-Full-3	6000	6.051
1239568	1	24500	Yarmouth	Rural	Full	2	I 295 SB	1-Rural-Full-2	3700	6.622
1239489	3	12093	Portland	Urban	Unknown	2	AUBURN ST	3-Urban-Unknown-2	2320	5.213
1239638	4	12416	Kittery	Urban	Unknown	2	SHAPLEIGH RD	4-Urban-Unknown-2	1920	6.467

Joining Population Data to Block Groups

Population data were obtained in Census Summary File 1. This file contains a field called GEO.id2, a 12-digit identifier designed to join to the GEOID field of Census shapefiles (U.S. Census Bureau, n.d.). The two files were joined, appending population data to the Census block group geometry. Table 6 (below) shows a sample of the joined data. HD01_VD01 represents total population in 2010. In further steps of the analysis, an alias was created for this field to give it the more intuitive name POP_2010.

Table 6: Census geometry and data joined (sample)

From Census Geometry						From Census Summary File		
STATE FP	COUNTY FP	TRACT CE	BLKGRP CE	GEOID	NAMELSAD	GEO_id2	GEO_displa	HD01_VD01
23	005	002300	1	230050023001	Block Group 1	230050023001	Block Group 1, Census Tract 23, Cumberland County, Maine	1538
23	005	002300	2	230050023002	Block Group 2	230050023002	Block Group 2, Census Tract 23, Cumberland County, Maine	2198
23	005	002400	3	230050024003	Block Group 3	230050024003	Block Group 3, Census Tract 24, Cumberland County, Maine	238

Joining Population Data to Road Segments

In order to make sure that only those road segments within a block group would be analyzed as part of that block group, the road segments needed to be intersected against the block groups. This effectively splits the road segments at the block group boundaries, creating two segments if necessary (ESRI, 2014a). Figure 2 (below) shows an illustration of such a segment. Haskell Road has been intersected by the town boundary, which crosses through the bottom left corner of the frame. When the identify tool is used, only the northern portion of Haskell Road appears in red as being selected – the segment ends at the town boundary.

The intersect operation causes an increase in the total number of road segments. One segment may pass through two or more municipalities, so it will be split into multiple segments. Aside from the geometry-related fields such as length, which are adjusted automatically to reflect the new and different segments, each segment carries forward an identical set of data fields. (Remember that segments also are intersected as necessary to reflect changes in the number of through lanes, access control, etc.)

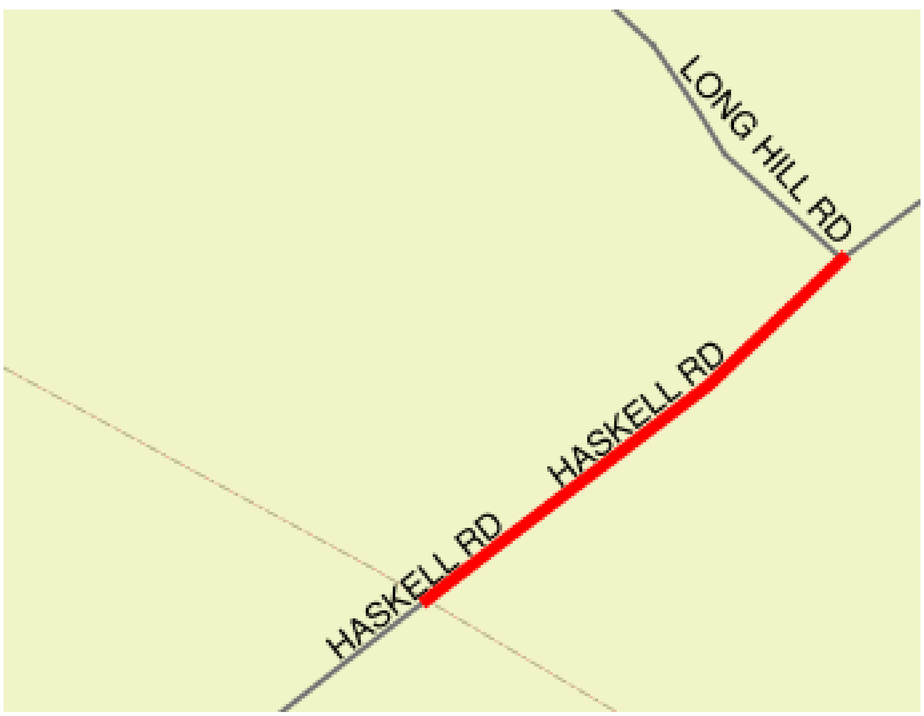

Figure 2: The intersected road segment, selected in red, extends only to the town boundary

As a result of the intersect operation, the road segments inherit fields from the block groups that contain them. In particular, they inherit the 2010 population, POP_2010, from the block group. At this point in the analysis, each road segment “knows” the population of its block group. FAADT and capacity are replicated on both sides of the new intersection point. Because these values are not dependent on the length of the segment, this does not skew the analysis. The segments do not need to be adjusted proportionally according to the location of the new intersection or to the percentage of the segment passing through one block group versus another.

FAADT per Person

At this point a new field, FAADT_POP_2010, was added to the roads layer to reflect FAADT normalized by population. Using field calculator, this field was calculated as FAADT divided by POP_2010. FAADT_POP_2010 reflects a measure of traffic per person on the road segment in 2010.

Population Change 2010-2030

Population projections for 2030 at the city and town level were obtained in Excel format (Maine Office of Policy and Management, 2013); a simplified version is shown below in Table 7. The Excel sheet was imported into ArcGIS, exported using a Copy Rows operation to a temporary data table, and then joined to the roads layer. Both the projections and the roads layer contain the Town variable, so this field was used as a join key. The field Pct_Change_2010_2030 was added to the roads layer.

Table 7: Population projections by city and town (sample)

Town	Pct_Change_2010_2030
Auburn	-0.011606148
Durham	0.255414266
Greene	0.131123739
Leeds	0.299118007
Lewiston	0.051190473

Because the unit of population analysis is the block group, the actual city and town population projections were discarded at this step. Retaining only the percent change value allows us to adjust each block group individually on a segment-by-segment basis. For example, segment 620832 (Webb Rd) in Windham is in tract 004803, block group 2. Block group 2 had a population of 3,098 in 2010. Windham's population is expected to increase 13% between 2010 and 2030. Therefore, we assume that block group 2's population will be 3,501 in 2030.

To accommodate 2030 population a new field, POP_2030, was added to the roads layer. This field represents the population projection outlined above. Using the field calculator, POP_2030 was calculated as POP_2010 * (1 + Pct_Change_2010_2030).

Projecting FAADT and FAADT/C to 2030

With 2030 projected population, POP_2030, having been added to the roads layer, it was possible to determine an estimate of traffic in 2030. Because there is no reliable and definitive information to the contrary, it is assumed for the purpose of this analysis that underlying road capacity and driving patterns will remain constant in 2030.

A new field, FAADT_2030, was added to the roads layer and, using the field calculator, FAADT_2030 was calculated as FAADT_2010 multiplied by the percentage change in population (Pct_Change). This gives us a projection of factored annual average daily traffic in 2030. A second new field, FAADT_C_2030, was added to the roads layer and calculated as FAADT_2030 divided by Capacity.

Aggregating Traffic and Capacity Measures to Block Groups: Comparative Methods

Each road segment now holds a number of variables needed for the analysis: FAADT, Capacity, FAADT_C, POP_2010, FAADT_POP_2010 (traffic, capacity and congestion measures for 2010); POP_2030, FAADT_2030, FAADT_C_2030 (traffic and congestion measures for 2030); and segment length. Table 8 (below) shows a sample of the roads data as prepared at this point in the analysis. Having prepared these variables, it becomes possible to aggregate them to polygon units of area. The areal unit in the present study is the Census block group, but any other areal unit could be used (TAZ, zoning district, Census tract, etc.).

Table 8: Roads layer with 2010 and 2030 FAADT (sample)

SEGMENT_ID	FACT_AADT	CAPACITY	FAADT_C	POP_2010	FAADT_ POP_2010	POP_2030	FAADT_ 2030	FAADT_ C_2030	Length
1239552	7778	3400	2.29	3012	2.58	3352	8656	2.55	37.998
1114688	36305	6000	6.05	887	40.93	795	32544	5.42	63.737
1239568	24500	3700	6.62	1173	20.89	1063	22202	6	158.422
1239489	12093	2320	5.21	1407	8.59	1370	11777	5.08	41.078
1239638	12416	1920	6.47	961	12.92	861	11130	5.8	31.21
1243572	10346	2400	4.31	2846	3.64	3386	12308	5.13	64.417

Because this is a new approach, three methods were used to aggregate roads data to census block groups; having three methods available will allow for sensitivity analysis with the data. The *average* method used a simple average of FAADT_C (2010) and FAADT_C_2030 for all segments contained within the census block group. The *maximum* method used the maximum FAADT_C or FAADT_C_2030 value found within the census block group; this represents a sort of worst-case scenario.

The final method, the *weighted average* method, multiplied each segment's FAADT or FAADT_2030, and its capacity, by its length. Then the FAADT and capacity were summed and an overall FAADT/C calculated. This method can minimize the impact of a relatively short segment with an unusually high FAADT/C, for example. On the other hand, if the longest segments in the block group are relatively free flowing, this will result in a lower aggregate FAADT/C for the block group as a whole.

The three methods are illustrated below in Figure 3. In this illustration, each road segment is labeled with its FAADT, its capacity, its FAADT/C, and its length. For example, the right-most segment is labeled "303 / 1000 (0.303) (480.38m)." Its FAADT is 303, its capacity is 1000 vehicles/hr, its FAADT/C is 0.303, and its length is 480.38 meters. By the maximum method, the block group's FAADT/C would be 3.208, which is sort of a worst-case scenario. By the average method, this block group's FAADT/C would be 1.471. In this example, the average of 1.471 is probably a bit higher than realistic. The presence of one high-scoring road running from north to south inflates the block group's FAADT/C because it is broken into three segments, each with an FAADT/C of over 3.0. The weighted average method, in contrast, brings the block group's FAADT/C down to 0.983 by normalizing the individual FAADT/C scores by their lengths, nullifying any effect of multiple similar segments. The weighted average method has the additional benefit of minimizing the overall effect of short segments with unusually high FAADT/C scores.

The congestion index, or FAADT/C, of a segment corresponds to the segment's level of service (LOS) rating (see Appendix A: MaineDOT Level of Service (LOS) Assumptions, on page 44). A segment FAADT/C score of 9 or greater indicates a likelihood of demand exceeding capacity – and congestion – at certain times. However, most roads in Maine have an FAADT/C below 9 (Hanscom, 2011). The distribution of the FAADT/C scores for both the segment and block group levels for 2015 and 2013 appears below in Table 9.

Table 9: FAADT/C descriptive statistics, 2015 and 2030

			FAADT/C (2015)			
Feature	**Aggregation Method**	**N**	**Min**	**Mean**	**Median**	**Max**
Road Segments		52496	0.003	2.825	2.214	27.302
Block Groups	Average	309	0.482	2.651	2.528	6.022
	Maximum		1.567	8.103	7.559	27.302
	Weighted Average		0.430	2.236	2.053	5.367

			FAADT/C (2030)			
Feature	**Aggregation Method**	**N**	**Min**	**Mean**	**Median**	**Max**
Road Segments		52496	0.004	2.886	2.264	25.761
Block Groups	Average	309	0.508	2.684	2.486	6.116
	Maximum		1.839	8.177	7.465	25.761
	Weighted Average		0.466	2.261	2.084	5.226

For each of the three measures, a spatial join operation was performed. This operation joins one table or layer to another based on their proximity to one another. When many features in one layer match a single feature in another layer, the features being joined must be aggregated in some way. (Oddly, ArcGIS refers to this relationship as a "one-to-one join.") In ArcGIS, a variety of aggregate statistics are available for spatial joins, including sum, max and average (ESRI, 2014b).

Average and Maximum Methods

For both of these methods, the Spatial Join ArcToolbox tool was used. This tool allows greater flexibility than the native join functionality that one can access via a layer's context menu in the ArcMap interface.

The target features for the spatial join were the census block groups, and the join features were the roads layer. A JOIN_ONE_TO_ONE operation was chosen, and the match type was INTERSECT. In the field map, all fields were removed except for FAADT_C and

FAADT_2030_C; the match rule for these was AVERAGE or MAXIMUM, depending on the current method. This resulted in FAADT_C and FAADT_2030_C being added to the block groups. In this case, these fields represent the block group average or maximum, depending on the method.

With FAADT_C and FAADT_2030_C having been calculated, the block groups layer was sorted by these fields, and the top/bottom 20 block groups selected and exported into new block group layers. There were eight such layers: top20_2015_avg and max, top20_2030_avg and max, bot20_2015_avg and max, and bot20_2030_avg and max.

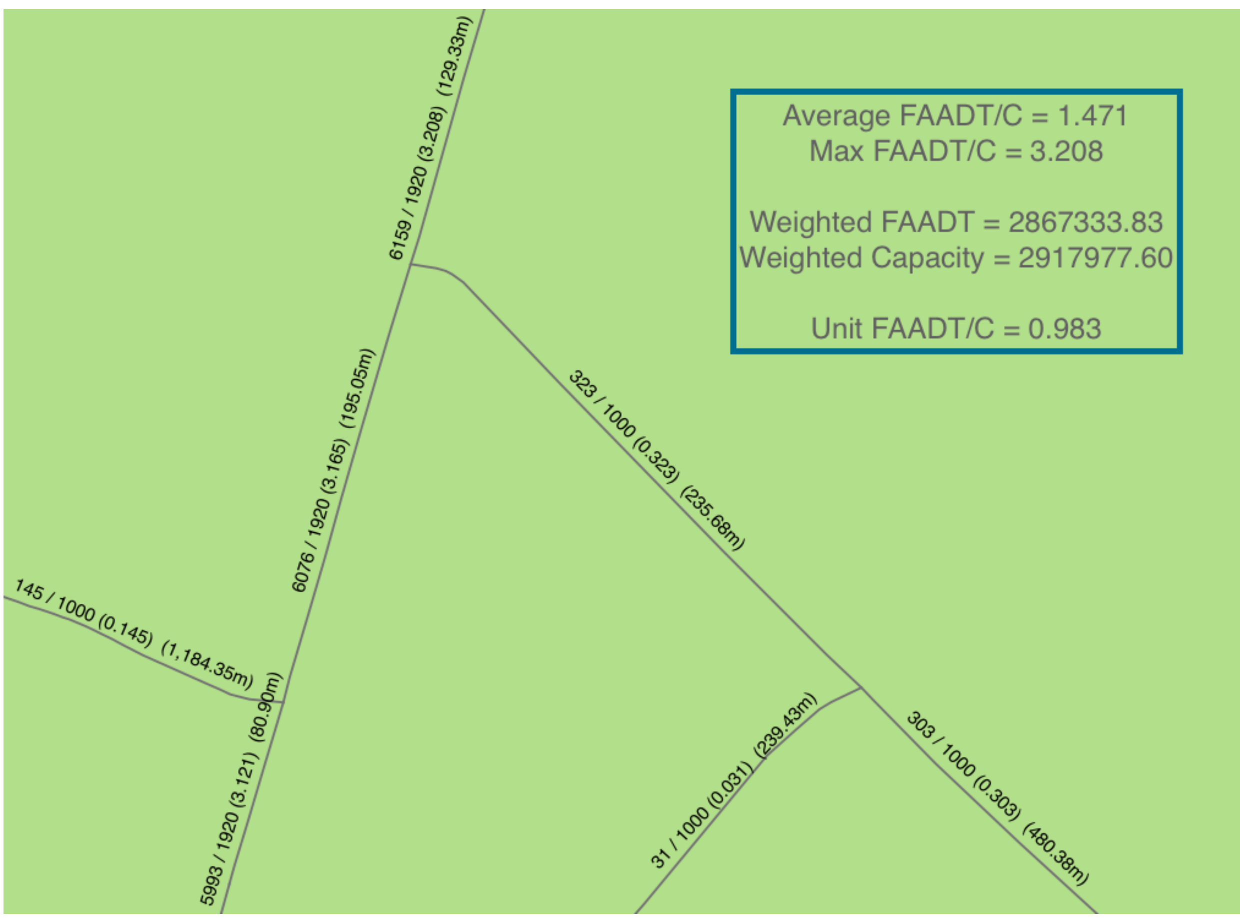

Figure 3: FAADT/C methods comparison sample (not to scale)

Weighted Average Method

In the weighted average method, each segment's length was taken into consideration. For this calculation, three new fields were added. FAADT_2010_W and FAADT_2030_W represent weighted FAADT in 2010 and 2030, respectively. Using the field calculator, they were calculated as FAADT_2010 (or FAADT_2030) * Shape_Length. The third field was CAPACITY_W, or the weighted capacity of the segment. This field was calculated as Capacity * Shape_Length.

With FAADT_2010_W, FAADT_2030_W, and CAPACITY_W prepared, another spatial join was performed. The target features for the spatial join were the census block groups, and the join features were the roads layer. A JOIN_ONE_TO_ONE operation was chosen, and the match type was INTERSECT. In the field map, all fields were removed except for FAADT_2010_W, FAADT_2030_W, and CAPACITY_W; the match rule for these was SUM. This resulted in FAADT_2010_W, FAADT_2030_W and CAPACITY_W being added to the block groups. In this case, these fields represent the block group sums.

The final step in the weighted average method was to calculate an overall weighted average FAADT/C for the block group. Two new fields were added to the block groups, BG_FAADT_C_2010 and BG_FAADT_C_2030. These were calculated as FAADT_2010_W / CAPACITY_W and FAADT_2030_W / CAPACITY_W, respectively.

Table 10 (below) shows a sample of the block groups layer after having calculated the overall FAADT/C for 2010 and 2030.

Table 10: Weighted average FAADT/C by block group (sample)

Join_Count	FAADT_2010_W	FAADT_2030_W	Capacity_W	BG_FAADT_C_2010	BG_FAADT_C_2030
118	37332782	43479848	63790286	0.585	0.682
75	14474986	15494306	21982429	0.658	0.705
206	15608751	16041150	18049768	0.865	0.889
92	5051531	4751517	7897757	0.640	0.602
192	40326138	41206477	52684806	0.765	0.782

The block group layers created by all three spatial join operations contain a new field called JOIN_COUNT. This field contains the number of join features joined to the target feature. In this case, it is the number of road segments that were joined to the census block group. The JOIN_COUNT field is useful for spot-checking to be sure that the correct features have been joined.

With BG_FAADT_C and BG_FAADT_2030_C calculated, the block groups layer was sorted by these fields, and the top/bottom 20 block groups selected and exported into new block group layers. There were four such layers: top20_2015_weighted, top20_2030_weighted, bot20_2015_weighted, and bot20_2030_weighted.

Determining Method Agreement

This analysis leaves aside the question of which method – average, maximum, or weighted average – is best or most appropriate for a given application in planning. However, any agreement among the methods could be interpreted as being more reliable. Therefore, a series of selection operations was performed against the layers to see where they matched.

Comparisons were made within the four new categories of block group layers: one set of comparisons within each of the top and bottom 20 block group layers for 2010 and 2030. All comparisons were made using the select by location toolbox tool. The feature relationship tested was specified as ARE_IDENTICAL_TO (testing to select those features from the first layer that are identical to features in the second layer). First, the average layer was compared against the maximum layer, and a temporary layer called avg-max was output. Then, the avg-max layer was tested against the weighted average layer, and a layer called avg-max-weighted was output. There were four such layers: top_20_2015_avg-max-weighted, top_20_2030_avg-max-weighted, bot_20_2015_avg-max-weighted, and bot_20_2030_avg-max-weighted.

These output layers each contain only those block groups having been rated as being in the top 20 most or least likely to experience congestion *regardless of the aggregation method.* Even accounting for the potential effect of outliers such as very short segments with high congestion indices, these block groups still show high (or low) potential for congestion relative to the rest of the region.

Determining Zoning near a Low/High Congestion Block Group

With a number of top 20 block groups most/least likely to experience congestion at present or in 2030 having been defined, it is now possible to examine the surrounding land uses. Southern Maine does not have a comprehensive land use inventory, but we can make use of the unified zoning layer (see page 11 above) as a proxy for land use.

In the current work, a number of select by location operations were performed. Features were selected from the unified zoning layer that had a feature relationship of INTERSECT with the features in top20_2015_weighted, top20_2030_weighted, bot20_2015_weighted, and bot20_2030_weighted. Each operation causes the selection of those zones that intersect (that touch, overlap, or are contained by) the block groups identified in the four top and bottom 20 weighted layers. Each zoning intersection was exported separately, resulting in four new zoning intersection layers.

For the purposes of this study, one block group was selected at random[2] from among the top 20 block groups least likely to experience congestion in 2030. Its intersecting zones were selected from the corresponding zoning intersection layer. Both

[2] The selection was not entirely at random. The zoning layer does not cover the entire area of interest. Therefore, a block group was chosen from an area where zoning information was available.

the selected block group and the intersecting zones were exported to new, temporary layers. From the temporary zoning intersection layer, a summary statistics operation was run to determine the amount of land dedicated to each of the intersecting zoning types. From the summary statistics tool, the statistics field was SHAPE_AREA, the statistic type was sum, and the case field was PrimUseNam. This causes the summary statistics tool to calculate the sum of the zone areas for each primary use. With a summary of areas in hand, it becomes possible for planners to more closely examine the amounts of land dedicated to various uses and determine whether, for example, certain areas might benefit from interventions such as changes in zoning.

Results

While there was variation among the three methods – average, maximum and weighted average – some patterns do emerge (see Figure 4 through Figure 15, below). In general, those block groups most likely to experience congestion, in both 2015 and 2030, are situated along the more densely populated I-95 and I-295 corridors. The block groups least likely to experience congestion tend to be located in the exurban areas in the west and north of the study area, although there are exceptions. Coastal block groups in the Biddeford/Saco/OOB area scored among the top 20 least likely to experience congestion, as did block groups on the Portland peninsula as well as in South Portland. Likewise, several block groups to the southwest of Portland scored in the top 20 most likely to experience congestion, by various measures.

Top 20 Block Groups Most and Least Likely to Experience Congestion, 2015

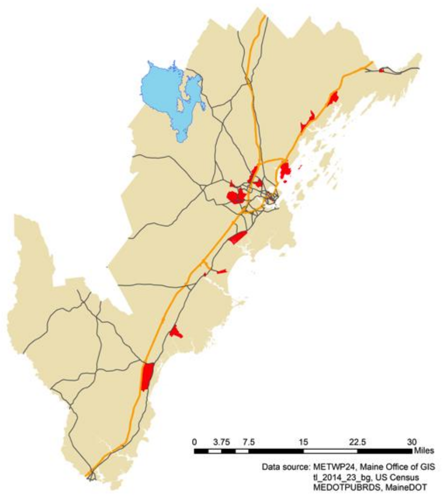

Figure 4: Most likely (average by block group)

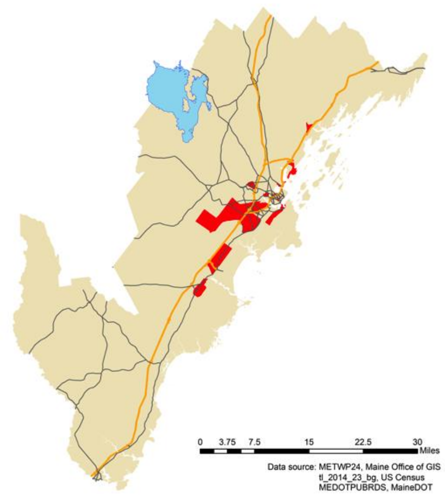

Figure 5: Most likely (maximum by block group)

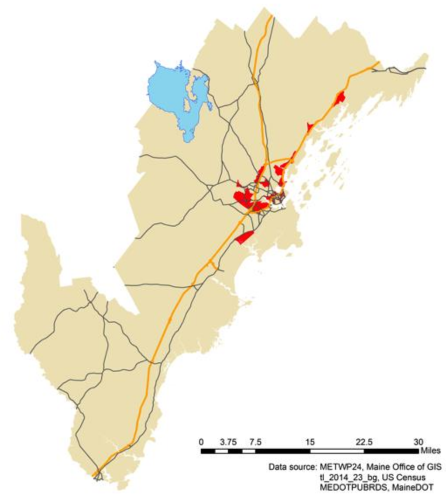

Figure 6: Most likely (weighted average by block group)

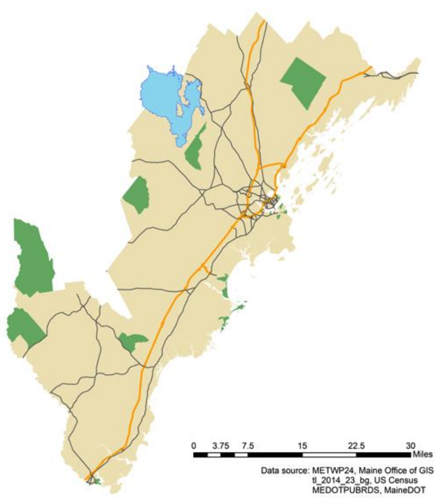

Figure 7: Least likely (average by block group)

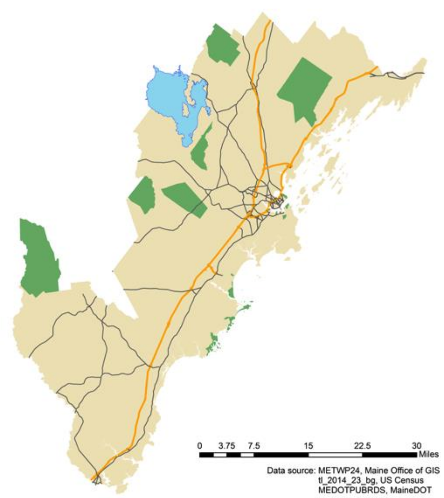

Figure 8: Least likely (maximum by block group)

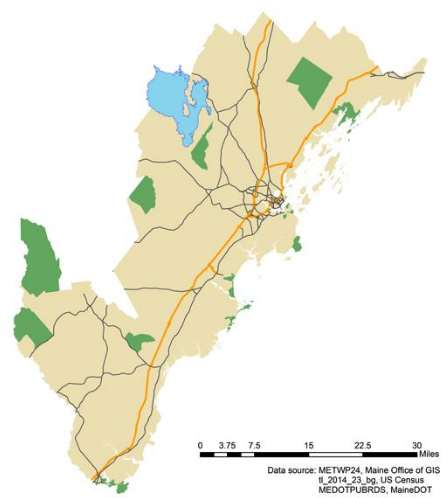

Figure 9: Least likely (weighted average by block group)

Top 20 Block Groups Most and Least Likely to Experience Congestion, 2030

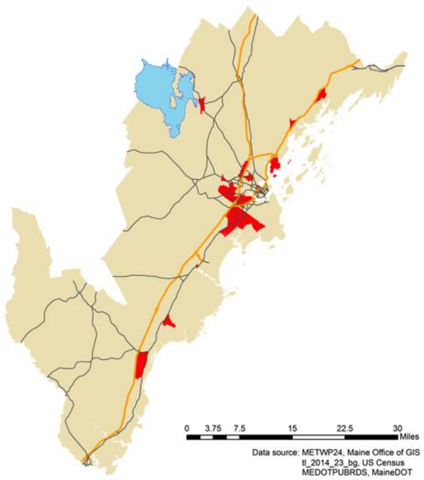

Figure 10: Most likely (average by block group)

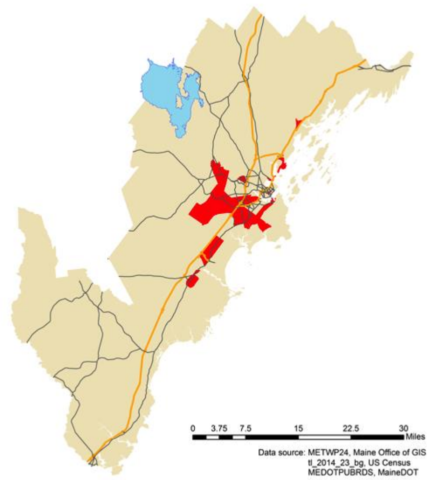

Figure 11: Most likely (maximum by block group)

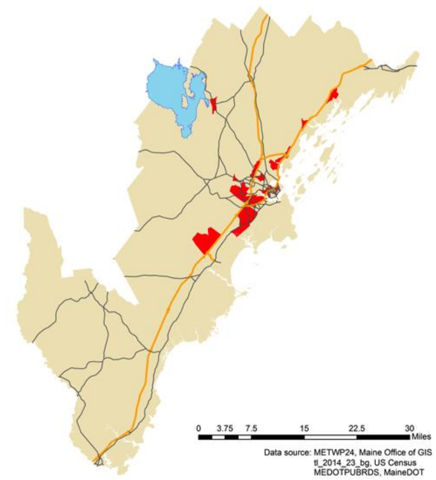

Figure 12: Most likely (weighted average by block group)

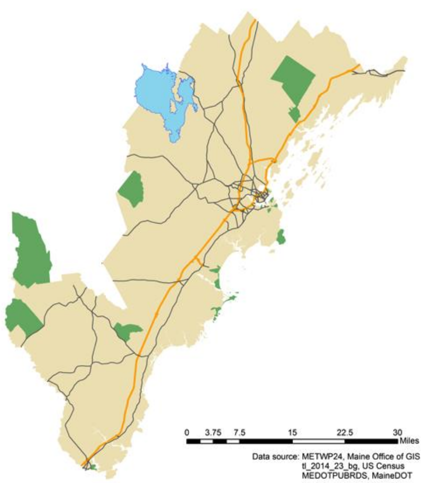

Figure 13: Least likely (average by block group)

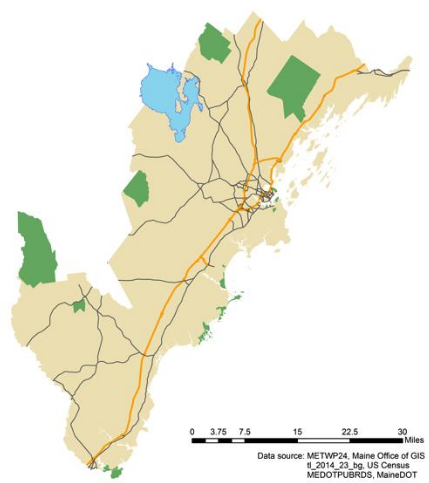

Figure 14: Least likely (maximum by block group)

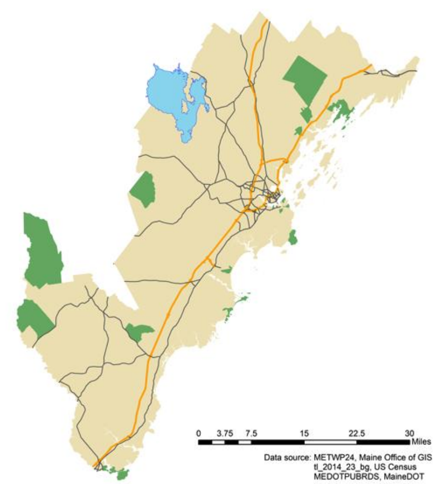

Figure 15: Least likely (weighted average by block group)

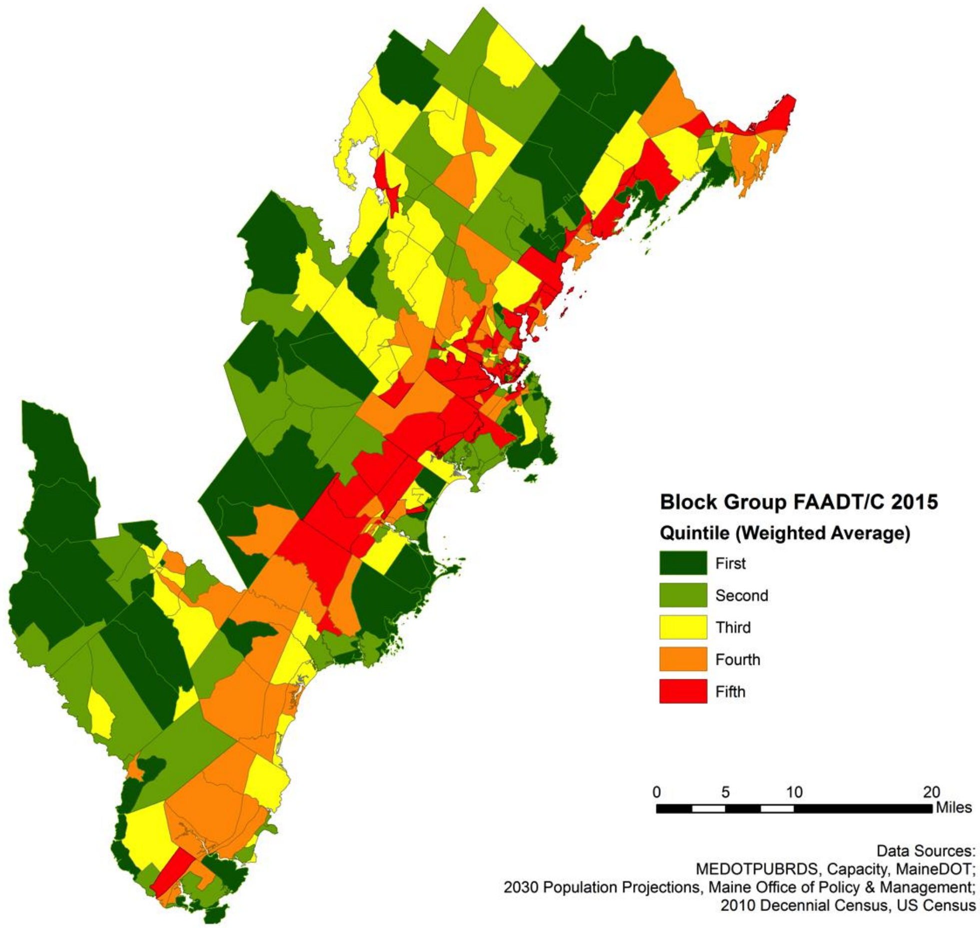

Figure 16: Block group FAADT/C, 2015, weighted average method

FAADT/C by Weighted Average, 2015 and 2030

The methods presented here allow for block groups to be ranked across the entire study area by block group FAADT/C. The results here show an unsurprising pattern of greater susceptibility to congestion along the more-densely populated I-95 and I-295 corridors, and less susceptibility to congestion in exurban areas. Nevertheless, viewing the results in this way will allow planners to visualize block groups other than just the ones scoring at the highest or lowest ends of the congestion index range. It also allows for examination of those block groups scoring

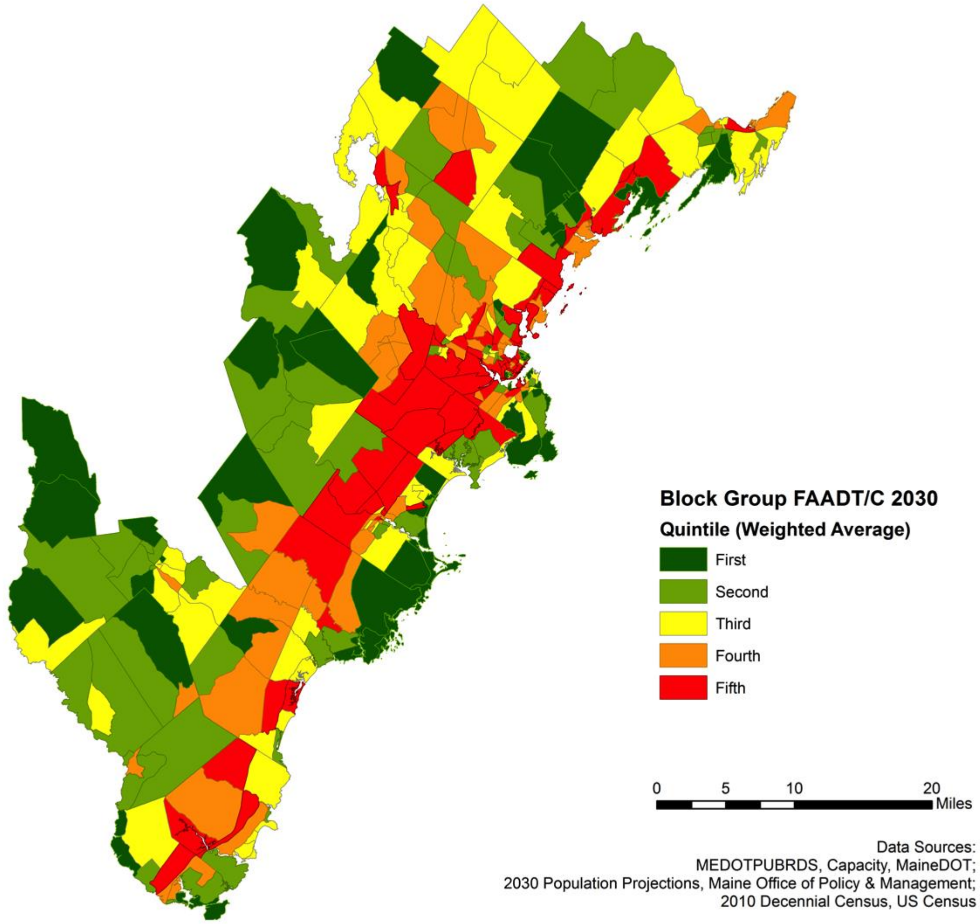

Figure 17: Block group FAADT/C, 2030, weighted average method

in the fourth quintile, for example. These areas may benefit from planning intervention in order to keep congestion levels acceptable.

Where the Three Aggregation Methods Agree

The three aggregation methods – average, maximum and weighted average – each produced separate rankings of the top 20 block groups most (and least) likely to experience congestion. Some block groups appeared on a top 20 list according to one method, but not the others. But certain block groups appeared on each of the

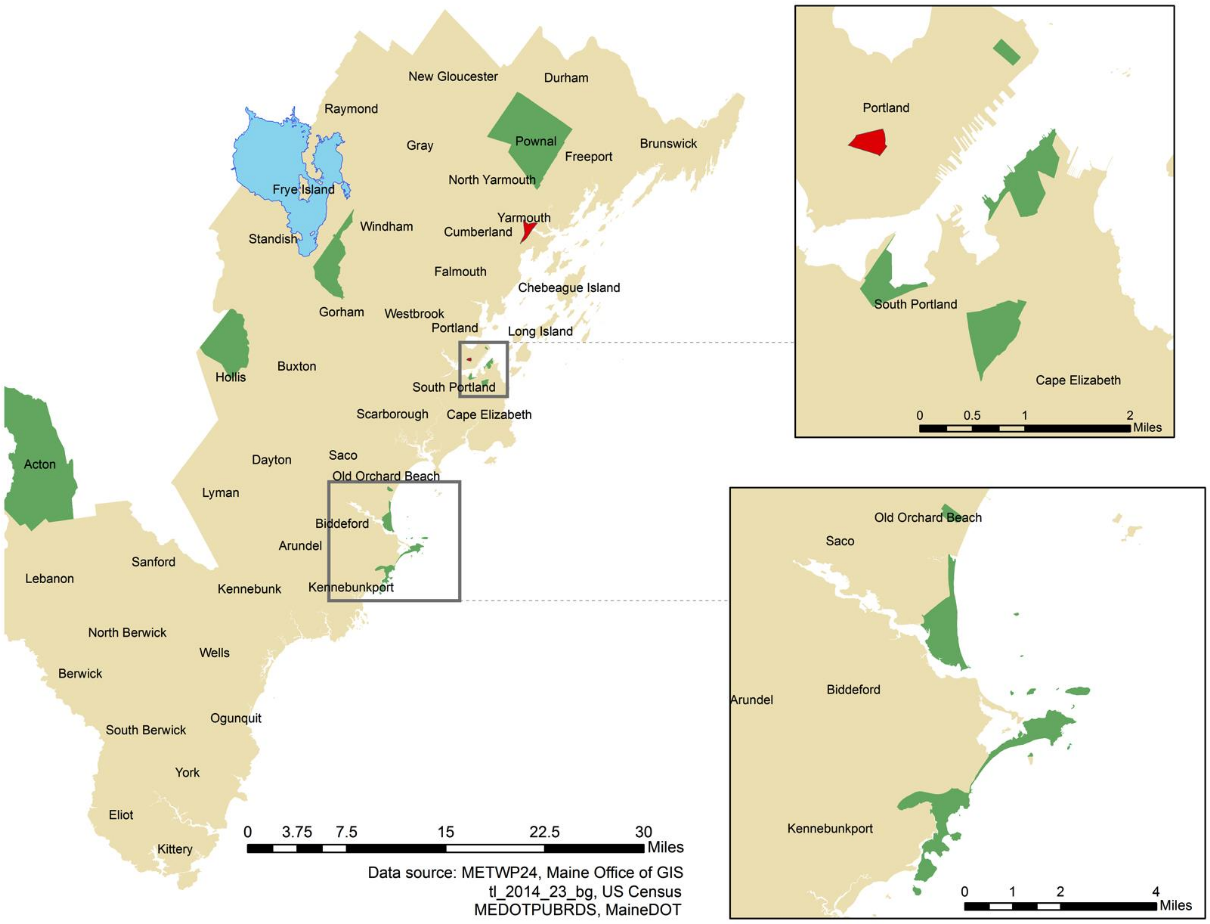

Figure 18: Top 20 most (red) and least likely (green) to experience congestion according to all three methods, 2015

three top 20 lists. That is, these particular block groups consistently showed relatively high (or low) congestion index scores, a possible indication of a more reliable result. Such agreements occurred between the three aggregation methods in both the 2015 (Figure 18, above) and 2030 (Figure 19, below) analyses. In general, there was broader agreement between the methods on those block groups least likely to experience congestion: 12 block groups made each top 20 list in 2015 and 11 in 2030. In comparison, among those block groups most likely to experience congestion, only 2 block groups made each top 20 list in 2015, and 4 in 2030. This

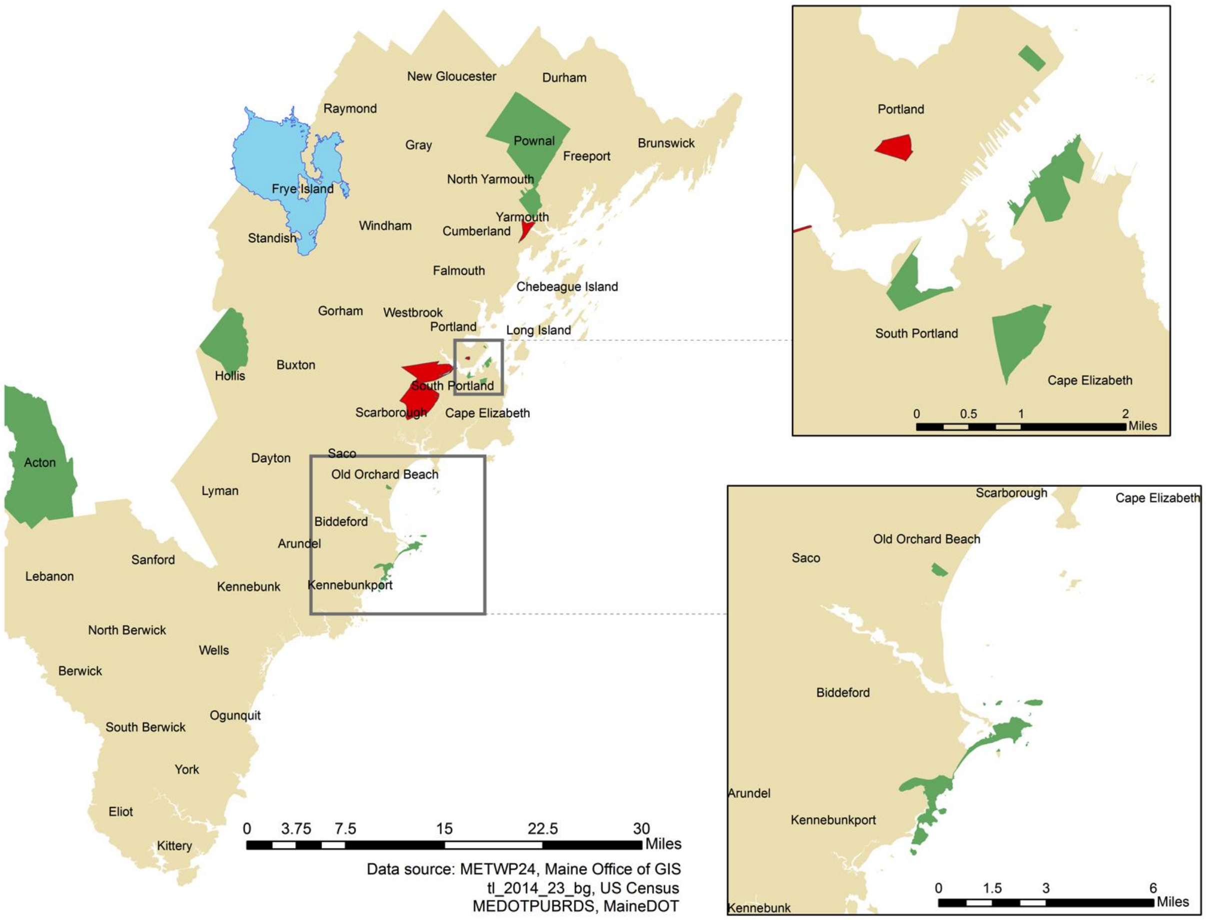

Figure 19: Top 20 most (red) and least likely (green) to experience congestion according to all three methods, 2030

trend may be because of a varying influence of outliers at higher levels of FAADT/C. As there are relatively few such segments in those block groups less likely to experience congestion, we can expect less variability among those block groups overall – no matter how they are measured.

Adjacent Zoning

Starting with the more- or less-congestion prone areas and examining adjacent zoning is one method available to planners for making use of congestion

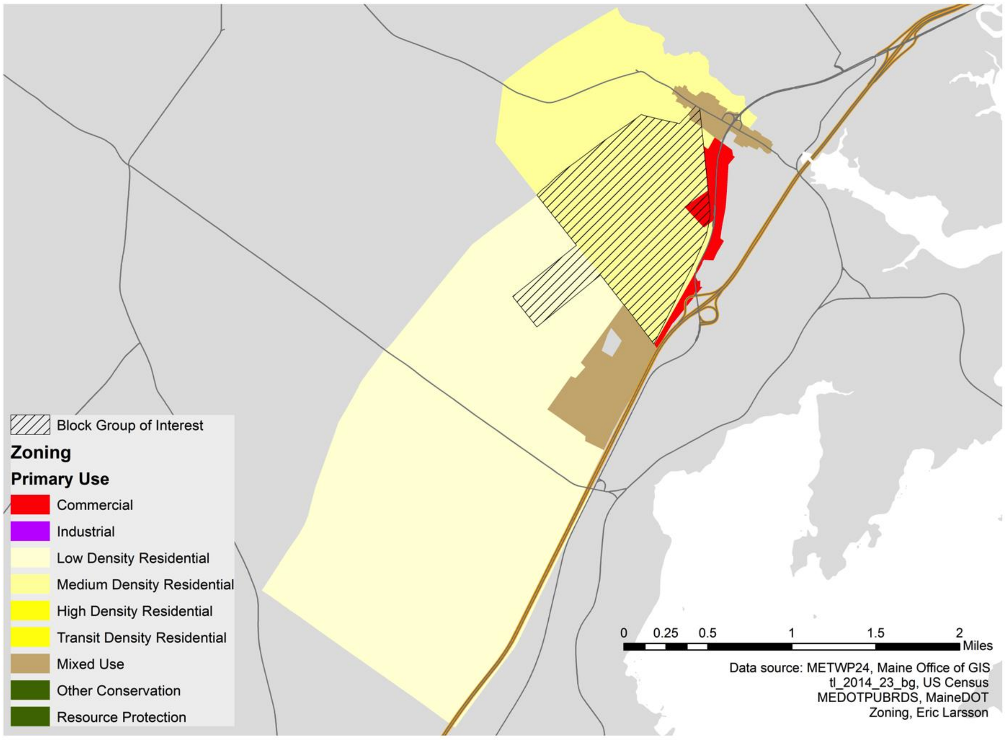

Figure 20: Zoning adjacent to a block group least likely to experience congestion in 2030 (sample)

Table 11: Summary statistics for zoning adjacent to a block group of interest (sample)

Primary Use Name	Num. Zones	Acres	Square Miles
Commercial	1	73.0	0.1
Low Density Residential	2	2297.1	3.6
Medium Density Residential	1	1024.1	1.6
Mixed Use	2	213.8	0.3

data. The sample block group chosen was block group 3 of Census tract 44.01 in Yarmouth. This was one of the top 20 block groups projected least likely to experience congestion in 2030. Selecting intersecting features by location from the unified zoning layer results in six adjacent zones, in a mix of residential, commercial, and mixed uses (see Figure 20 and Table 11, above).

In this example, the vast majority of the adjacent zoning is residential. Low-density residential zoning accounts for 63.7 percent of the area, with medium-density residential accounting for 28.4 percent. With 3.6 square miles adjacent to a block group that is projected to be relatively less likely to experience congestion, this may indicate an area in the region where it would be possible to upzone to increase residential densities if that met other objectives, since there is capacity there.

This example location is notable for other reasons. It is situated on I-295, a high-capacity road, with good proximity to Portland. This makes it a more suitable location for increased densities than block groups in exurban areas that might have ranked similarly in terms of susceptibility to congestion. In addition, it has existing mixed-use areas, as indicated by zoning.

Discussion

Information about traffic congestion is valuable to planners. However, congestion data apply to network features, and typically are designed for engineering use. Dating back to the beginnings of GIS, planners have used data in polygonal units: census block groups or tracts, political boundaries, watershed boundaries, traffic analysis zones, and other areal units.

The present study outlines a number of methods planners can use to aggregate congestion data into any such areal unit using readily available tools. This allows for these data to be combined into the standard suitability analyses used in the planning field: they can be combined with Census data, other demographic data, soils and slopes data, zoning data, or any other data valuable and available to planners. Despite the fair amount of work necessary to prepare data, the general method is a fairly simple one that should be easily explained and defensible as part of a broad enough overall planning toolkit.

Limitations

While these methods have a fair amount of potential utility for planners, there are a number of things that should be kept in mind when using this approach. First, the analysis is a relative one: it allows one to determine which areal units are more or less prone to congestion. It does not allow one to make the statement that any such unit is “free of congestion” or is “congested” *per se*. A susceptibility to congestion says nothing about timing or duration. It could be that congestion happens at a particular time at a particular intersection, and is severe enough to skew the calculation for the unit overall, without adverse impacts on the majority of drivers and the majority of their trips. It may also be that congestion levels are so high (or so low) overall that even the best performing units are still generally troublesome for drivers. So while the top 20 block groups most and least likely to experience congestion in 2015 and 2030 are identified here, it is not possible to say declaratively that conditions in these blocks are or will be bad or good.

Second, congestion should be seen as but one variable among many considered in any proper analysis. The present work is a level-of-service (LOS) based method, and LOS is all about moving motor vehicles in the most efficient way possible. LOS has nothing to say about alternate modes of travel such as biking or walking; it does not account for subjective points that are important to humans such as whether speeds are kept low for the safety and benefit of neighbors. However, evidence of congestion issues in a certain area may lead to an examination of the options for improving connectivity by other modes.

Third, anyone wishing to use this exact method, and these exact data sources, should be aware of a few items regarding current FAADT, population, and the projections of both measures to 2030. Current population and projections of 2030 population are based on 2010 population. But current FAADT is based on counts from the past 1-2 years. So when current FAADT/population is calculated, there is a slight mismatch built in. Another important point of note is the assumption that driving patterns and road capacity will remain unchanged in 2030. In the case of driving patterns, this may or may not be the case; in the case of road capacity, it surely is not. However, all such assumptions are based on the data available. In addition, population changes in 2030 are assumed to apply equally to all block groups within a municipality; future work could incorporate a cohort-survival projection at the block group (or other areal unit) level.

There are also some notes pertaining to the analysis of transportation generally. The current work cannot be seen as a fully-fledged transportation model: it does not take into account origins or destinations, or any other data (car ownership, etc.) relating to driving habits. It considers only population change, and not changes in commercial activity or other changes in land use, when estimating future traffic volumes.

It uses Census block groups as the areal unit to which congestion information is aggregated. However, the traffic analysis zone (TAZ) would have been an appropriate unit. The choice of Census block groups rather than TAZs was due to two reasons. First, block groups are readily available, cover the whole nation, and are compatible with a wealth of supplemental data. The TAZs available for southern Maine, in contrast, did not cover the entire study area, and it was not possible to obtain clarifying information about population forecast data that might be attached to TAZs.

Additionally, one important limitation is the lack of easy access to congestion-related data. MaineDOT has been responsive in terms of providing data on multiple occasions. However, one needs to know the right contacts and place a request for the proper data items. (Sadly, this is consistent with other experience of data that simply don't exist on a regional or statewide scale in Maine, such as land use data and other infrastructure data.) Given the small number of variables that would need to be added to the public data set MEDOTPUBRDS – number of lanes, rural/urban setting, and access control – adding these to the regular publication would be a benefit to planners statewide.

Relieving Congestion

As noted above, the methods above are not intended to identify a binary condition of congestion or no congestion. But if additional analysis identifies congestion as a concern, is the solution to add capacity? The answer is not quite so simple. Downs's Law of Peak-Hour Expressway Congestion suggests that even with additions to capacity in the form of new limited-access highways, congestion is still a matter of equilibrium. New found capacity will attract some drivers for a while, but eventually congestion will follow. Some drivers may even be lured away from transit, making the problem worse. In time, Downs argues, peak hour congestion will always rise to exceed the optimal capacity of the road (Downs, 1962). And even if congestion doesn't rise as predicted, the road network will nevertheless attract development of commercial establishments wanting to tout easy access (Daniels, Keller, Lapping, Daniels, & Segedy, 2013, p. 151). Focusing efforts on congestion may, in fact, perpetuate the problem by increasing capacity ever farther from the city rather than addressing land use patterns directly (So, 1979, p. 139).

It is important to note the scale of a potential congestion problem. So (1979, p. 143) notes congestion difficulty in the vicinity of a park and ride lot. Surely, in this case, the park and ride lot actually helps to ease regional congestion on a larger scale by facilitating carpooling. In this case, congestion is a micro-level problem best addressed by engineering or by planners within the scope of only one site.

Congestion on a larger scale can be addressed by other means. We can attempt to direct growth to specific regionally identified centers, as in the Sustain Southern Maine work, and allow more intensive land uses there, allowing people to complete more tasks with less driving. We can encourage alternate modes of transportation: these range from carpooling, biking and walking, all mentioned above, to public transit. Another strategy is transportation demand management, or TDM, which can include components to shift demand to less congested times of day or locations thanks to flexible work schedules or telecommuting options. Employers can offer incentives for carpooling, and increased fees for parking (Weiner, 2008, pp. 143–144).

Parking, in fact, receives an entire chapter's treatment in Arnott's *Alleviating Urban Traffic Congestion*. Arnott suggests that planners are, if anything, somewhat too focused on parking at a site level, when instead they should be considering parking on a regional scale. He argues as well that parking generally is priced so low as to create excess demand, which causes undue social costs in the form of congestion caused by cruising for low-cost parking (2005, pp. 90–91).

Finally, we will not succeed in, nor should we desire to, eliminate all traffic from our regions. Nor will we, in all likelihood, find a way to construct our regions so as to allow the unfettered flow of traffic at any time of day or night. Therefore we must seek a balanced approach – a balanced transportation system that, in all its available modes, serves the variety of other goals and activities we have for our communities (Vuchic, 1999, pp. 11–14).

In the end, congestion is a problem with myriad causes and possible solutions. Clearly, divining both sides of the equation is beyond the scope of the present work. Nevertheless, it is hoped that the present work will be able to facilitate bringing our best minds – from both the transportation engineering and planning fields – to bear on the problem.

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Appendix A: MaineDOT Level of Service (LOS) Assumptions

HCM2000-based Level of Service (updated December 2008)

Level of Service : AADT/C Equivalency Table

Area Type (State)	Access Control	Level of Service A	B	C	D	E	F	Sources and Assumptions
Urban	Full	**0 to 3**	**3 to 5**	**5 to 7**	**7 to 9**	**9 to 10**	**10 plus**	HCM2000, Exhibit 23-2
	Partial		**0 to 7.5**	**7.5 to 8**	**8 to 9**	**9 to 10**	**10 plus**	HCM2000, Exhibit 10-7, Class I
	None			**0 to 7**	**7 to 9.5**	**9.5 to 10**	**10 plus**	HCM2000, Exhibit 10-7, Class II,III,IV
Rural	Full	**0 to 3**	**3 to 5**	**5 to 7**	**7 to 9**	**9 to 10**	**10 plus**	HCM2000, Exhibit 23-2
	Partial	**0 to 1**	**1 to 2.5**	**2.5 to 4**	**4 to 6**	**6 to 10**	**10 plus**	HCM2000, 2-lane, level, ffs60, 8pts, 55:45, .95, 10%HT
	None	**0 to 1**	**1 to 2.5**	**2.5 to 4**	**4 to 6**	**6 to 10**	**10 plus**	HCM2000, 2-lane, level, ffs60, 8pts, 55:45, .95, 10%HT

Area Type (State)	Access Control	AADT/C 0.0 to 1.0	1.0 to 2.5	2.5 to 3.0	3.0 to 4.0	4.0 to 5.0	5.0 to 6.0	6.0 to 7.0	7.0 to 7.5	7.5 to 9.0	9.0 to 9.5	9.5 to 10.0	10.0 plus
Urban	Full	**A**	**A**	**A**	**B**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**F**
	Partial	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**B**	**C**	**E**	**E**	**F**
	None	**C**	**C**	**C**	**C**	**C**	**C**	**C**	**D**	**D**	**D**	**E**	**F**
Rural	Full	**A**	**A**	**A**	**B**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**F**
	Partial	**A**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**E**	**E**	**E**	**F**
	None	**A**	**B**	**C**	**C**	**D**	**D**	**E**	**E**	**E**	**E**	**E**	**F**

Source: MaineDOT (Hanscom, 2015).

Appendix B: Determining Population Capacity in a Block Group

Planners may wish to calculate a block group (or other areal unit)'s capacity to absorb increases in population without having that block group wind up in the top 20 most congestion prone block groups. Such calculations would be possible if population data were retained and aggregated throughout the analysis. For example, if one selected a block group projected to have a relatively low BG_FAADT_C in 2030, she might wish to know the difference in population needed to bring this block group's BG_FAADT_C up to the mean for the region. Multiplying the block group's traffic by the mean congestion index for the region, and then dividing by the block group's congestion index gives the new amount of overall traffic required to make the block group's congestion index rise to the mean level. Dividing that value by the block group's overall traffic per person gives the "new" total population, assuming driving patterns are unchanged. Expressed as variable names, this is BG_FAADT_2030 * Mean(BG_FAADT_2030_C) / BG_FAADT_2030_C / BG_FAADT_2030_PP = Population. Subtracting the new total population from the starting population gives the capacity for increase while having FAADT/C approach the mean for the region.

Given such a block group, it is possible to make the following calculation: (BG_FAADT_2030 * Mean(BG_FAADT_2030_C) / BG_FAADT_2030_C / BG_FAADT_2030_PP) - Original Population.