INDICATOR DICTIONARY

Snapshot Module

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Indicator: **S100. Population density**

Definition and Units: Persons per gross acre including residents and employees; also used in 4D method (see Appendix A).

Formula:

$$\frac{\sum Emps + \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}}{SketchArea\,Boundary}$$

DU = dwelling units by Dwelling Subscript

$ppHH$ = persons per household by Dwelling Subscript

Dwelling Subscripts:

sf = single family

mh = mobile home

$mf\,2-4$ = multi-family (2-4 units)

$mf\,5+$ = multi-family (5+ units)

GQ = Group Quarters

Shapefiles/Attributes:
Existing land-use (polygon) / dwelling unit count (integer)
Existing land-use (polygon) / dwelling unit type (string)
Employment (point) / Employment count (integer)
Sketch Boundary

User-Defined Parameters:
Single family persons per household
Mobile home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group quarters persons per household

Illustrative Scores: Varies by location in county, e.g. 9.97 persons/acre in Burlington and 0.09 persons/acre in Westford.

Indicator: **S101. Use mix**

Definition and Units: Index of use dissimilarity among one-acre grid cells expressed on a 0-1 scale with 1 being the highest dissimilarity.

Formula:

$$\frac{\sum D_i}{\sum C_i}$$

D_i = number of dissimilar cells adjacent to cell i

C_i = number of cells adjacent to cell i

$0 \le C_i, D_i \le 8$

Shapefiles/Attributes: Existing land-use (polygon) / existing land-use class (string)

User-Defined Parameters: None.

Illustrative Scores: Varies by location in county, e.g. 0.1 in rural areas, up to 0.6 in highly mixed urban areas.

Note: This indicator measures use mix in terms of diversity among spatial units of a sketch area, in this case an imaginary grid of 1-acre cells laid over the top of land-uses. In effect, the model determines whether the eight cells adjacent to a subject cell contain different uses than the subject cell; this process is repeated for all cells and summed into a single value for the entire area. Instead of characterizing the absolute amount of different uses in an area, it measures the frequency of encountering different uses when moving across an area. The score can be read as the percentage of time a person would encounter different uses as they walked through an area. For this reason, any score above 0.5 indicates a relatively high-mixed area.

Indicator: **S102. Average parcel size**

Definition and Units: Avg. size of parcels in sq.ft.

Formula:

$$\frac{\sum A_i}{n}$$

A_i = Area of parcel i
n = number of parcels

Shapefiles/Attributes: Existing land-use (polygon) / existing land-use class (string)

User-Defined Parameters: None.

Illustrative Scores: Varies by location in county, e.g. 32,944 sq.ft. in Burlington and 1,176,525 sq.ft. in Westford.

Note: This indicator calculates the average size of all parcels in a sketch area regardless of use type or relationship to a study subject. It is intended to generally characterize an area's "grain" of parcelization, building massing, and other urban design contributors to the physical scale of the built environment. To calculate average size for a subgroup of parcels in a sketch area, the user must redraw the sketch boundary to coincide with the smaller group of parcels, or make the calculation outside of DSS in ArcView.

Indicator: **S103. Developed acres per capita**

Definition and Units: Total developed residential and nonresidential net acres divided by total number of residents. Any parcel with one or more dwellings or employees is considered developed, unless it is designated with a land-class defined by the user as non-buildable, e.g. natural resource activity.

Formula:

$$\frac{\sum A_{DEV}}{TotPop}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}$$

Subscripts:

sf = single family

mh = mobile home

$mf\,2-4$ = multi-family (2-4 units)

$mf\,5+$ = multi-family (5+ units)

GQ = Group Quarters

A_{DEV} = total acres of developed residential ($DU \geq 1$) and nonresidential (EmpCount ≥ 1) parcels of existing land use, unless designated as undeveloped.

DU = dwelling units from Existing Land Use

$ppHH$ = persons per household

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Existing land-use (polygon) / dwelling unit type (string)
Employment (point)

User-Defined Parameters: Single family persons per household
Mobile home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group quarters persons per household

Illustrative Scores: Varies by location in county, e.g. 0.107 acres/capita in Burlington and 4.173 acres/capita in Westford.

Indicator: **S104. Sketch-to-region diversity ratio**

Definition and Units: Relation of study area population/employment ratio versus region population/employment ratio, used only for 4D method expressed on 0-1 scale (see detailed explanation in Appendix A).

Formula:

$$1-\frac{abs\left\{\left(\frac{\mathrm{Re}\,gEmp}{\mathrm{Re}\,pPop}*TotPop\right)-TotEmp\right\}}{\left(\frac{\mathrm{Re}\,gEmp}{\mathrm{Re}\,pPop}*TotPop\right)+TotEmp}$$

$$TotEmp=\sum Employees$$

$$TotalPop=\sum DU_{sf}*ppHH_{sf}+\sum DU_{mh}*ppHH_{mh}+\sum DU_{mf\,2-4}*ppHH_{mf\,2-4}+\sum DU_{mf\,5+}*ppHH_{mf\,5+}+\sum DU_{GQ}*ppHH_{GQ}$$

$\mathrm{Re}\ gEmp$ = regional population
$\mathrm{Re}\ gPop$ = regional population
DU = dwelling units
$ppHH$ = persons per household

Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Existing land-use (polygon) / dwelling unit type (string)
Employment (point) / Employment count (integer)

User-Defined Parameters: Regional employment
Regional population
Single family persons per household
Mobile Home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group Quarters persons per household

Illustrative Scores: Higher values, e.g. 0.75-0.95, represent study areas whose population/employment mix is closer to the regional population/employment mix; lower values reflect study areas that have mixes that are unlike the regional mix.

Indicator: **S200. Conforming dwelling density**

Definition and Units: DU/net acre of residential land. Only developed parcels that conform to the planned land-use are included.

Formula:

$$\frac{\sum DU_{res}}{\sum A_{res}}$$

$$DU_{res} = \text{dwelling units in parcels that overlay planned residential land-use}$$
$$A_{res} = \text{area (acres) of pacels that overlay planned residential land-use}$$
$$\text{where } DU_{res} \geq 1$$

Shapefiles/Attributes: Planned land-use (polygon) / land-use class (string)
Existing land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 7.08 DU/acre in Burlington and 0.05 DU/acre in Westford.

Note: The “conforming” nature of this calculation means that it only includes dwellings in residential zones, and does not include “non-conforming” dwellings that have been built in non-residential zones. This indicator is therefore appropriate when the user is evaluating a case against plan and/or zoning standards, e.g. if an area’s planning goal is 10 DU/ac, then how close is it to achieving the goal?

Indicator: **S201. Non-conforming dwelling density**

Definition and Units: DU/net acre of all land regardless of plan designation.

Formula: $\frac{\sum DU_{ALL}}{\sum A_{ALL}}$

DU_{ALL} = dwelling units in all parcels
A_{ALL} = area (acres) of all parcels where $DU \geq 1$

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 0.05 in rural areas, 7.0 in urban areas.

Note: The “non-conforming” nature of this calculation means that it includes all residences, including non-conforming dwellings that have been built outside of residential zones. This indicator is appropriate when the user is not concerned about plan or zoning compliance, but instead wants to identify all residential impacts to the transportation system regardless of their plan or zoning status, e.g. a “grandfathered” apartment building will still generate significant numbers of vehicle trips even after its area has been up-zoned.

Indicator: **S202. Single-family housing share**

Definition and Units: % of dwelling units that are single family.

Formula:

$$\frac{\sum DU_{sf}}{\sum DU}*100 \quad \frac{\sum DU_{GQ}}{\sum DU}*100 \quad \frac{\sum DU_{mh}}{\sum DU}*100 \quad \frac{\sum DU_{mf\,2-4}}{\sum DU}*100 \quad \frac{\sum DU_{mf\,5+}}{\sum DU}*100$$

$DU =$ total dwelling units

$DU_{sf} =$ single family dwelling units

$DU_{mh} =$ mobile home dwelling units

$DU_{mf\,2-4} =$ multi - family (2 - 4 units) dwelling units

$DU_{mf\,5+} =$ multi - family (5 + units) dwelling units

$DU_{GQ} =$ Group Quarters dwelling units

Shapefiles/Attributes: Existing land-use (polygon) / dwelling type (string)
Existing land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 45% single-family in Burlington and 92% single-family in Westford.

Indicator:	**S203. Mobile home housing share**
Definition and Units:	% of dwelling units that are mobile home.
Formula:	See Indicator S202.
Shapefiles/Attributes:	See Indicator S202.
User-Defined Parameters:	None
Illustrative Scores:	Varies by location in county, e.g. 1-2%.

Indicator:	**S204. Multi-family 2-4 housing share**
Definition and Units:	% of dwelling units that are multi-family 2-4 units.
Formula:	See Indicator S202.
Shapefiles/Attributes:	See Indicator S202.
User-Defined Parameters:	None
Illustrative Scores:	Varies by location in county, e.g. 28% in Burlington and 8% in Westford.

Indicator: **S205. Multi-family 5+ units housing share**

Definition and Units: % of dwelling units that are multi-family 5 or more units.

Formula: See Indicator S202.

Shapefiles/Attributes: See Indicator S202.

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 22% in Burlington and 0% in Westford.

Indicator:	**S206. Group quarters housing share**
Definition and Units:	% of dwelling units that are group quarters.
Formula:	See Indicator S202.
Shapefiles/Attributes:	See Indicator S202.
User-Defined Parameters:	None
Illustrative Scores:	Varies by location in county, e.g. 0-5%.

Indicator: **S207. Housing proximity to transit**

Definition and Units: Avg. distance from all dwellings to closest transit stop in ft.

Formula: $$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in feet from parcel p to a transit stop
D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Transit stops (point)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 975 ft. in Burlington and 44,072 ft. in Westford.

Indicator: **S208. Housing proximity to recreation**

Definition and Units: Avg. distance from all dwellings to closest park or school in ft.

Formula:
$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in feet from parcel p to parcels designated as parks or schools with $Year \le SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Parks and Schools (polygon) / Year (4-digit year)

User-Defined Parameters: Snapshot Year

Illustrative Scores: Varies by location in county, e.g. 1,623 ft. in Burlington and 12,909 ft. in Westford.

Indicator: **S209. Housing proximity to education**

Definition and Units: Avg. distance from all dwellings to closest school and/or day care in ft.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to points designated as schools or day care with $Year \leq SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Schools and Daycare Facilities (point) / Year (4-digit year)

User-Defined Parameters: Snapshot Year

Illustrative Scores: Varies by location in county, e.g. 1,809 ft. in Burlington and 15,781 ft. in Westford.

Indicator: **S210. Housing proximity to key amenities**

Definition and Units: Avg. distance from all dwellings to closest key service/amenity in ft.

Formula:

$$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to parcels designated as a key service or amenity with $Year \leq SnapshotYear$

D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Key Amenities (point) / Year (4-digit year)

User-Defined Parameters: Snapshot Year

Illustrative Scores: Varies by location in county, e.g. 1,330 ft. in Burlington and 14,425 ft. in Westford.

Indicator: **S211. Dwellings within 1/8 mi. of 3+ modes**

Definition and Units: % of dwellings within 1/8 mi. of three or more modes.

Formula: $$\frac{\sum DU_{mm}}{\sum DU}$$

DU_{mm} = dwelling units contained in 1/8 mi. buffer of three or more modes with $Year \leq SnapshotYear$
DU = dwelling units

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line) / sidewalk attribute (integer)
Transit routes (line) / Year (4-digit year)
Bike routes (line) / Year (4-digit year)

User-Defined Parameters: Snapshot Year

Illustrative Scores: Varies by location in county, e.g. 78% in Burlington and 0% in Westford.

Indicator: **S212. Housing proximity to employment center**

Definition and Units: Average distance from all dwellings to closest employment center in ft.

Formula: $$\frac{\sum P_{par} * D_{par}}{\sum D_{par}}$$

P_{par} = shortest network path length in miles from parcel p to employment center points
D_{par} = number of dwelling units on parcel p

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line)
Employment Centers (point)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 6,333 ft. in Burlington and 14,940 ft. in Westford.

Indicator: **S213. Residential water consumption**

Definition and Units: Gallons/day/capita for single-family residential parcels of 15,000 sq.ft. or less, and all other residential types regardless of parcel size.

Formula:

$$\frac{0.85*Grass_{\%}+0.5*GrndCov_{\%}+0.2*Shrub_{\%}}{100}*\frac{\sum A_{pervious}*VFactor*0.623}{365*TotalPop}+HHIWU$$

$Grass_{\%} =$ % Typical Landscaping - Grass
$GrndCov_{\%} =$ % Typical Landscaping - Groundcover
$GrndCov_{\%} =$ % Typical Landscaping - Shrubs and Trees
$APerv_i =$ pervious area on Parcel i
$VFactor =$ V Factor from Water Requirement Region
$HHIWU =$ Household Internal Water Use
$TotalPop =$ From Housing Diversity Indicator

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters:
Household Internal Water Use
% Typical Landscaping - Grass
% Typical Landscaping - Groundcover
% Typical Landscaping - Shrubs and Trees
V Factor from Water Requirement Region
HousingDiversity Indicator, which produces *TotalPop* calc

Illustrative Scores: Varies by household size and parcelization patterns, e.g. 50-150 gal/day/capita.

Notes: This indicator calculates water use inside homes for domestic consumption purposes, and outside for landscape irrigation. Guidance for user-defined internal and external water use parameters should be obtained from local water agencies. A comprehensive survey of usage rates among North American cities appears in the Handbook of Water Use and Conservation, 2001, Amy Vickers, WaterPlow Press, Amherst, Massachusetts.

Indicator: **S214. Residential energy consumption**

Definition and Units: MMBtu/yr/capita for housing and auto travel.

Formula:

$$E_{auto} + E_{du}$$

$$E_{auto} = \frac{VMT_{capita-day}}{MPG_{lightvehicle}} * (0.1154\ \text{MMBtu/gal}) * 365\ \text{days/year}$$

$$E_{du} = \frac{\sum (E_p * D_p)}{TotalPop}$$

$$E_p = \overbrace{\begin{cases} \overbrace{BaseEnergy}^{\rho \le 13} \\ \overbrace{BaseEnergy * 0.86}^{\rho > 20} \\ \overbrace{BaseEnergy * (1 - ((2 * \rho - 26)/100))}^{13 < \rho \le 20} \end{cases}}^{if}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf2-4} * ppHH_{mf2-4} + \sum DU_{mf5+} * ppHH_{mf5+} + \sum DU_{GQ} * ppHH_{GQ}$$

Dwelling Subscripts:

sf = single family

mh = mobile home

$mf2-4$ = multi-family (2-4 units)

$mf5+$ = multi-family (5+ units)

GQ = Group Quarters

D_p = number of dwelling units on parcel p

E_p = density based energy coefficient for parcel p

DU = dwelling unit count by Dwelling Subscript

$ppHH$ = persons per household by Dwelling Subscript

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Existing land-use (polygon) / dwelling unit type (string)
Existing land-use (polygon) / dwelling unit type (single)

User-Defined Parameters: Base energy usage(0-13dwelling units/acre) – MMBtu/DU/yr
$MPG_{lightvehicle}$
$VMT_{capita-day}$ (indicators S610, S611)
Single family persons per household
Mobile Home persons per household
Multi-family 2-4 units persons per household
Multi-family 5+ units persons per household
Group Quarters persons per household

Illustrative Scores: Varies by housing density and amount of household driving, e.g. 100-200 MMBtu/yr/capita.

Indicator: **S300. Employment**

Definition and Units: Total number of employees.

Formula: $\sum Employees_{sa}$

$Employees_{sa} = \text{Employees inside the sketch boundary}$

Shapefiles/Attributes: Employment (point) / Employment count (integer)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Varies by location in county and size of study area.

Indicator: **S301. Jobs/housed workers balance**

Definition and Units: Ratio of total jobs to total housed workers.

Formula:

$$\frac{\sum Employees}{\sum DU_{sf} * wpHH_{sf} + \sum DU_{mh} * wpHH_{mh} + \sum DU_{mf\,2-4} * wpHH_{mf\,2-4} + \sum DU_{mf\,5+} * wpHH_{mf\,5+} + \sum DU_{GQ} * wpHH_{GQ}}$$

DU = dwelling units by Dwelling Subscript
$wpHH$ = workers per household by Dwelling Subscript

Dwelling Subscripts:
sf = single family
mh = mobile home
$mf\,2-4$ = multi-family (2-4 units)
$mf\,5+$ = multi-family (5+ units)
GQ = Group Quarters

Shapefiles/Attributes:
Existing land-use (polygon) / dwelling unit type (string)
Existing land-use (polygon) / dwelling unit count (integer)
Employment (point) / Employment count (integer)
Sketch Boundary

User-Defined Parameters:
Single family workers per household
Mobile Home workers per household
Multi-family 2-4 units workers per household
Multi-family 5+ units workers per household
Group Quarters workers per household

Illustrative Scores: Varies by location in county and configuration of study area, e.g. 1.38 in Burlington and 0.2 in Westford.

Indicator: **S302. Conforming employment density**

Definition and Units: Employees per net acre of employment-designated land. Only developed parcels that conform to the planned land-use are included.

Formula:

$$\frac{\sum Emp_{nonres}}{\sum A_{nonres}}$$

Emp_{nonres} = employees in parcels that overlay planned non-residential land-use
A_{nonres} = area (acres) of pacels that overlay planned non-residential land-use
where $Emp_{nonres} \geq 1$

Shapefiles/Attributes: Planned land-use (polygon) / land-use (string)
Employment (points) / employee count (integer)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 44.32 employees/acre in Burlington and 2.09 employees/acre in Westford.

Note: The "conforming" nature of this calculation means that only businesses inside non-residential zones are included, and business located outside of non-residential zones are excluded. This indicator is appropriate when the user is evaluating a sketches' compliance with applicable plan and/or zoning standards.

Indicator: **S303. Non-conforming employment density**

Definition and Units: Employees per net acre of all land regardless of plan designation.

Formula:

$$\frac{\sum Emp_{ALL}}{\sum A_{ALL}}$$

Emp_{ALL} = total employees in all parcels
A_{ALL} = area (acres) of all parcels containing emp points with $EmpCount \geq 1$

Shapefiles/Attributes: Employment (points) / employee count (integer)

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 14.89 employees/acre in Burlington and 0.24 employees/acre in Westford.

Note: The “non-conforming” nature of this calculation means that all businesses are included, including those establishments located outside of non-residential zones. This indicator is appropriate when the user is not concerned with plan or zoning compliance, but rather employment impacts to the transportation system, e.g. a “grandfathered” manufacturing plant will still generate significant vehicle trips even after being changed to a non-manufacturing designation.

Indicator: **S304. Employment proximity to transit**

Definition and Units: Avg. distance from all employment locations to closest transit stop in ft.

Formula:

$$\frac{\sum P_{par} * E_{par}}{\sum E_{par}}$$

P_{par} = shortest network path length in feet from parcel p to a transit stop
E_{par} = number of employees on parcel p

Shapefiles/Attributes: Existing land-use (polygon)
Employment (points) / employee count (integer)
Transit stops

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 523 ft. in Burlington and 43,578 ft. in Westford.

Indicator: **S400. Imperviousness**

Definition and Units: Amount of impervious surface in acres per DU.

Formula:

$$\frac{\sum Length_i * Width_i / 43560(sf\ /\ acre) + \sum A_p * Coverage_p}{\sum DU}$$

$Length_i$ = Length of street segment i intersecting parcel p
$Width_i$ = StreetWidth of street segment i
A_p = Area of parcel p
$Coverage_p$ = Coverage percent by land - use class for parcel p
DU = DU count

Shapefiles/Attributes: Existing land-use (polygon) / existing land-use class (string)
Existing land-use (polygon) / dwelling unit count (integer)
Street centerlines (line) / StreetWidth (integer)

User-Defined Parameters: Building coverage % by existing land-use class

Illustrative Scores: Varies by location in county and land-use character of study area, e.g. 0.1 acres/DU in rural areas, 0.03 in urban areas.

Notes: Assumes that % impervious coverage is the same for all parcels sharing the same existing land-use class, regardless of a particular parcel's dwelling unit or employee count, which varies between parcels sharing the same existing land-use class. The user should enter a % imperviousness for each land-use class as a weighted value that reflects study area densities for each land-use class.

Indicator: **S401. Stormwater runoff**

Definition and Units: Total cubic ft/yr of stormwater runoff from sketch area.

Formula: Contained in separate documentation for EPA SGWATER software.

Shapefiles/Attributes: Soil (polygon) / hydrologic group (string)
Existing land-use (polygon) / land-use class (string)
Street centerlines (line) / StreetWidth (integer)

User-Defined Parameters: Annual precipitation file Rainfall.csv
Building Coverage % by existing land-use class

Illustrative Scores: Varies by size and land-use character of study area.

Notes: Rainfall.CSV file must be a comma-separated text file containing only 2 fields/row: Date, Rainfall (in inches). Rainfall.CSV must contain at least one row for every day of the year (365 rows)

Indicator: **S402. Total suspended solids**

Definition and Units: Kg/yr contained in stormwater.

Formula: Contained in separate documentation for EPA SGWATER software.

Shapefiles/Attributes: Soil (polygon) / hydrologic group (string)
Existing land-use (polygon) / land-use class (string)
Street centerlines (line) / StreetWidth (integer)

User-Defined Parameters: Annual precipitation file Rainfall.csv
Building Coverage % by existing land-use class
EMC Pollutant Runoff: TSS (mg/L) by existing land-use class

Illustrative Scores: Varies by size and land-use character of study area.

Indicator:	**S403. Phosphorus**
Definition and Units:	Kg/yr contained in stormwater.
Formula:	Contained in separate documentation for EPA SGWATER software.
Shapefiles/Attributes:	Soil (polygon) / hydrologic group (string) Existing land-use (polygon) / land-use class (string) Street centerlines (line) / StreetWidth (integer)
User-Defined Parameters:	Annual precipitation file Rainfall.csv Building Coverage % by existing land-use class EMC Pollutant Runoff: Phosphate (mg/L) by existing land-use class
Illustrative Scores:	Varies by size and land-use character of study area.

Indicator:	**S404. Nitrogen**
Definition and Units:	Kg/yr contained in stormwater.
Formula:	Contained in separate documentation for EPA SGWATER software.
Shapefiles/Attributes:	Soil (polygon) / hydrologic group (string) Existing land-use (polygon) / land-use class (string) Street centerlines (line) / StreetWidth (integer)
User-Defined Parameters:	Annual precipitation file Rainfall.csv Building Coverage % by existing land-use class EMC Pollutant Runoff: Phosphate (mg/L) by existing land-use class
Illustrative Scores:	Varies by size and land-use character of study area.

Indicator: **S407. Open space**

Definition and Units: % of total sketch area dedicated to open space.

Formula:

$$\frac{\sum P_{Open}}{\sum P_{All}}$$

P_{Open} = number of Parcels designated Open Space
P_{All} = total number of Parcels

Shapefiles/Attributes: Existing land-use (polygon) / existing land-use class (string)

User-Defined Parameters: Open space designation by existing land-use class

Illustrative Scores: Varies by location in county, e.g. 9% in Burlington and 37% in Westford.

Indicator: **S408. Park space availability**

Definition and Units: Acres of park space per 1,000 persons.

Formula:

$$\frac{\sum A_{park}}{(TotPop/1000)}$$

$$TotalPop = \sum DU_{sf} * ppHH_{sf} + \sum DU_{mh} * ppHH_{mh} + \sum DU_{mf\,2-4} * ppHH_{mf\,2-4} + \sum DU_{mf\,5+} * ppHH_{mf\,5+} + \sum DU_{GQ} * ppHH_{GQ}$$

Dwelling Subscripts:

sf = single family

mh = mobile home

$mf\,2-4$ = multi-family (2-4 units)

$mf\,5+$ = multi-family (5+ units)

GQ = Group Quarters

A_{park} = total acres of parkland or schoolyards with $Year \leq SnapshotYear$

DU = dwelling units by dwelling subscript

$ppHH$ = persons per household by dwelling subscript

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit count (integer)
Parks and Schools (polygon) / Year (4-digit year)

User-Defined Parameters: Persons per household: Single family, mobile home, multi-family (2-4 units), multi-family (5+ units), group quarters

Illustrative Scores: Varies by location in county, e.g. 38 acres/1,000 persons in Burlington and 50 acres/1,000 persons in Westford.

Indicator: **S500. Residential wastewater production**

Definition and Units: Total gallons/day.

Formula:

$$\sum DU_{sf} * wppHH_{sf} + \sum DU_{mh} * wppHH_{mh} + \sum DU_{mf\,2-4} * wppHH_{mf\,2-4} + \sum DU_{mf\,5+} * wppHH_{mf\,5+} + \sum DU_{GQ} * wppHH_{GQ}$$

DU = dwelling units by dwelling subscript

$wppHH$ = wastewater production per household by dwelling subscript

Dwelling Subscripts:

sf = single family

mh = mobile home

$mf\,2-4$ = multi-family (2-4 units)

$mf\,5+$ = multi-family (5+ units)

GQ = Group Quarters

Shapefiles/Attributes: Existing land-use (polygon) / dwelling unit type (string)
Existing land-use (polygon) / dwelling unit count (integer)

User-Defined Parameters: Single family wastewater production (gals/day/DU)
Mobile home wastewater production (gals/day/DU)
Multi-family 2-4 units wastewater production (gals/day/DU)
Multi-family 5+ units wastewater production (gals/day/DU)
Group Quarters wastewater production (gals/day/DU)

Illustrative Scores: Varies by study area size and land-use character.

Indicator: **S501. Nonresidential wastewater production**

Definition and Units: Total gallons/day.

Formula: $\sum Employees * wppWORKER$

$Employees$ = total number of employment points in study area
$wppWORKER$ = wastewater production per employee

Shapefiles/Attributes: Employment (point)

User-Defined Parameters: Employee wastewater production (gals/day/employee)

Illustrative Scores: Varies by study area size and land-use character.

Indicator: **S600. Sidewalk completeness**

Definition and Units: Ratio of total sidewalk centerline distance vs. total street centerline distance; also used in 4D method (see Appendix A).

Formula:

$$\frac{\sum SW_s}{\sum CL_s * 2}$$

CL_s = length of street centerline segment s
SW_s = sidewalk count for street centerline segment s

Shapefiles/Attributes: Street centerline (line) / Sidewalk Count (integer)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 40% in Burlington and 0% in Westford.

Indicator: **S601. Pedestrian route directness**

Definition and Units: Average ratio of walking distances from random sample origin points to central node versus straight line distances between same points; also used in 4D method (see Appendix A).

Formula:

$$\frac{\sum \frac{Network_{p-cn}}{Straightline_{p-cn}}}{n}$$

$Network_{p\text{-}cn}$ = nework distance from parcel p to the closest central node

$Straightline_{p\text{-}cn}$ = straightline distance from parcel p to the closest central node

n = number of parcels with 1/2 mile of a central node (straightline distance)

Shapefiles/Attributes: Existing land-use (polygon)
Street centerlines (line)
Central neighborhood nodes

User-Defined Parameters: None

Illustrative Scores: Areas with favorable route directness will score 1.5 or less; unfavorable areas will score higher than 1.5.

Indicator: **S602. Street network density**

Definition and Units: Street centerline mi./sq.mi.; also used in 4D method (see Appendix A).

Formula: $$\frac{\sum StCL}{A}$$

$StCL = \text{length, street centerlines}$
$A = \text{area, sketch boundary}$

Shapefiles/Attributes: Street centerline (line)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 11.1 mi./sq.mi. in Burlington and 1.7 mi./sq.mi. in Westford.

Indicator: **S603. Street connectivity**

Definition and Units: Ratio of intersections vs. intersections and cul-de-sacs expressed on a 0-1 scale with greatest connectivity at 1.

Formula:

$$\frac{\sum I}{\sum (I + C)}$$

$I = \text{studyarea intersections}$
$C = \text{study area cul-du-sacs}$

Shapefiles/Attributes: Street centerline (line)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Favorable areas will score 0.75 or higher.

Indicator: **S604. Pedestrian design index**

Definition and Units: Composite index of street network density, sidewalk completeness, and pedestrian route directness used only in the 4D method (see detailed explanation in Appendix A).

Formula: $(0.0195 * SND) + (1.18 * SC) + (3.63 / PRD)$

$SND =$ street network density
$SC =$ sidewalk completeness
$PRD =$ pedestrian route directness

Shapefiles/Attributes: N/A

User-Defined Parameters: None.

Illustrative Scores: Varies by location in county.

Indicator: **S605. Bicycle network**

Definition and Units: % of total street centerline distance with designated bike route.

Formula:

$$\frac{\sum BR_s}{\sum CL_s}$$

CL_s = length of street centerline segment s
BR_s = length of bike route centerline segment s

Shapefiles/Attributes: Street centerline (line)
Bike route centerline (line) / Year (4-digit year)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 31% in Burlington and 0% in Westford.

Indicator: **S606. Transit stop coverage**

Definition and Units: Transit stops per sq.mi.

Formula:

$$\frac{\sum Stop_i}{A}$$

$Stop_i = \text{stop i}$
$A = \text{area, sketch boundary}$

Shapefiles/Attributes: Transit stops (point)
Sketch Boundary

User-Defined Parameters: None

Illustrative Scores: Varies by location in county, e.g. 32.8 stops/sq.mi. in Burlington and 0 stops/sq.mi. in Westford.

Indicator: **S607. ITM-derived regional accessibility**

Definition and Units: Mean travel time from sketch area centroid to all other regional destinations (TAZs) weighted by mode shares; used only in the 4D method (see Appendix A).

Formula: Uses ITM-calculated value as input for snapshot base case.

Shapefiles/Attributes: N/A

User-Defined Parameters: Accessibility value is entered by user based on separate ITM calculation for a given sketch area.

Illustrative Scores: Varies by location in county, e.g. 20-30 minutes.

Note: This indicator is calculated by ITM and not by DSS. It should be used when ITM is available for operation in tandem with the DSS, and when alternate cases include transportation feature changes that would impact accessibility, e.g. new street construction, expanded transit service.

Indicator: **S608. Home-based vehicle trips**

Definition and Units: HB VT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VT = VT_{input\ parameter}$
Alternate case sketch:

$$VT_{base} * (1 + \Delta VT)$$
$$\Delta VT = (-0.042 * \Delta Den) + (-0.058 * \Delta Div) + (-0.022 * \Delta Des)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$

Shapefiles/Attributes: N/A

User-Defined Parameters: VT (base sketch parameter)
Population density (base and alternate sketch indicators)
Land-use diversity (base and alternate sketch indicators)
Pedestrian environment design (base and alternate sketch indicators)

Illustrative Scores: Varies by location in county, e.g. 2-4 VT/day/capita.

Indicator: **S609. Non home-based vehicle trips**

Definition and Units: NHB VT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VT = VT_{input\ parameter}$
Alternate case sketch:

$$VT_{base} * (1 + \Delta VT)$$
$$\Delta VT = (-0.042 * \Delta Den) + (-0.058 * \Delta Div) + (-0.022 * \Delta Des)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$

Shapefiles/Attributes: N/A

User-Defined Parameters: VT (base sketch parameter)
Population density (base and alternate sketch indicators)
Land-use diversity (base and alternate sketch indicators)
Pedestrian environment design (base and alternate sketch indicators)

Illustrative Scores: Varies by location in county, e.g. 1-3 VT/day/capita.

Indicator: **S610. Home-based vehicle miles traveled**

Definition and Units: HB VMT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VMT = VMT_{input\ parameter}$
Alternate case sketch:

$$VMT_{base} * (1 + \Delta VMT)$$
$$\Delta VMT = (-0.045 * \Delta Den) + (-0.051 * \Delta Div) + (-0.052 * \Delta Des)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$

Shapefiles/Attributes: N/A

User-Defined Parameters: VMT (base sketch parameter)
Population density (base and alternate sketch indicators)
Land-use diversity (base and alternate sketch indicators)
Pedestrian environment design (base and alternate sketch indicators)

Illustrative Scores: Varies by location in county, e.g. 20-30 HB VMT/day/capita.

Indicator: **S611. Non home-based vehicle miles traveled**

Definition and Units: NHB VMT/day/capita; used in the 4D method (see Appendix A).

Formula: Base case sketch: $VMT = VMT_{input\ parameter}$
Alternate case sketch:

$$VMT_{base} * (1 + \Delta VMT)$$
$$\Delta VMT = (-0.045 * \Delta Den) + (-0.051 * \Delta Div) + (-0.052 * \Delta Des)$$
$$\Delta Den = \frac{(PopDen_{altcase} - PopDen_{basecase})}{PopDen_{basecase}}$$
$$\Delta Div = \frac{(LUDiv_{altcase} - LUDiv_{basecase})}{LUDiv_{basecase}}$$
$$\Delta Des = \frac{(PED_{altcase} - PED_{basecase})}{PED_{basecase}}$$

Shapefiles/Attributes: N/A

User-Defined Parameters: VMT (base sketch parameter)
Population density (base and alternate sketch indicators)
Land-use diversity (base and alternate sketch indicators)
Pedestrian environment design (base and alternate sketch indicators)

Illustrative Scores: Varies by location in county, e.g. 5-10 HB VMT/day/capita.

Indicator: **S612. Parking demand**

Definition and Units: Required parking spaces at user-defined rates.

Formula:

$$\sum DU_i * LUCoeff_{res} + \sum \frac{BANonR_i * LUCoeff_{NonRes}}{1000}$$

DU_i = Dwelling Unit Count in residential parcel i
$LUCoeff_{res}$ = Parking space demand per du for residential parcel i by existing land-use class
$BANonR_i$ = building area of non-residential parcel i
$LUCoeff_{NonRes}$ = Parking spaces per 1000 sq.ft. $BANonR_i$ by existing land-use class

Shapefiles/Attributes: Existing land-use (polygon) / existing land-use class (string)
Existing land-use (polygon) / dwelling unit count (string)
Existing land-use (polygon) / Building Area (numeric) in sq.ft.

User-Defined Parameters: Residential Parking spaces per DU by existing land-use class
Non residential parking spaces per 1000 sq.ft. of building area by existing land-use class

Illustrative Scores: Dependent on user-defined parking requirements, and size and land-use character of study area.

Indicator: **S613. Parking supply**

Definition and Units: Number of existing on-street and off-street spaces.

Formula: $\sum OnStreet_s + \sum OffStreet_p$

$OnStreet_s = \text{on-street parking for street segment s}$
$OffStreet_p = \text{off-street parking for parcel p}$

Shapefiles/Attributes: Existing land-use (polygon) / off-street parking (integer)
Street centerlines(line) / on-street parking (integer)

User-Defined Parameters: None

Illustrative Scores: Dependent on size and land-use character of study area.

Indicator: **S700. Carbon monoxide (CO)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell})/2000$$

$$P_{trav} = VMT_{percapita} * CO_2Coef * 365/453.6$$

$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$

$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters:
Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Building CO coefficients, electricity and natural gas and heating oil, lb/MMBtu
Travel CO coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 500-600 lbs/yr/capita.

Indicator: **S701. Hydrocarbon (HC)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell})/2000$$
$$P_{trav} = VMT_{percapita} * CO_2Coef * 365/453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$
$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters: Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Building HC coefficients, electricity and natural gas and heating oil, lb/MMBtu
Travel HC coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 75-100 lbs/yr/capita.

Indicator: **S702. Oxides of sulphur (SOX)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell})/2000$$
$$P_{trav} = VMT_{percapita} * CO_2Coef * 365/453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$
$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters: Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Building SOX coefficients, electricity and natural gas and heating oil, lb/MMBtu
Travel SOX coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 10-15 lbs/yr/capita.

Indicator: **S703. Oxides of nitrogen (NOX)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell}) / 2000$$
$$P_{trav} = VMT_{percapita} * CO_2Coef * 365 / 453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$
$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters: Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Building NOX coefficients, electricity and natural gas and heating oil, lb/MMBtu
Travel NOX coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 40-60 lbs/yr/capita.

Indicator: **S704. Particulate matter (PM)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell})/2000$$
$$P_{trav} = VMT_{percapita} * CO_2Coef * 365/453.6$$
$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$
$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters: Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Travel PM coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 1-2 lbs/yr/capita.

Indicator: **S705. Carbon dioxide (CO2)**

Definition and Units: Lbs/yr/capita (see Appendix B for emission factors).

Formula:

$$(P_{trav} + P_{dwell})/2000$$

$$P_{trav} = VMT_{percapita} * CO_2Coef * 365/453.6$$

$$P_{dwell} = ResBldgEnergy_{percapita} * EnergyCoeff$$

$$EnergyCoeff = (Elec_{\%} * BldgElecPollCoef + NatGas_{\%} * BldgNatGasPollCoef + HeatOil_{\%} * BldgHeatOilPollCoef)$$

Shapefiles/Attributes: None

User-Defined Parameters:
Residential building energy, MMBtu/capita (indicator, component of Energy Consumption)
$VMT_{capita\text{-}day}$ (indicator)
Building energy: percent electric, percent natural gas, percent heating oil
Building CO_2 coefficients, electricity and natural gas and heating oil, lb/MMBtu
Travel CO_2 coefficients, g/mile

Illustrative Scores: Varies by amount of household driving, e.g. 12,000-20,000 lbs/yr/capita.

Appendix A
4D METHOD TECHNICAL MEMORANDUM

Introduction

This appendix summarizes the “4D” methodology for estimating travel demand impacts from land-use and urban design changes. The methodology uses a set of elasticity factors that relate a neighborhood’s built environment characteristics and regional accessibility to the amount of vehicular travel generated in the neighborhood. These factors are used to compute the percentage change in vehicle trips (VT) and vehicle miles traveled (VMT) resulting from different land-use plans and urban designs. The method’s name derives from the four factors used to characterize the built environment and regional accessibility: density, diversity, design, and destinations or the 4Ds.

In the DSS, the 4D method is used only in snapshot sketches (forecast sketches use the travel submodel or ITM for estimating travel changes). The 4D method is applied in snapshot sketches by defining baseline VT and VMT in base cases, and then altering built environment characteristics whose impacts on travel are computed in terms of VT and VMT change.

Research Approach

The 4D method is based on research into the relationship between land-use and travel behavior. Nationally, over forty studies are available on this subject by such noted authors as Robert Cervero of the University of California and the authors of Portland’s LUTRAQ study. Taken as a group, the studies indicate how changes in land-use characteristics, such as density, relate to changes in travel generation as measured by vehicle trips and vehicle miles of travel. A bibliography of the research appears at the conclusion of this memorandum.

Using this research data, the 4D method was developed as follows:

- Elasticities were derived between vehicular travel (VT and VMT) and primary descriptors of the built environment and accessibility for each study in Attachment A whose research provided valid, comparable results. An elasticity is a measure of the percentage change that occurs in an dependent variable (VT or VMT) as a result of a percentage change in an influential variable (density, diversity, design or destinations). For example, if vehicle trips increase by 0.1% for each 1% increase in development density, then vehicle trips are said to have an elasticity of 0.1 with respect to density. If vehicle trips *decrease* by 0.05% for each 1% increase in density, then vehicle trips are said to have an elasticity of -0.05 with respect to density.

- Individual study results were synthesized into a unified matrix of partial elasticities. These express percentage changes in VT and VMT as a function of percentage changes in each of the 4Ds. The 4Ds are expressed in terms of: 1) density (population and employment per square mile); 2) diversity (the ratio of jobs to population); 3) design (pedestrian environment variables including street grid density, sidewalk completeness, and route directness); and 4) destinations (accessibility to other activity concentrations, expressed as the mean travel time to all other destinations within the region, e.g. a location within the regional core will ordinarily have a higher 'destinations' rating than a location on the fringe of the urban area, because the central location offers greater accessibility to a higher percentage of the region's employment).

- Creation of a table of elasticities as a quick-response tool for assessing the relative benefits of one land-use pattern compared with another.

Research Findings

Table A-1 presents the data synthesis. These results advance the state-of-the-art for quick response evaluations in the following respects:

- They include a larger number and wider range of research studies than previous syntheses, including recent studies in Portland (Sun, Lawton, PBQD), Seattle (Hess) and the San Francisco Bay Area (Cervero, Kockelman, Holtzclaw). These three were tightly controlled and statistically sophisticated.

- One of the research studies directly measures pedestrian travel through counts of pedestrian volumes entering commercial centers, whereas most studies rely on household or workplace questionnaires which are known to under-report walk travel.

Table A-1
4D ELASTICITIES

	Vehicle Trips	Vehicle Miles Traveled
Density	–0.043	–0.035
Diversity	–0.051	–0.032
Design	–0.031	–0.039
Destinations (accessibility)	–0.036	–0.204

Density = Percent Change in [(Population + Employment) per Square Mile]

Diversity = Percent Change in {1 - [ABS(b * population - employment) / (b * population + employment)]}

where: *b* = regional employment / regional population

Design = Percent Change in Design Index

Design Index = 0.0195 * street network density + 1.18 * sidewalk completeness + 3.63 * route directness

where:

0.0195 = coefficient applied to street network density, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

street network density = length of street in miles/area of neighborhood in square miles

1.18 = coefficient applied to sidewalk completeness, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

sidewalk completeness = length of sidewalk/length of public street frontage

3.63 = coefficient applied to route directness, expressing the relative weighting of this variable relative to the other variables in the Design Index formula,

route directness = average airline distance to center/average road distance to center

Destinations (accessibility) = Percent Change in Gravity Model denominator for study TAZs "I": Sum[Attractions(j)*Travel Impedance(i,j)] for all regional TAZs "j"

- The fourth D or accessibility factor accounts for the fact that the other 3Ds (density, diversity, and design) will not produce the same effects on travel behavior in remote areas surrounded by typical suburban neighborhoods as they will at centrally-located infill locations. Several studies (including the research on which LUTRAQ is based) have demonstrated that the effects of the first three 4Ds on travel are weaker in outlying areas than infill areas, even if the areas are similar in other respects, such as transit service and average household income. When used in region-wide analysis, the accessibility factor also enables the analysis to recognize the benefits of placing development near transportation corridors, and at locations that are centrally located relative to compatible activities.

Application of the Elasticities

Ideally, the 4D method should only be applied in areas covered by a regional transportation demand model of the type normally operated by metropolitan planning organizations. A regional transportation model is needed to provide accurate baseline inputs for vehicle travel, as well as characterizing existing and future accessibility levels. If a transportation model is not available, the method should be applied with the assistance of a qualified transportation planner using professional judgment based on experience in the area.

The density, diversity, and design elasticities in Table A-1 may be used in cases where multiple land-use alternatives are being considered for the same site. The accessibility elasticities in Table A-1 do not need to be applied in this instance since a single site's relative regional accessibility would not vary from one land-use alternative to another. However, even when one site is under consideration and accessibility is not expected to change over time or as a function of different transportation concepts at the site, it is important to start the analysis with realistic baseline trip rates as influenced by the site's location within its region and its relative level of accessibility.

The accessibility elasticities in Table A-1 must be applied when accounting for changes in transportation systems or services to a single site. They require that a travel demand forecasting model be used to account for differences in accessibility that such transportation changes would create.

In summary, the method is applied to single sites as follows:

A. Define Study Area, Baseline Urban Form, Accessibility, and Trip Generation

1. Using the regional transportation model, identify which traffic analysis zone (TAZ) or TAZs encompass the study area. The boundaries of these host TAZs should match the study area boundary as closely as possible.

2. Compute the baseline density, diversity, design, and accessibility factors of the host TAZ as described in the variable definitions in Table A-1. If the area is greater than two miles in diameter or 2,000 acres, measure its density, diversity, and design by sampling those variables within 2-mile diameter subareas inside the larger area, and calculating average values.

3. Compute the baseline trip rates for the host TAZ. If the host TAZ is largely vacant or undeveloped, trip rates should be estimated at levels appropriate for the location using nearby developed TAZs for guidance. The baseline trip rates should be calculated as home-based (HB) VT and VMT per TAZ resident, and non home-based (NHB) VT and VMT per TAZ employee.

B. Calculate Change in 4D's for Each Land-Use Alternative

1. Compute the percentage change in density, diversity, and design under each land-use alternative relative to the base case.

2. Estimate any changes in regional accessibility envisioned for the study area using indicators such as projected change in highway travel speeds, transit frequency, or walk distance to transit. Data from the regional transportation model should be used in this step, such as percentages of transit trip time spent walking to, waiting for, and riding transit; or vehicle hours of delay or average highway travel speed.

C. Estimate Changes in Travel Indicators for Each Land-Use Alternative

1. For each land-use alternative, apply the elasticity value for density to the computed percentage change in area density from the baseline, to obtain the percentage change in HB VT and HB VMT per capita as a result of the density change. Similarly, compute the percentage changes in HB VT and HB VMT per capita resulting from changes in diversity and design. Sum the resulting percentage changes to obtain the total percentage change in trip generation resulting from the combined effects of density, diversity and design. Apply the resulting sum to the baseline HB VT and HB VMT per capita to obtain the new HB VT and HB VMT per capita resulting from the land-use alternative.

2. Repeat the process to obtain the NHB VT and NHB VMT per employee resulting from the land-use alternative.

3. If regional accessibility is expected to change from one land-use alternative to another, apply the Table A-1 accessibility elasticity to the percentage change in accessibility from baseline to obtain the percent change expected in HB and NHB VT and VMT per capita and per employee, if any.

4. Compare the resulting VT and VMT changes between land-use alternatives to obtain relative differences in transportation performance.

This procedure assumes that study area household size and auto ownership does not change from one land-use alternative to another.

A hypothetical example of applying the method is given in worksheet form in Table A-2. This example assumes that a 1.5 sq.mi. study area is undergoing redevelopment in a region of 50,000 persons and 35,000 jobs. The study area's proposed redevelopment includes an increase in population and employment, with a greater share of residential uses than before; construction of new streets and sidewalks to improve the area's pedestrian environment; and expanded transit service that will improve the area's accessibility by reducing transit travel time to and from the area. The Table A-2 worksheet illustrates HB VMT calculations; the same procedure would be used for NHB VMT, HB VT, and NHB VT calculations.

Size and Homogeneity of Study Areas

As noted above, the areas to which the 4D elasticities are directly applied should be less than two miles in diameter or 2,000 acres. If larger areas are under study, the 4D's should be sampled within two-mile subareas of the larger area, and the results averaged. This is because the effects of the 4Ds on auto travel and trip length are primarily due to the proximity of supportive and well-designed land-uses to one another, and the opportunity this provides for walk and bicycle travel between them. For example, a large area with employment clustered at one end and residential uses at the other should not be considered as diverse as an area with block-by-block mixing of land-uses. Therefore, this sampling and averaging technique is recommended to better capture the 4D effects in large study areas. Users should not allow undeveloped subareas within a study area to dilute the calculated density unless the undeveloped subarea lies well within active areas, thereby lengthening the travel distance for those traveling from one point to another within the active area. Open acreage on the edge of the study area should not be counted in the density calculation.

Table A-2

HYPOTHETICAL EXAMPLE WORKSHEET

1. STUDY PARAMETERS

1) Study Area:

➢ Square miles:	1.5

1.2 Region Demographics:

➢ Population	50,000
➢ Employment	35,000

1.3 Study Area Base Case Conditions:

➢ Population:	1,000
➢ Employment:	2,000
➢ Street network density:	17 mi./sq.mi.
➢ Sidewalk completeness:	75%
➢ Pedestrian route directness:	0.6
➢ Accessibility:	23 mean min.
➢ HB VMT/capita/day:	20

1.4 Study Area Alternative Case Conditions:

➢ Population:	2,000
➢ Employment:	2,500
➢ Street network density:	19 mi./sq.mi.
➢ Sidewalk completeness:	100%
➢ Pedestrian route directness:	0.8
➢ Accessibility:	20.75 mean min.

2. DENSITY

2.1 Base Density:

1,000 population
+ 2,000 employees
3,000 persons ÷ 1.5 sq.mi. = 2,000

study area *persons/ sq.mi.*

2.2 Alternative Density:

2,000 population
+ 2,500 employees
4,500 persons ÷ 1.5 sq.mi. = 3,000

study area *persons/ sq.mi.*

2.3 Density Change:

3,000 persons
- 2,000 persons
1,000 persons ÷ 2,000 persons = 0.5 or 50%

density increase

2.4 HB VMT Change From Density Change:

50% x -0.035 = -1.75%

density increase *elasticity* *HB VMT decrease*

3. DIVERSITY

3.1 Base Diversity:

study area pop *study area pop*

$$\{ 1 - [ABS (0.7 \times 1{,}000 - 2{,}000) \div (0.7 \times 1{,}000 + 2{,}000)] \} = 0.52$$

region emp/pop *study area emp* *region emp/pop* *study area emp*

3.2 Alternative Diversity:

study area pop *study area pop*

$$\{ 1 - [ABS (0.7 \times 2{,}000 - 2{,}500) \div (0.7 \times 2{,}000 + 2{,}500)] \} = 0.72$$

region emp/pop *study area emp* *region emp/pop* *study area emp*

3.3 Diversity Change:

$$\begin{array}{r} 0.72 \\ \underline{-\ 0.52} \\ 0.20 \end{array} \div 0.52 = 0.38 \text{ or } 38\%$$

diversity increase

3.4 HB VMT Change From Diversity Change:

$$38\% \times -0.032 = -1.22\%$$

diversity increase *elasticity* *HB VMT decrease*

1. DESIGN

4.1 Base Design:

st.mi./sq.mi. | *% walk complete* | *route directness*

(0.0195 x 17) + (1.18 x 0.75) + (3.63 x 0.6) = 3.39

var. weight coefficient | *var. weight coefficient* | *var. weight coefficient* | *design index*

4.2 Alternative Design:

st.mi./sq.mi. | *% walk complete* | *route directness*

(0.0195 x 19) + (1.18 x 1.00) + (3.63 x 0.8) = 4.45

var. weight coefficient | *var. weight coefficient* | *var. weight coefficient* | *design index*

4.3 Design Change:

4.45
-3.39
1.06 ÷ 3.39 = 0.31 or 31%

design index increase

4.4 HB VMT Change From Design Change:

31% x -0.039 = -1.21%

design index increase | *elasticity* | *HB VMT decrease*

5. DESTINATIONS

5.1 Base Accessibility:

Mean travel time to all regional employment:

auto	20 min
transit	40 min
% transit	15%

Weighted average travel time:

auto		transit		
20 min x 85%	+	40 min x 15%	=	23 min

5.2 Alternative Accessibility:

Mean travel time:

auto	20 min
transit	25 min

Weighted average travel time:

auto		transit		
20 min x 85%	+	25 min x 15%	=	20.75 min

5.3 Accessibility Change:

$$1 - \frac{20.75 \text{ min}}{23.00 \text{ min}} = 1 - 0.902 = -9.8\%$$

5.4 HB VMT Change From Accessibility Change:

-9.8% x -0.204 = -0.02 = -2%

accessibility increase (-9.8%)

elasticity (-0.204)

6. CUMULATIVE VMT CHANGE

6.1 HB VMT changes from:

Density change	- 1.75%
Diversity change	- 1.22%
Design change	- 1.17%
Accessibility change	- 2.00%
Total	- 6.14%

6.2 Alternative case HB VMT calculation:

20	x	0.0614	=	1.23
base case		*% reduction*		*VMT/capita/day reduction*

20	-	1.23	=	18.77
base case HB VMT /capita/day		*VMT reduction*		*alternate case HB VMT /capita/day*

Regional or Multi-Site Analysis

The 4D method may also be used for comparison of growth scenarios for an entire region or for multiple development sites scattered throughout a region. Regional analysis includes comprehensive assessments of development patterns over a large, relatively homogeneous area, or a large area consisting of multiple communities. Growth scenarios can be comparisons of existing versus future conditions, or comparisons of "trends" versus "smart growth," or comparisons of several community plan or specific plan alternatives. Regional analysis methods will generally be used for areas of 25 square miles or greater, subject to the sampling technique described above. Multi-site analysis refers to analyses that attempt to compare the effects of allocating growth to one site within the region versus others. Sites would differ with respect to one or more of the following: 1) their degree of centralization; 2) their distance to jobs and housing; 3) their context within the urban fabric (infill within a dense area versus an edge or suburban setting); and/or 4) their proximity to transportation facilities. As with the individual site analysis, the regional and multi-site analyses use data from the regional transportation model for baseline VT and VMT generation rates for each individual geographic unit within the region. The VT and VMT rates should be for the forecast year under study, so that the relevant transportation network characteristics are reflected in the accessibility measure for each geographic unit. If the comparison is being made between two different forecast years, each year should be represented via regional transportation model data. In all cases, the VT and VMT should each be expressed as:

- HB VT per Resident: HB VT / TAZ Population
- NHB VT Trips per Employee: NHB VT / TAZ Employment
- HB VMT per Resident: HB VMT / TAZ Population
- NHB VMT per Employee: NHB VMT / TAZ Employment

These rates can be obtained by taking the appropriate ratios among the zonal population, employment, home-based vehicle trips produced, and non-home-based vehicle trips attracted for the TAZs that encompasses the study area. The advantages of this approach include: a) multiple regional development patterns can be tested without running the four-step for each case; regional land-use form can be reflected (the effects of intensifying land-use in infill versus greenfield locations) and measured along with the effects of design, density and diversity within each development area; and b) the evaluation of land-use alternatives can be sensitive to the proximity of growth to regional transportation facilities, including fixed transit corridors.

Opportunities for Further Review and Enhancement

The 4D elasticities are based on a wide array of primary research studies. Some of the studies show results that disagree with one another. As a result of these disagreements, the resulting elasticities exhibit some apparent anomalies. For example, many experts may expect that the elasticity of VMT with respect to design should be lower than the elasticity of VT with respect to design. This is because many believe that the biggest impact of good urban design is to convert short-distance auto trips to walk or bike trips, while longer distance auto trips might not be affected by good design. However, the current elasticity results show a higher relationship for VMT than for VT. This is because, even though one of the reference studies indicated that the VMT elasticity should be lower than the VT elasticity, several other reputable studies disagreed. The LUTRAQ study, for example, found an elasticity of VMT to design significantly higher than the result of the 4D method synthesis. Two other studies found VMT/design elasticities very close to the 4D results and higher than the 4D VT/design elasticity. Therefore, the preponderance of empirical data available to the 4D synthesis suggests that good design reduces not only the amount of vehicle trip-making, but the average length of vehicle trips as well. While this may be counter-intuitive to some, the conventional wisdom on how the VMT and VT rates "should" compare with one another may not take into consideration the following phenomena:

- The effects of self-selection, where individuals who move to well-designed neighborhoods may have a pre-disposition to drive less for trips of any length.
- Developments that score high on the design index are often at infill locations nearer to a greater proportion of regional jobs and housing; therefore, average trip lengths may be shorter.
- Developments that score high on the design index are often at locations nearer to high-quality transit service than are locations with poorer design indices; therefore, residents of high-design neighborhoods may have better non-auto choices even for their longer trips than do residents of low-design neighborhoods.

Further research, using additional household survey datasets, could clarify these issues and otherwise improve the current 4D elasticities.

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Appendix B
AIR POLLUTANT & GREENHOUSE GAS EMISSION FACTORS

The DSS estimates air pollutant and greenhouse gas emissions for residential buildings and household travel as part of the indicator results for each sketch.

Table B-1 lists the emission coefficients used for electricity and natural gas consumption in the buildings sector. These coefficients are based on data published by the U.S. Department of Energy's Lawrence Berkeley Laboratory for natural gas utilization, and the Energy Information Administration for electricity utilization.

Table B-2 presents emission coefficients used for autos and light trucks in the transportation sector based on data published by U.S. EPA's Office of Mobile Sources. The DSS presently assumes a 50/50 mix of autos and light trucks when estimating transportation emissions.

It should be noted that estimates for both the buildings and transportation sectors are based on current emission rates, and do not take into consideration potential changes in future emission rates when long-range forecast sketches are prepared.

Table B-1
RESIDENTIAL BUILDING EMISSION FACTORS

	LBS/MMBTU					
	NOx	**SOx**	**HC**	**CO**	**CO2**	**PM**
Electricity	0.413	0.6514	0.003	0.0206	125.65	0.0653
Natural Gas	0.137	0.00059	0.00058	0.034	115	0.006
Oil	0.14085	0.552817	0.000400	0.03521	170	0.01408

Source: U.S. DOE, LBL and EIA, 1997.

Table B-2
VEHICLE EMISSION FACTORS

A. Annual Emissions and Fuel Consumption for an "Average" Passenger Car [1]

Pollutant Problem	**Amount [2]**	**Miles [3]**	**Pollution or Fuel Consumption [4]**
Hydrocarbons	2.9 grams/mile	12,500	80 lbs of HC
Carbon Monoxide	22 grams/mile	12,500	606 lbs of CO
Nitrogen Oxides	1.5 grams/mile	12,500	41 lbs of NOx
Carbon Dioxide	0.8 pound/mile	12,500	10,000 lbs of CO2

B. Annual Emissions and Fuel Consumption for an "Average" Light Truck [1]

Pollutant Problem	**Amount [2]**	**Miles [3]**	**Pollution or Fuel Consumption [4]**
Hydrocarbons	3.7 gram/mile	14,000	114 lbs of HC
Carbon Monoxide	29 gram/mile	14,000	894 lbs of CO
Nitrogen Oxides	1.9 gram/mile	14,000	59 lbs of NOx
Carbon Dioxide	1.2 pound/mile	14,000	16,800 lbs of CO2

Notes:

[1] These values are averages. Individual vehicles may travel more or less miles and may emit more or less pollution per mile than indicated here. Emission factors and pollution/fuel consumption totals may differ slightly from original sources due to rounding.

[2] The emission factors used here come from standard EPA emission models. They assume an "average," properly maintained car or truck on the road in 1997, operating on typical gasoline on a summer day (72 to 96 degrees F). Emissions may be higher in very hot or very cold weather.

[3] Average annual mileage source: EPA emissions model MOBILE5.

[4] Fuel consumption is based on average in-use passenger car fuel economy of 22.5 miles per gallon and average in-use light truck fuel economy of 15.3 miles per gallon.

Source: U.S. Environmental Protection Agency
National Vehicle and Fuel Emissions Laboratory, April 1997