An Exploratory Analysis of PAS Characteristics in Solving the Static Deterministic User Equilibrium Traffic Assignment Problem on a Large Scale Urban Network

By

Aroon Aungsuyanon

Bin Ran

University of Wisconsin-Madison

and

David Boyce

Northwestern University

For

the 13th TRB National Transportation Planning Applications Conference

May 8-12, 2011

Reno, Nevada

Overview

- Motivation
- Proportionality condition
- General structure of TAPAS algorithm
- Fundamental principles of Paired Alternative Segments
- Basic characteristics of a test network
- Solution characteristics of PASs
  - at aggregated levels
  - at disaggregated levels
- Contributions of PASs to forming equilibrium route patterns
- Summary findings of PAS solutions

Motivation

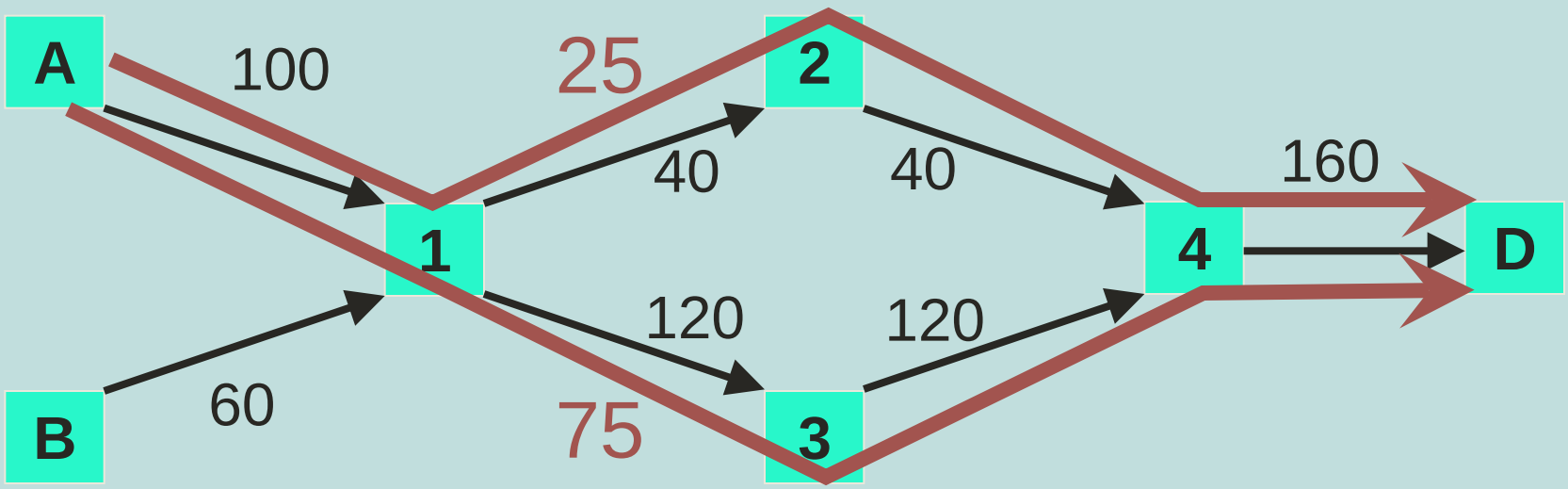
- Static deterministic user equilibrium (UE) traffic assignment has long been one of the most intensively applied tools utilized by transportation planners.
- The standard UE formulation provides a unique solution for total link flows, but not for route flows. However, route flows are often used in practice at various levels of aggregation.
- Bar-Gera (2010) proposed a new algorithm, Traffic Assignment by Paired Alternative Segments (TAPAS) to solve UE traffic assignments efficiently, while determining route flows uniquely by adding a condition of proportionality.
- Determining Pairs of Alternative Segments (PAS) is the key to the success of TAPAS. Focusing on PASs leads to fast convergence, consistent route sets, and unique route flows.
- Although successfully implemented at various scales, several characteristics of PASs, especially for large-scale urban road networks, have not been adequately explored and revealed.

Proportionality Condition

Same proportions apply to all travelers facing a choice between a pair of alternative segments

Consider the pair of segments [1,2,4] and [1,3,4].

AD segment proportions should be 1/4 and 3/4.



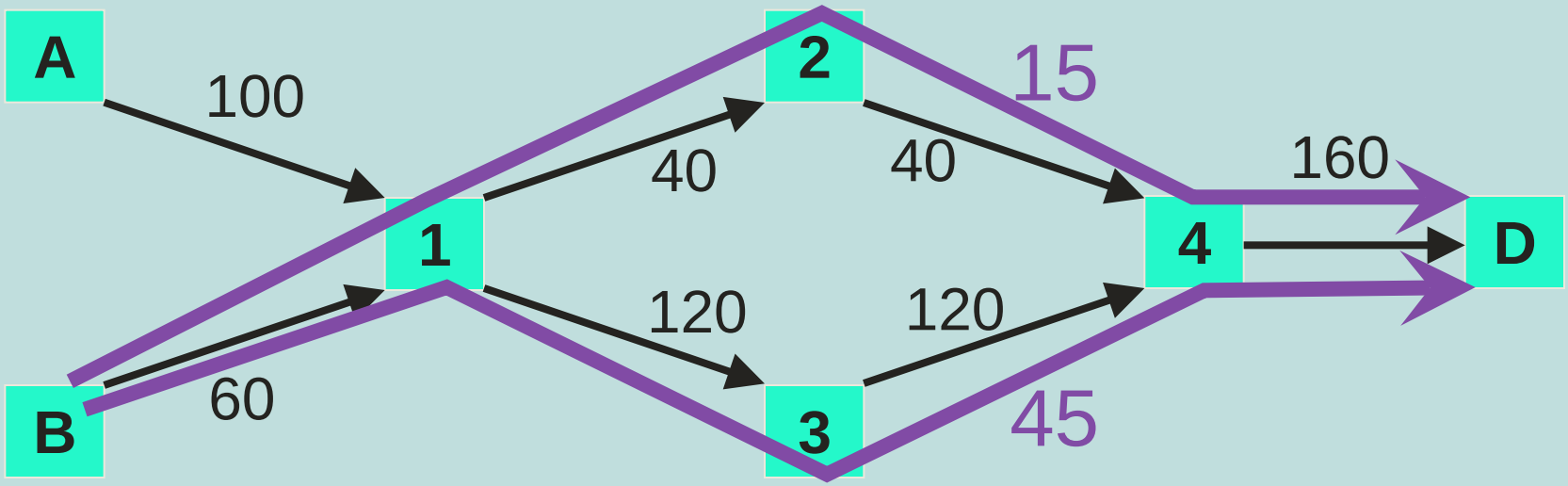
For travelers from A to D the proportion is 25/(25+75)=1/4.

Proportionality Condition

Same proportions apply to all travelers facing a choice between a pair of alternative segments

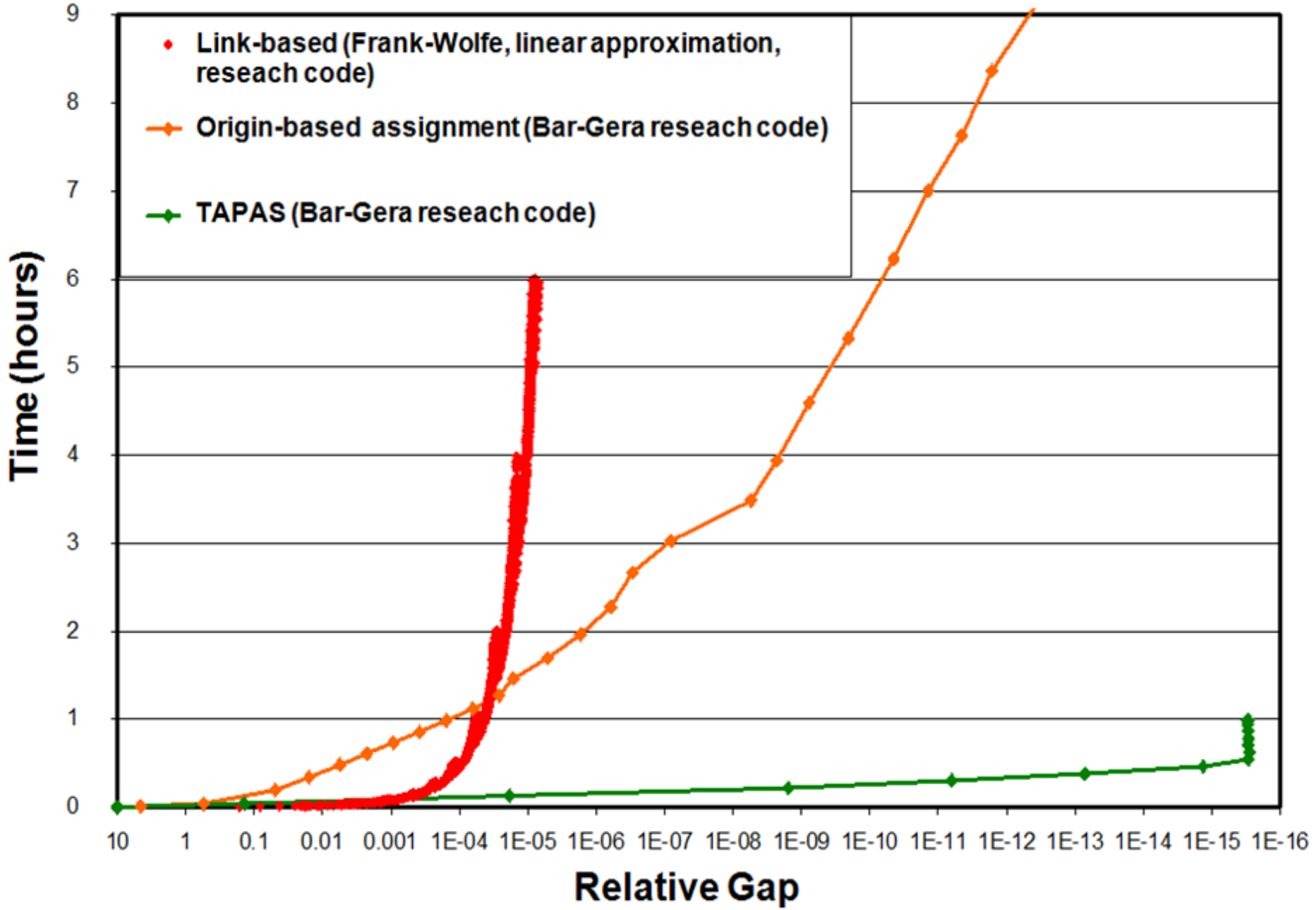
Consider the pair of segments [1,2,4] and [1,3,4].

BD segment proportions should also be 1/4 and 3/4.



For travelers from B to D the proportion is 15/(15+45)=1/4.

Algorithm Convergence on the Chicago Regional Network



The general structure of TAPAS algorithm

Find initial solution using AON assignment

Repeat iteratively:

For every origin

Remove all cyclic flows

Find tree of least cost routes

For every link used by the origin which is not part of the tree

If there is an existing effective PAS

Make sure the origin is listed as relevant

Else

Construct a new PAS

Choose a random subset of active PASs

Shift flow within each chosen PAS

For every active PAS

Check if it should be eliminated

Perform flow shift to equilibrate costs

Redistribute flows between origins by the assumption of proportionality

Final proportionality iterations:

For every active PAS

Redistribute flows between origins by the assumption of proportionality

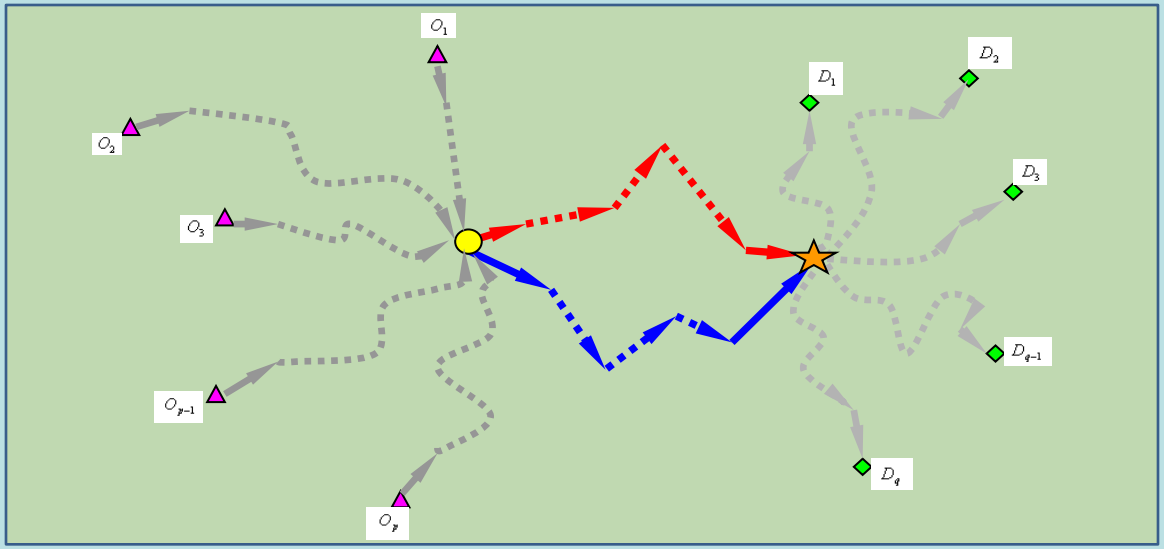
Two functions of PASs:

1) Cost Equilibration
   - → Flow shift within each PAS
   - → UE route flow solutions

2) Proportionality Adjustment
   - → Flow distribution between origins
   - → Practically equivalent to MEUE route flow solutions
   - → Route flow uniqueness (i.e. consistent choices of route flow solutions)

Bar-Gera (2010), Traffic Assignment by Paired Alternative Segments

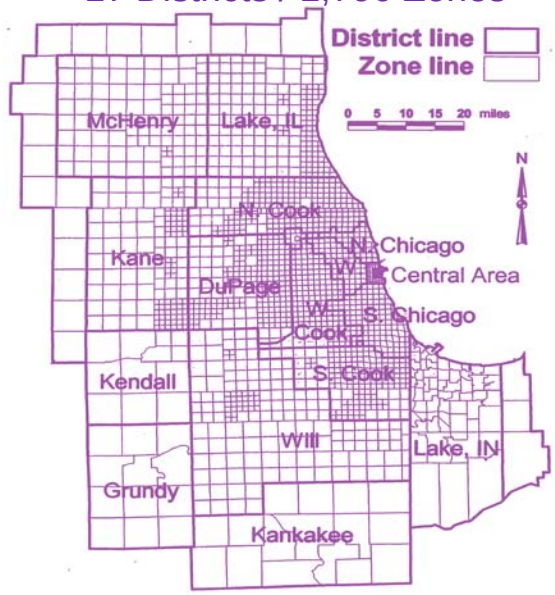
Fundamental principles of PAS



- Consider only Pairs of (distinct) Alternative Segments (PAS).
- Every PAS consists of two sequences of links connecting a pair of nodes, each called "the distinguishing component or (alternative) segment".
- Every PAS has a set of relevant origin(s), or a set of relevant destination(s).
- Every PAS has one originating node, the diverge node, and one terminating node, the merge node.
- A PAS can take any shape as long as the segment travel times are precisely equal.
- For every PAS, the routes taken from any origin to a diverge node and from a merge node to any destination are not at issue.
- Any PAS can be the distinguishing component for many pairs of routes.
- Equilibrium routes between OD pairs may have no or one or more PAS(s).

Basic characteristics of the Chicago regional network

17 Districts / 1,790 Zones



Physical Characteristics
of Chicago Regional Zone System

Mode-Origin-Destination Model:

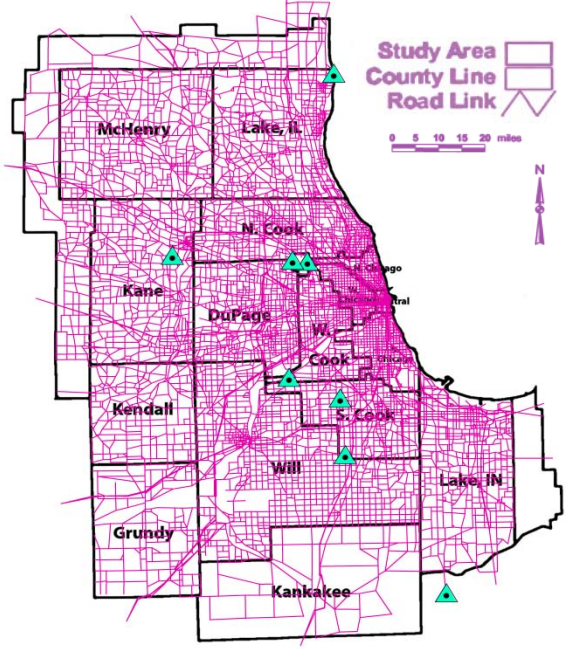
$$d_{mpq} = A_p B_q exp(-\mu * c_{mpq})$$

Where A_p, B_q = Balancing Factor

μ = Cost Sensitivity Parameters

c_{mpq} = Mode-Origin-Destination Level of Service/Cost

12,982 Nodes/ 39,018 Links/ 27,050.2 mi

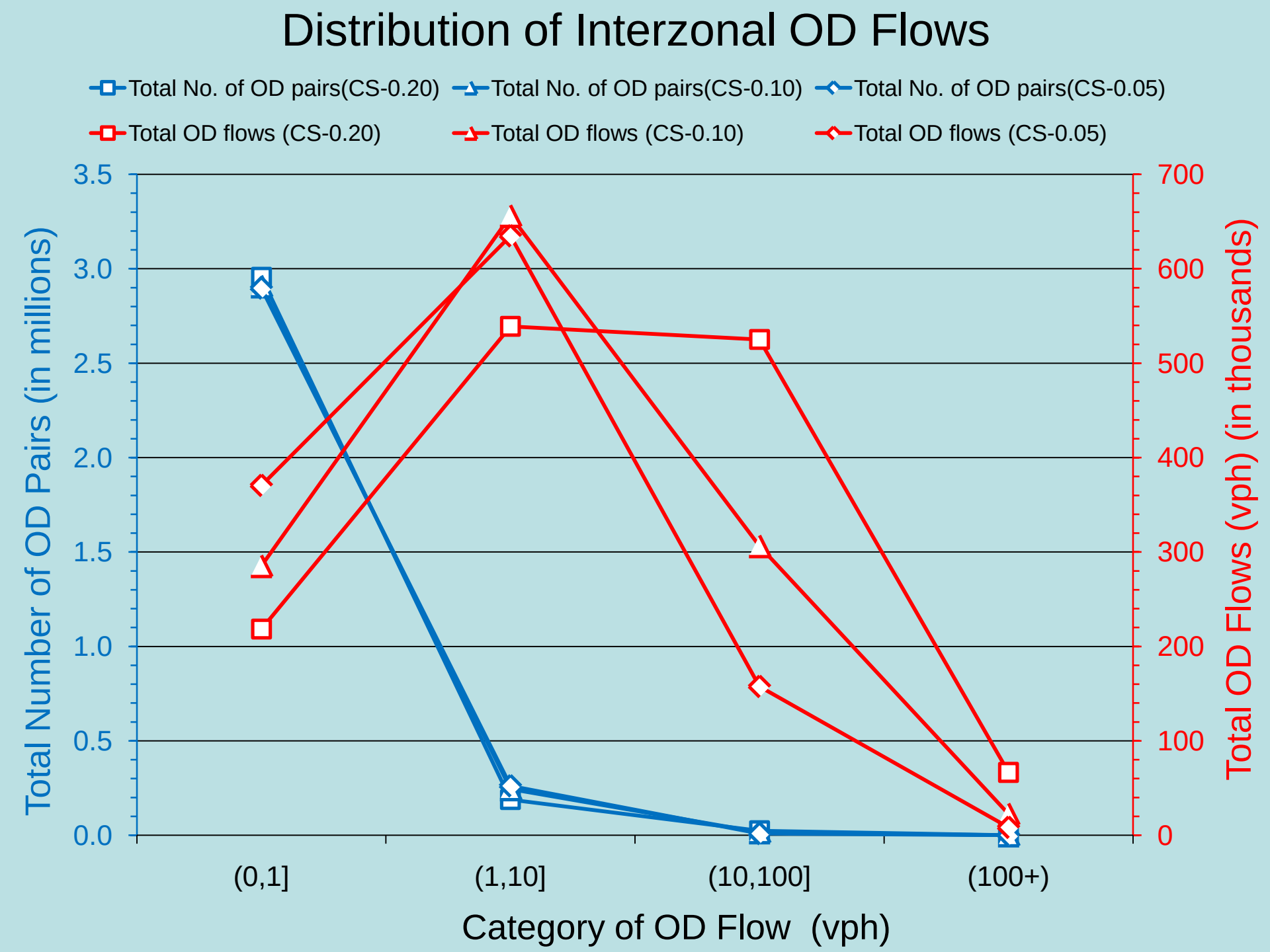


Physical Characteristics
of Chicago Regional Road Network

General characteristics of three OD trip matrices

Cost Sensitivity	Total number of O/D Zones	Number of OD pairs				Total number of OD pairs	OD flows		Total OD flows
		Interzonal		Intrazonal			Interzonal	Intrazonal	
		with flow	without flow	with flow	without flow				
0.20	1,790	3,168,206	34,104	1,771	19	3,204,100	1,349,081.1	80,820.0	1,429,901.2
		(98.9%)	(1.0%)	(0.1%)	(0.0%)	(100%)	(94.4%)	(5.6%)	(100%)
0.10	1,790	3,168,206	34,104	1,771	19	3,204,100	1,269,957.0	54,916.8	1,324,873.8
		(98.9%)	(1.0%)	(0.1%)	(0.0%)	(100%)	(95.9%)	(4.1%)	(100%)
0.05	1,790	3,168,206	34,104	1,771	19	3,204,100	1,171,166.1	41,884.9	1,213,051.0
		(98.9%)	(1.0%)	(0.1%)	(0.0%)	(100%)	(96.6%)	(3.4%)	(100%)

Distribution of Interzonal OD Flows

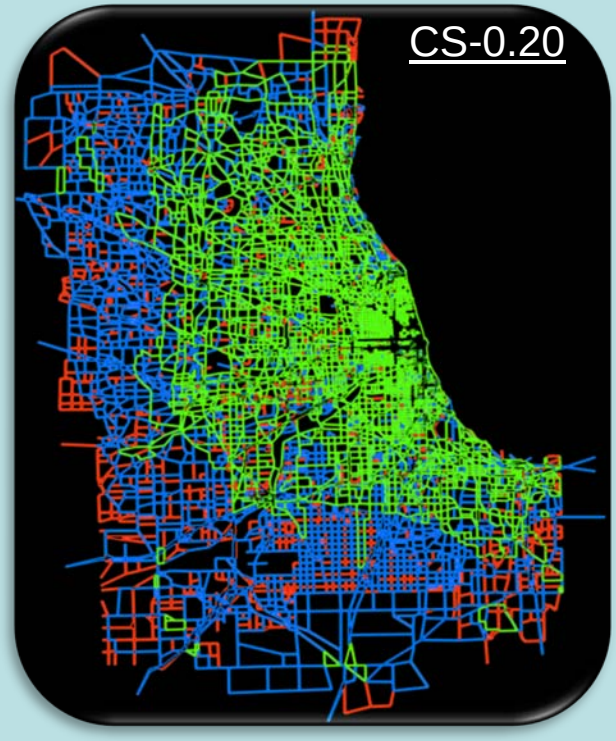


Aggregated characteristics of PAS solutions-1

A RED link is an UNUSED link.

A GREEN link is a USED link that is a PART of a PAS.

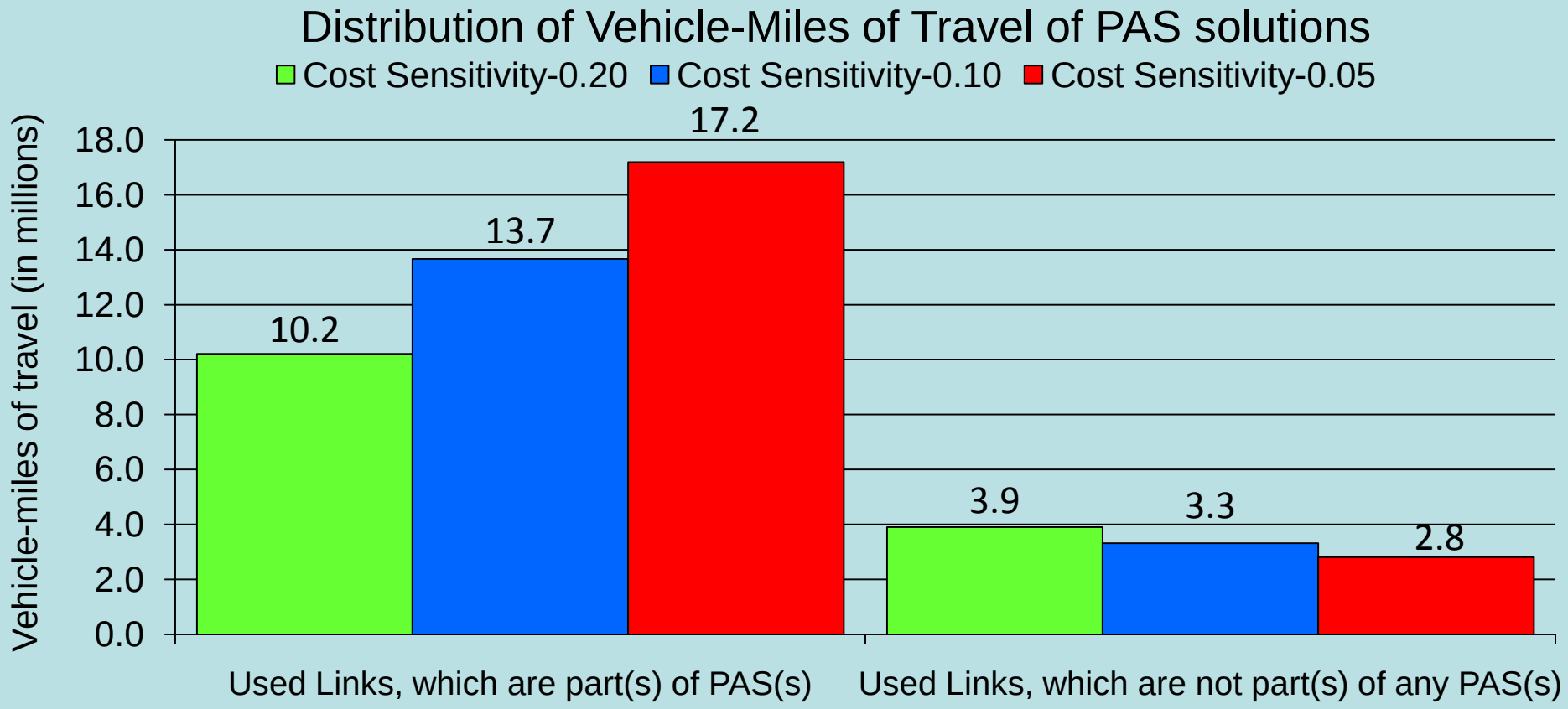
A BLUE link is a USED link that is NOT PART of any PAS.



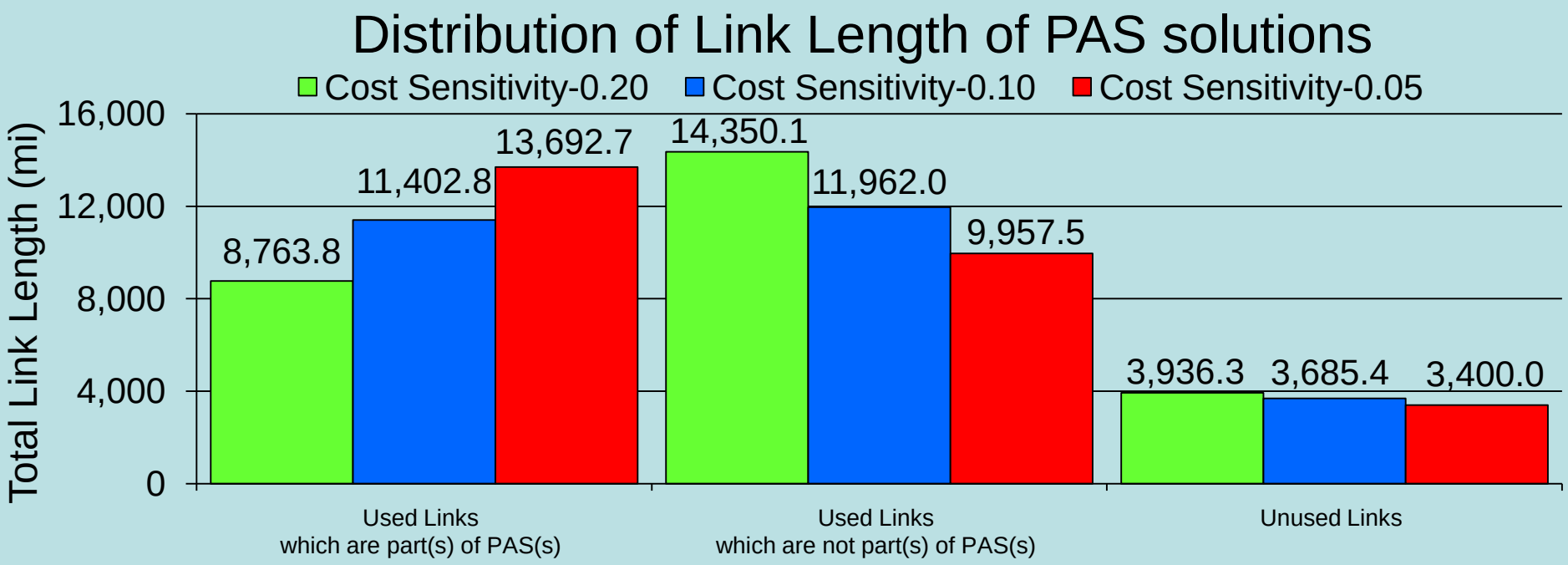
Aggregated characteristics of PAS solutions-2

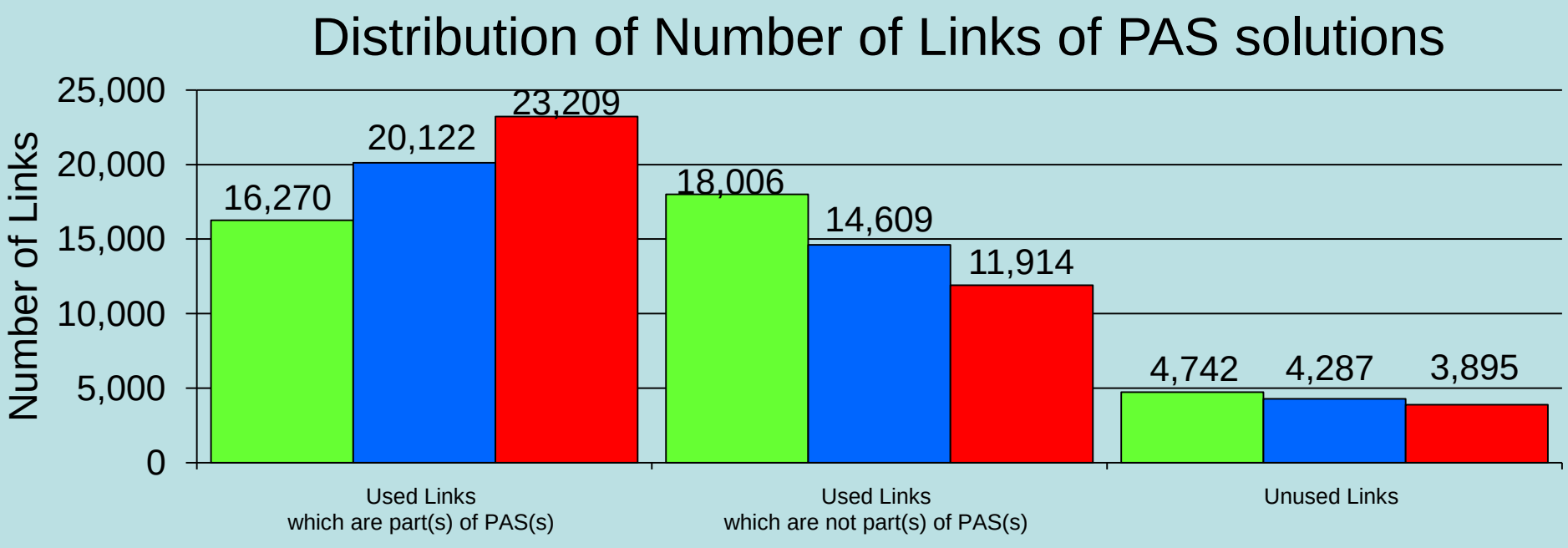
Cost sensitivity	Mean route travel time (minutes)	Number of PASs	Total length of PASs (miles)		PAS coverage (%) (a)	Length per PAS (miles)	Number of links per PAS	Number of origins per PAS	Number of equilibrium routes
			Overlaps included	Overlaps excluded					
0.20	52.6	5,617	57,342	8,7634	32.4	10.2	19.9	105.2	8,397,772
0.10	60.3	11,702	153,857	11,403	42.2	13.2	27.1	100.6	19,121,834
0.05	80.1	22,500	407,264	13,693	50.6	18.1	35.5	103.3	198,087,738

(a) (total length of all non-overlapping links on all PASs)/(total length of all links over a network)x100



Aggregated characteristics of PAS solutions-3



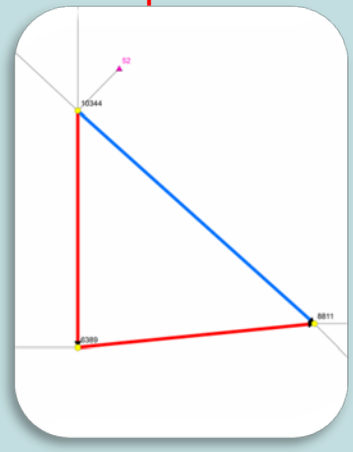


Disaggregated characteristics of PAS solutions - 1

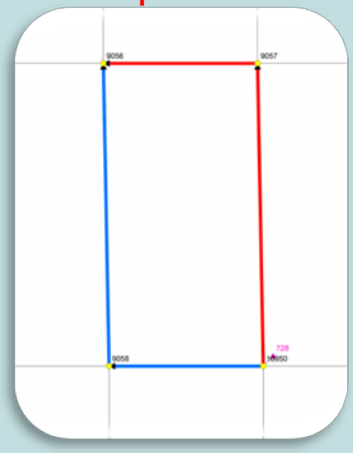
- All PASs must perfectly conform to the PAS definition.
  - No alternative segment is crossed at a node.

PASs without segment CROSSING

Simple PAS

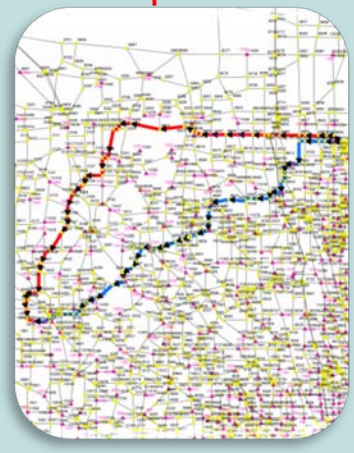


Simple PAS



Complex PAS

Complex PAS

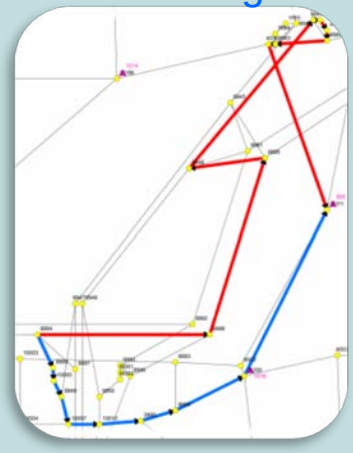


PASs with segment CROSSING(S)

1 crossing

2 crossings

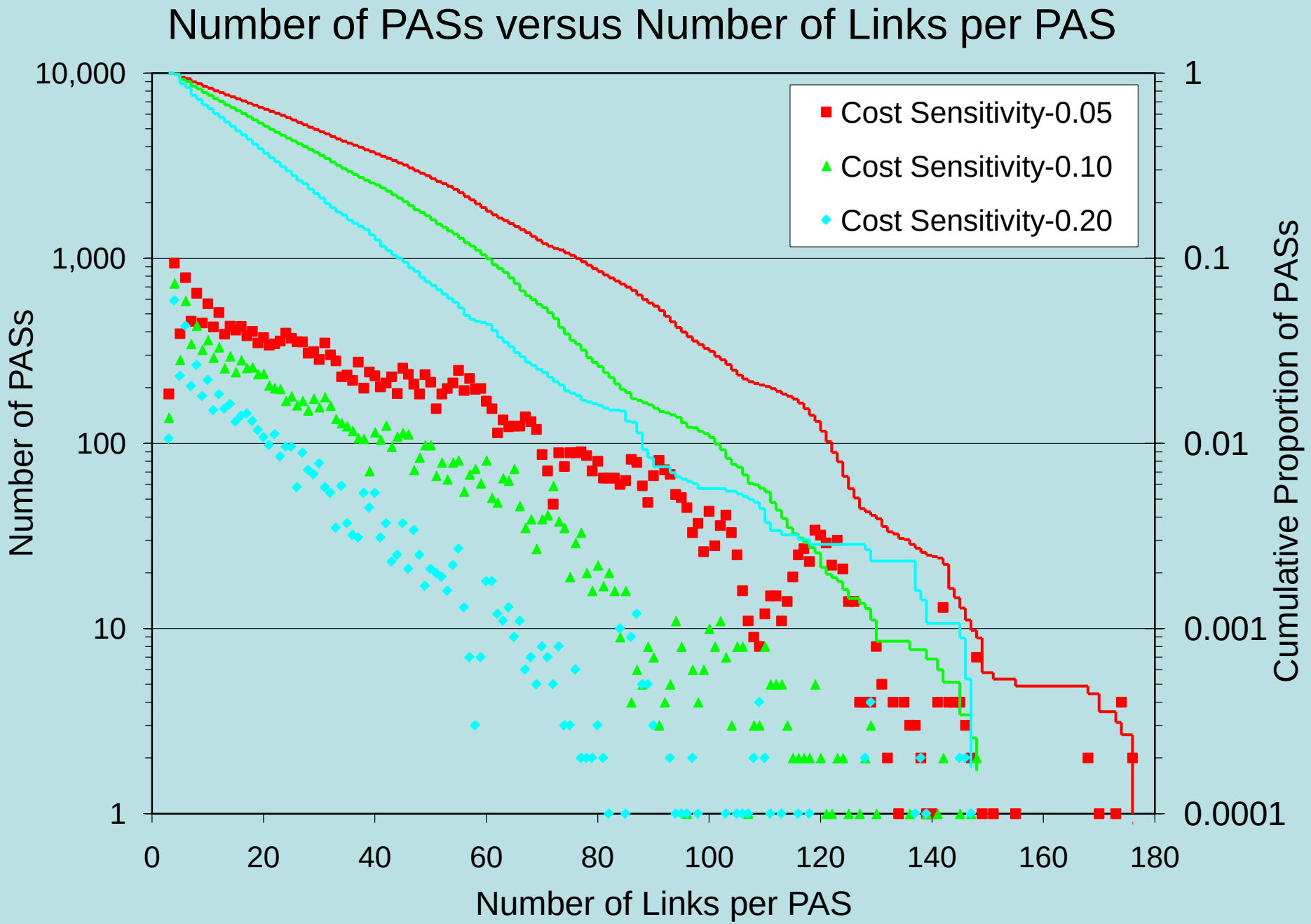
2 crossings



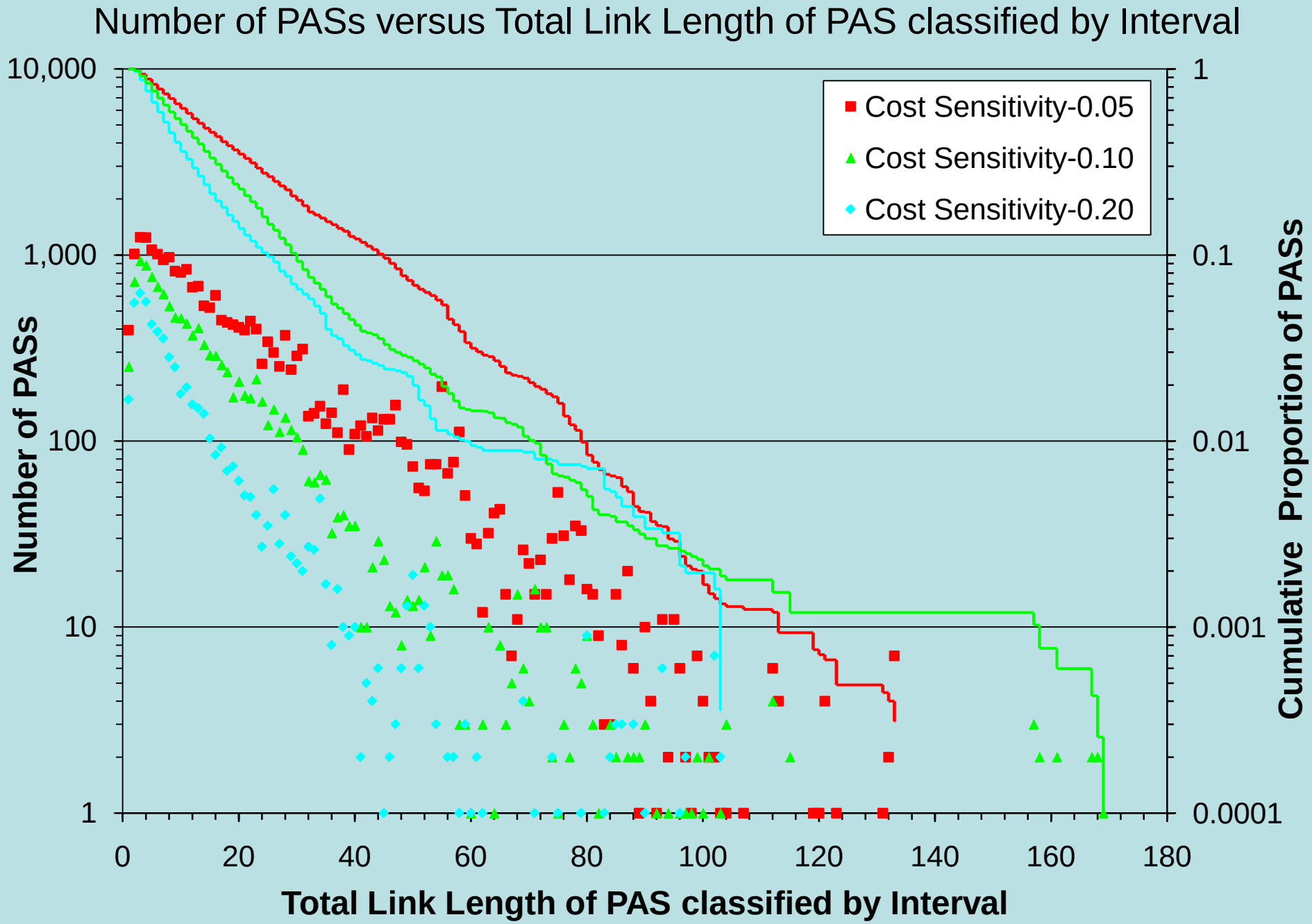
3 crossings

3+ crossings

Disaggregated characteristics of PAS solutions - 2

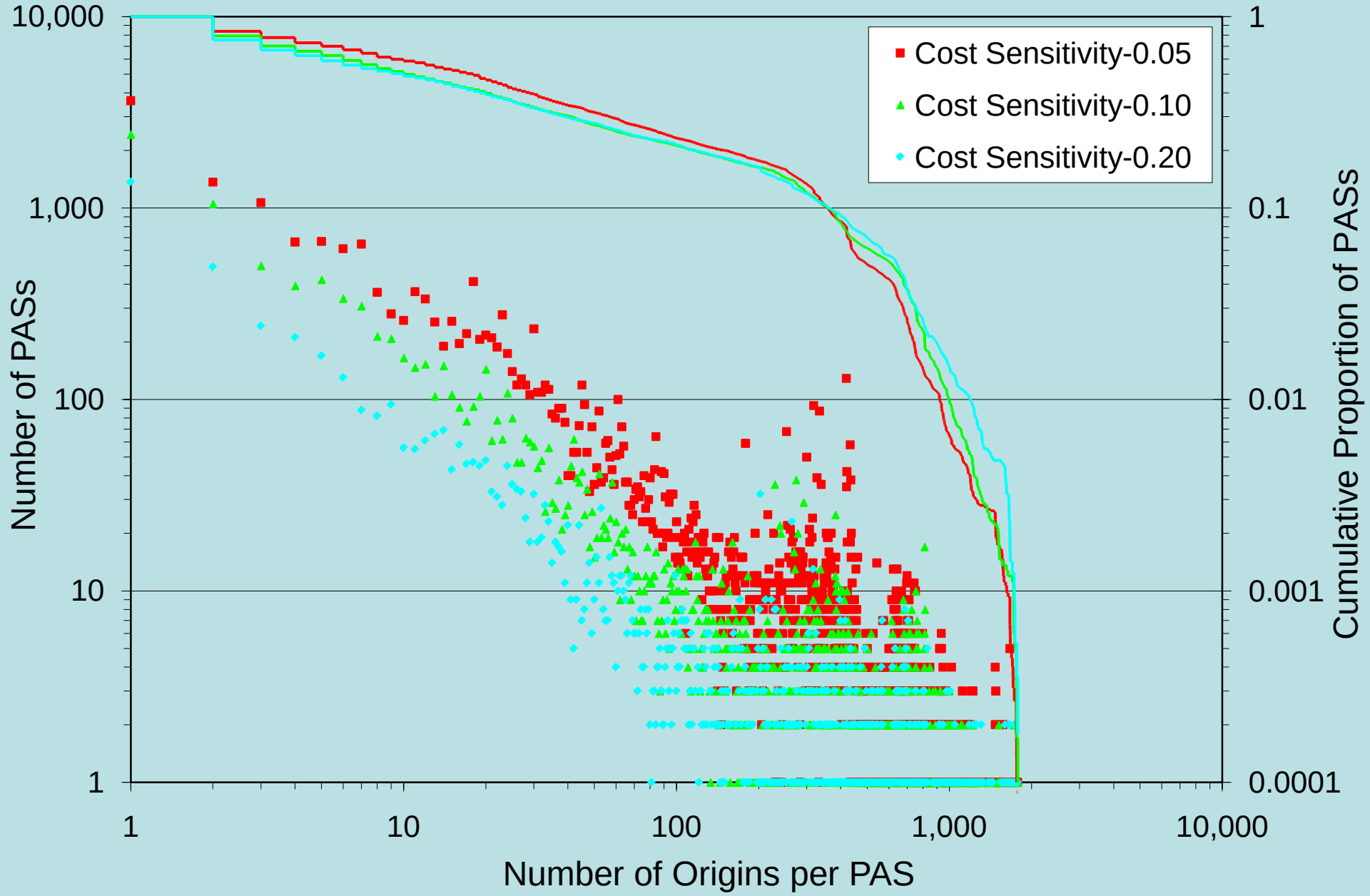


Disaggregated characteristics of PAS solutions - 3



Disaggregate characteristics of PAS solutions - 4

Number of PASs versus Number of Origins per PAS

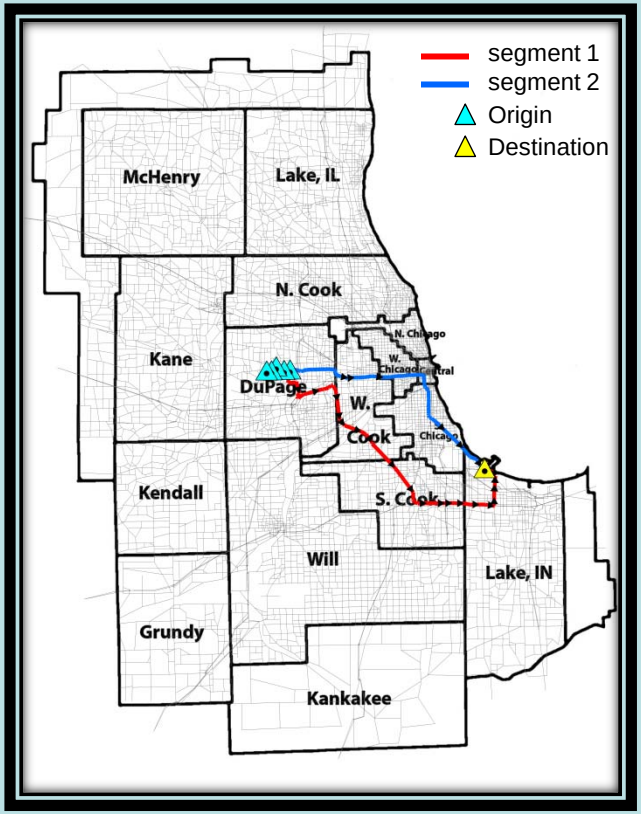


Disaggregate characteristics of PAS solutions - 5

Location and characteristics of PASs with maximum length by trip matrix

CS-0.20

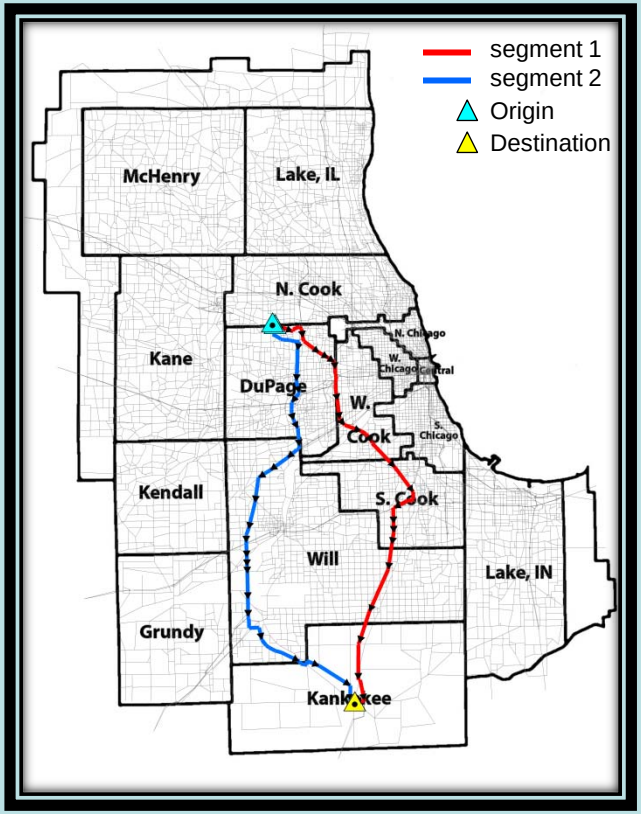
Length1: 58.8	Cost: 71.01
Length2: 43.5	Flow1: 0.024
#Links: 145	Flow2: 0.073
#Origins: 5	Prop1: 0.249
#Destinations: 1	Prop2: 0.751



Total Link Length of PAS =102.3 mi

CS-0.10

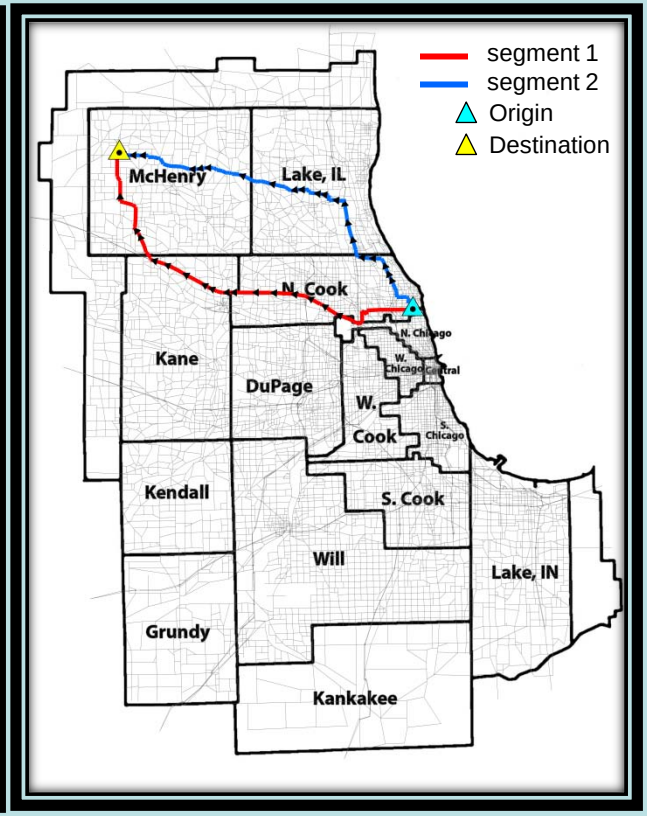
Length1: 85.2	Cost: 97.14
Length2: 83.0	Flow1: 0.113
#Links: 120	Flow2: 0.003
#Origins: 2	Prop1: 0.975
#Destinations: 1	Prop2: 0.025



Total Link Length of PAS =168.2 mi

CS-0.05

Length1: 68.7	Cost: 96.95
Length2: 64.1	Flow1: 0.00001
#Links: 174	Flow2: 0.00144
#Origins: 1	Prop1: 0.007
#Destinations: 1	Prop2: 0.993



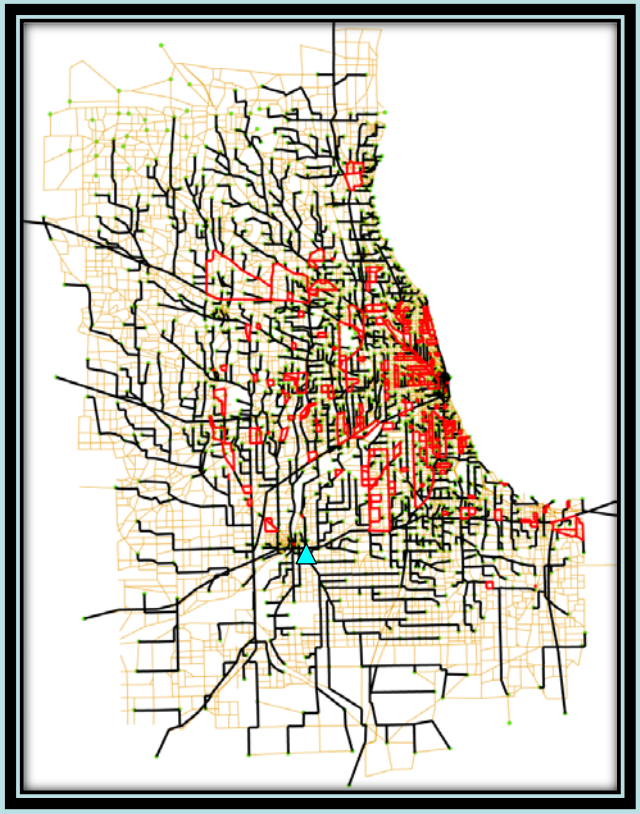
Total Link Length of PAS =132.9 mi

Contributions of PASs to formation of equilibrium route patterns

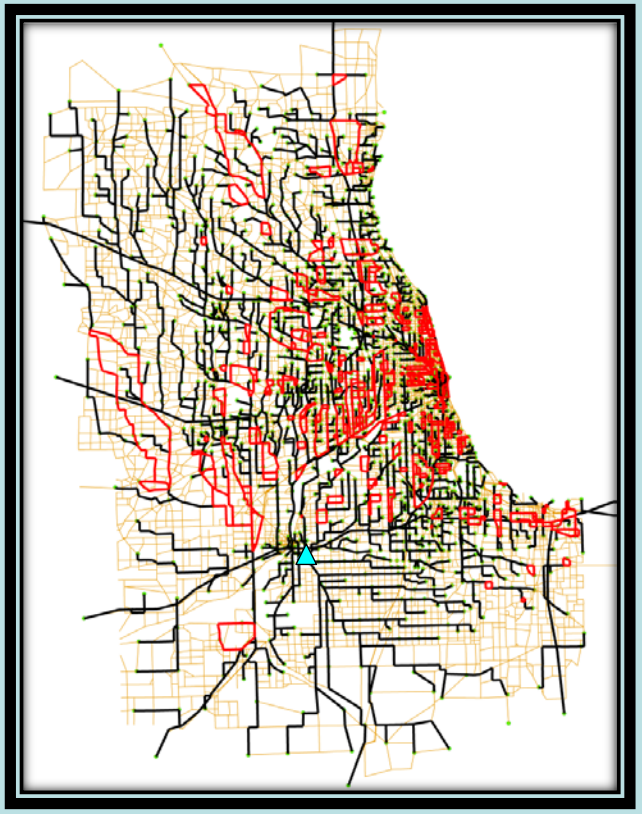
(Aggregation by an Origin)

Origins with Maximum Number of PASs on CS-0.20

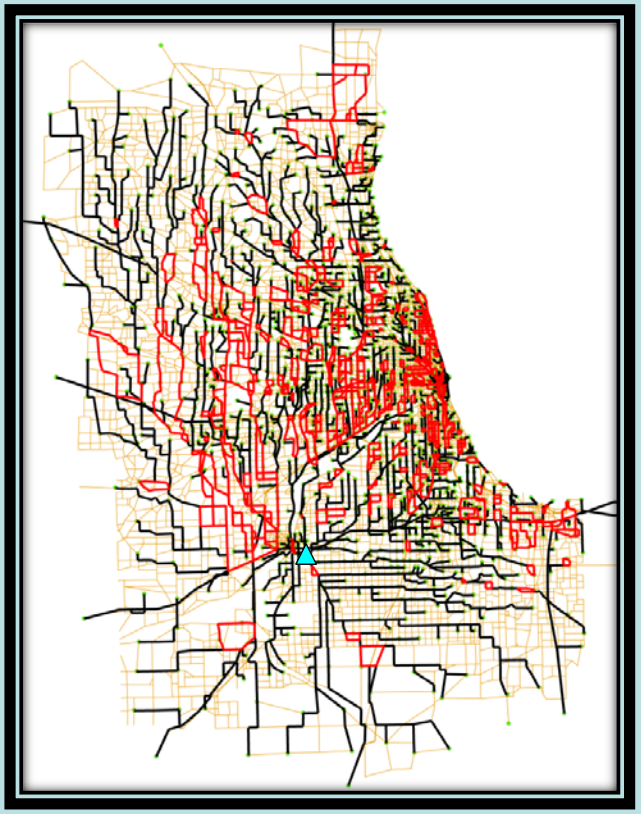
CS-0.20			CS-0.10			CS-0.05		
512	PASs	130.67 vph	945	PASs	120.71 vph	1,574	PASs	102.10 vph
3,378	routes(total)	55.79 min	6,687	routes(total)	66.26 min	51,847	routes(total)	81.39 min
855	routes(single)		576	routes(single)		445	routes(single)	



from Origin 1608



from Origin 1608



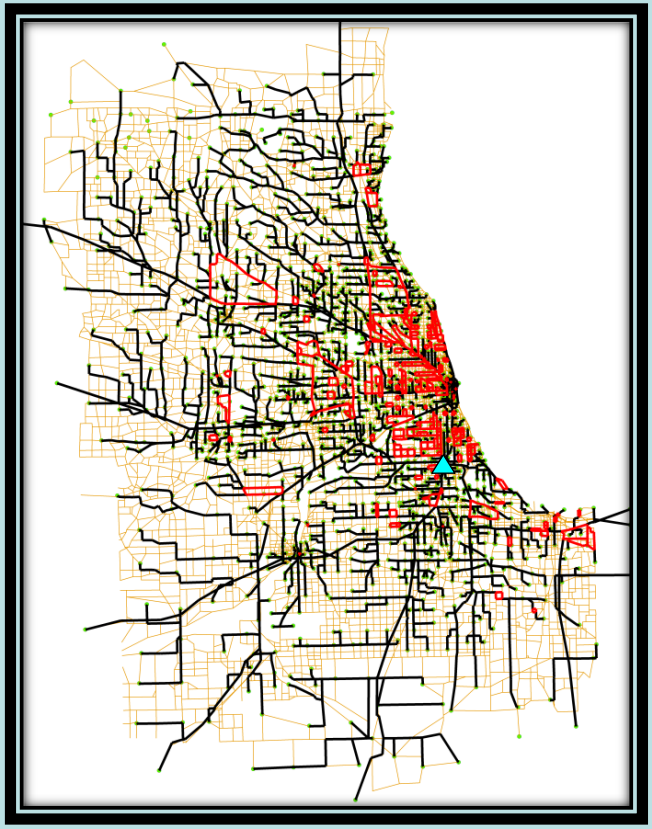
from Origin 1608

Contributions of PASs to formation of equilibrium route patterns

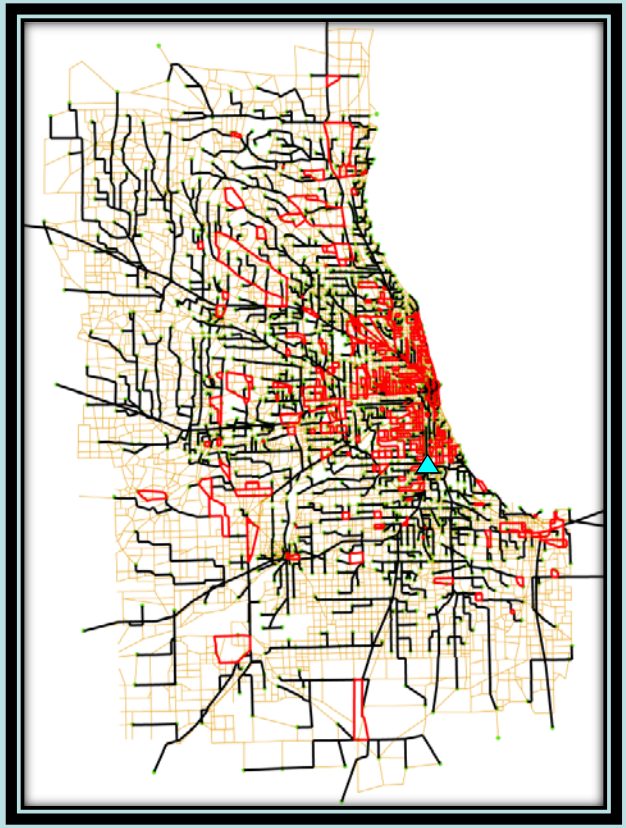
(Aggregation by an Origin)

Origins with Maximum Number of PASs on CS-0.10

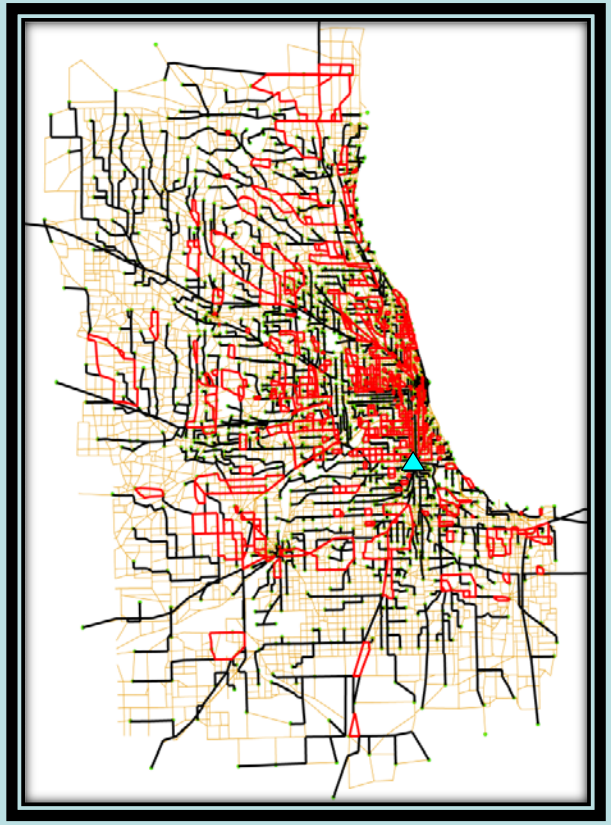
CS-0.20	CS-0.10	CS-0.05
478 PASs 822.70 vph	1,058 PASs 851.59 vph	2,034 PASs 826.56 vph
2,604 routes(total) 39.92 min	6,293 routes(total) 46.19 min	180,227routes(total) 64.86 min
1,459 routes(single)	887 routes(single)	363 routes(single)



from Origin 183



from Origin 183



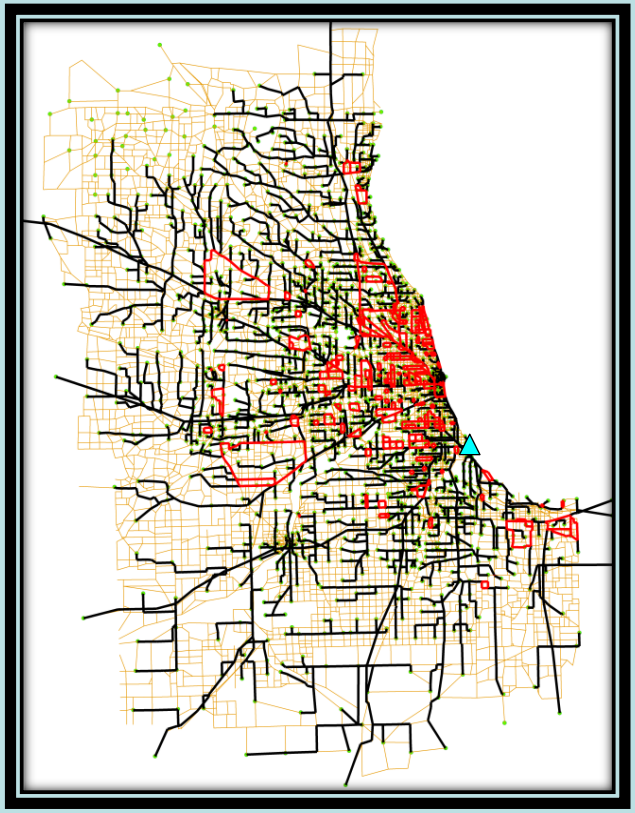
from Origin 183

Contributions of PASs in formulation of equilibrium route patterns

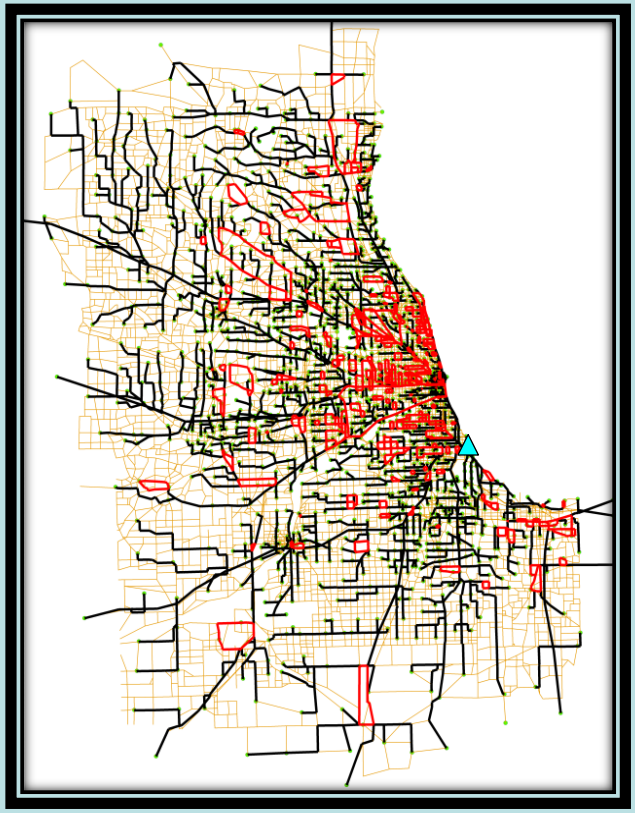
(Aggregation by an Origin)

Origins with Maximum Number of PASs on CS-0.05

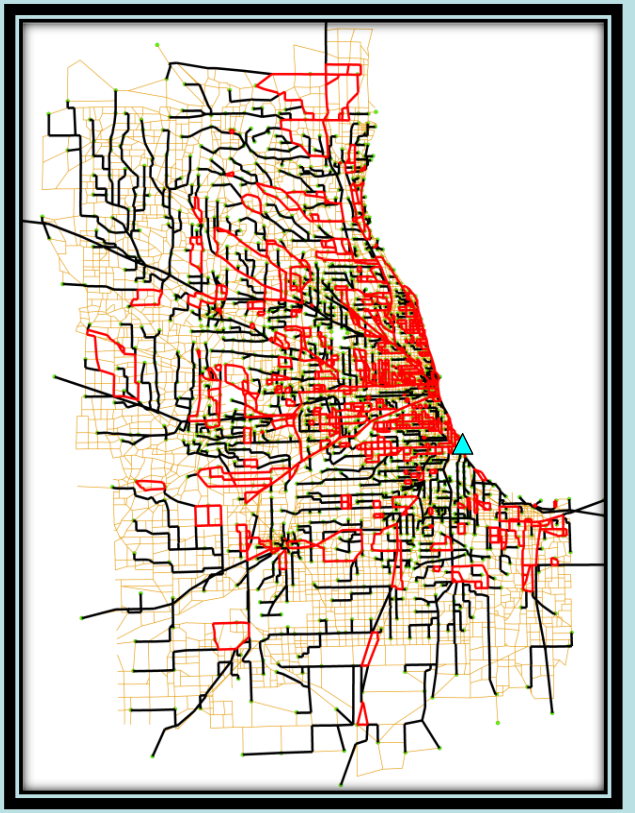
CS-0.20	CS-0.10	CS-0.05
409 PASs 160.52 vph	889 PASs 164.84 vph	2,472 PASs 169.54 vph
2,970 routes(total) 44.47 min	7,019 routes(total) 48.32 min	792,630 routes(total) 62.26 min
1,111 routes(single)	1,035 routes(single)	270 routes(single)



from Origin 3



from Origin 3



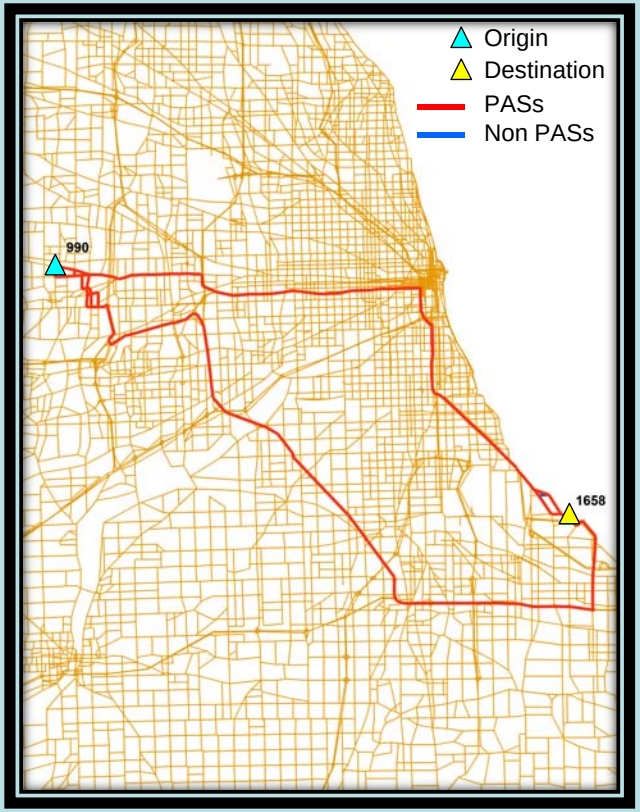
from Origin 3

Contributions of PASs in formulation of equilibrium route patterns

(Disaggregation by an OD pair)

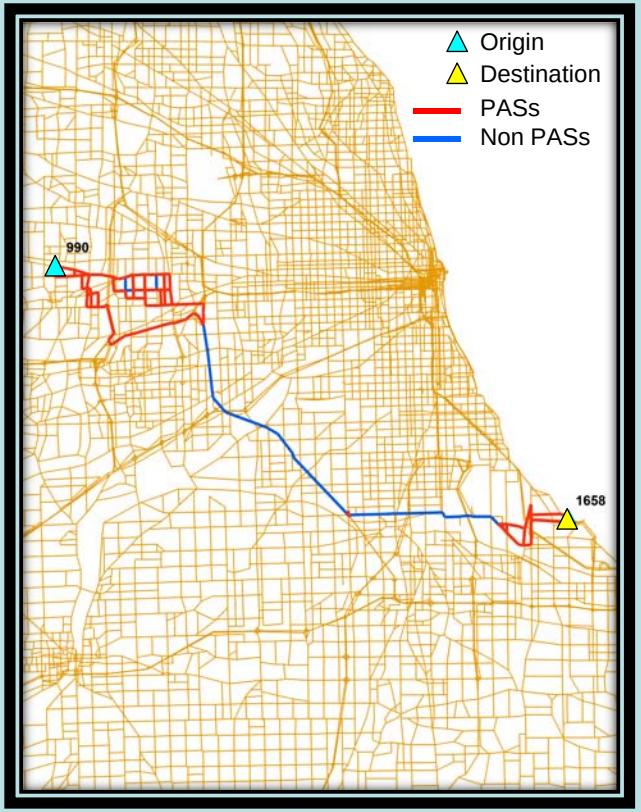
OD Pairs with Maximum Total Link Length of PAS on CS-0.20

CS-0.20		CS-0.10		CS-0.05	
21 PASs	86.45 min	17 PASs	89.53 min	55 PASs	111.59 min
42 routes	65.98 mi	50 routes	62.63 mi	294 routes	51.08 mi
0.140027 vph	45.86 mph	0.150210 vph	41.97 mph	0.283558 vph	27.46 mph



OD Pair 990 - 1658

OD Pair 990 - 1658



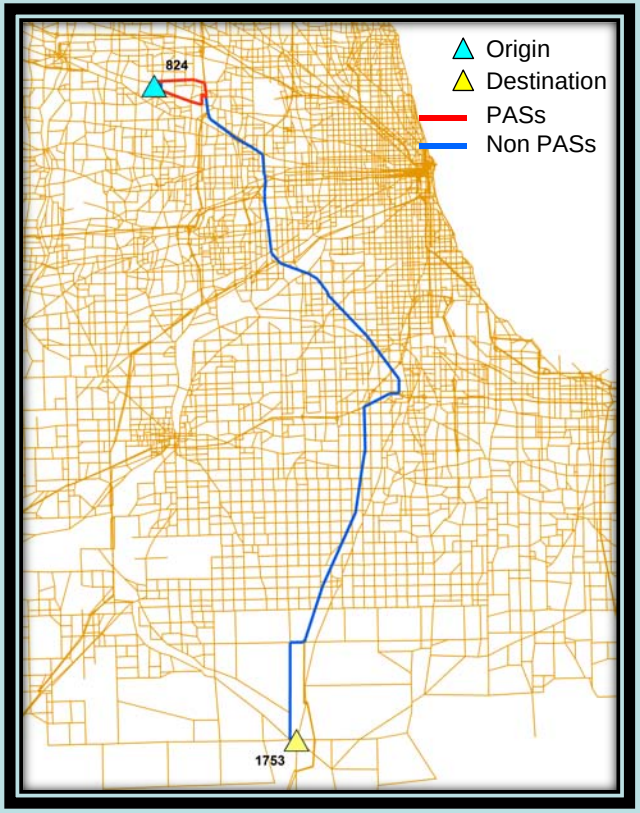
OD Pair 990 - 1658

Contributions of PASs in formulation of equilibrium route patterns

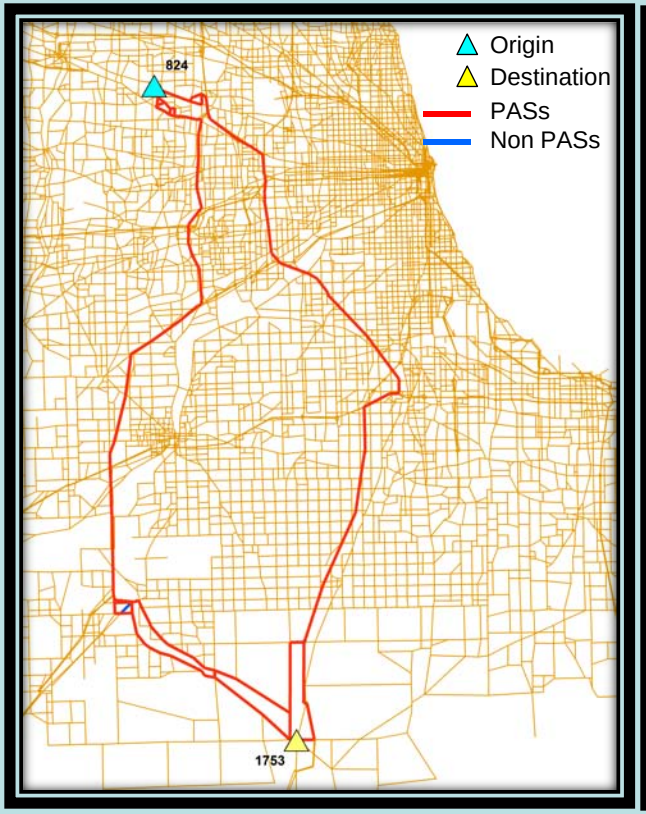
(Disaggregation by an OD pair)

OD Pairs with Maximum Total Link Length of PAS on CS-0.10

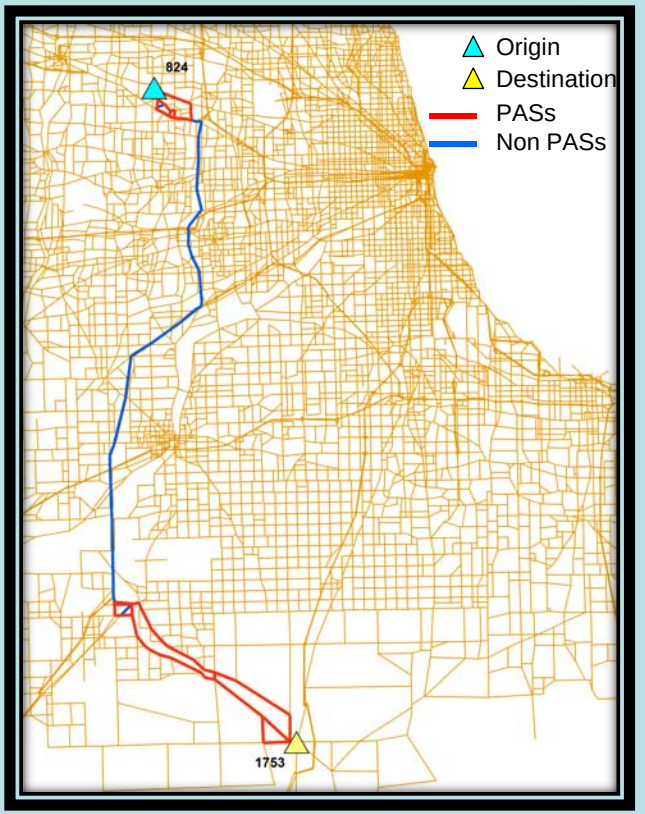
CS-0.20		CS-0.10		CS-0.05	
1 PAS	90.77 min	21 PASs	98.04 min	25 PASs	108.56 min
2 routes	84.73 mi	10 routes	85.57 mi	20 routes	85.04 mi
0.410000 vph	56.00 mph	0.411146 vph	52.37 mph	0.495564 vph	47.00 mph



OD Pair 824 - 1753



OD Pair 824 - 1753



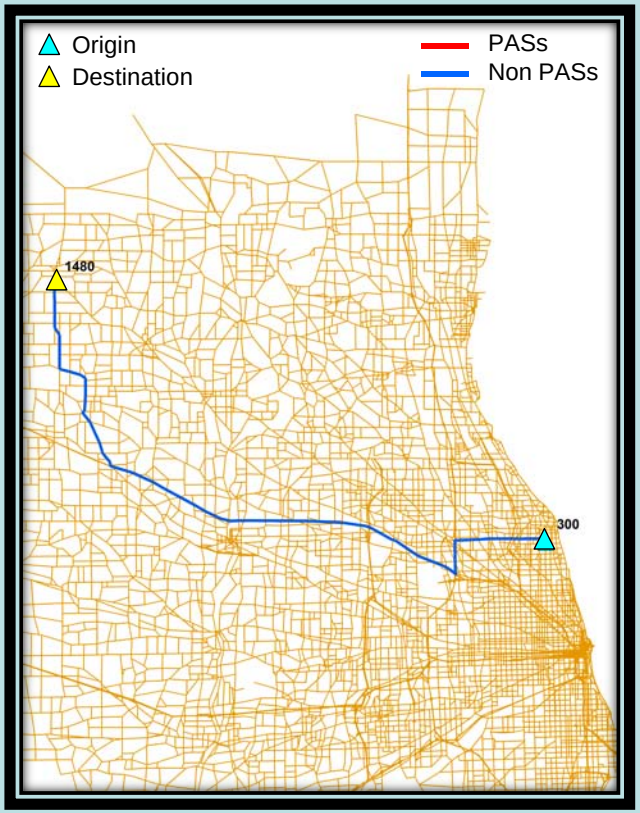
OD Pair 824 - 1753

Contributions of PASs in formulation of equilibrium route patterns

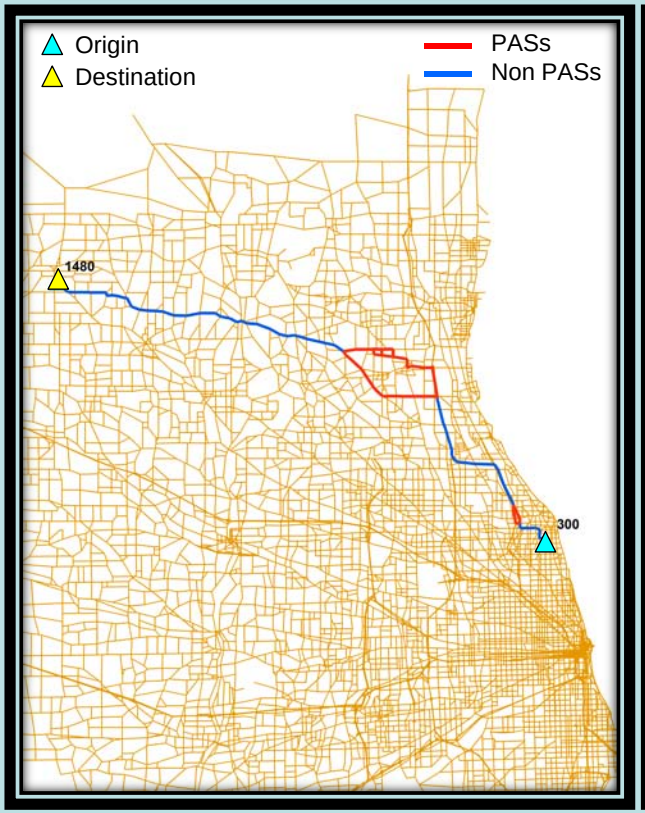
(Disaggregation by an OD pair)

OD Pairs with Maximum Total Link Length of PAS on CS-0.05

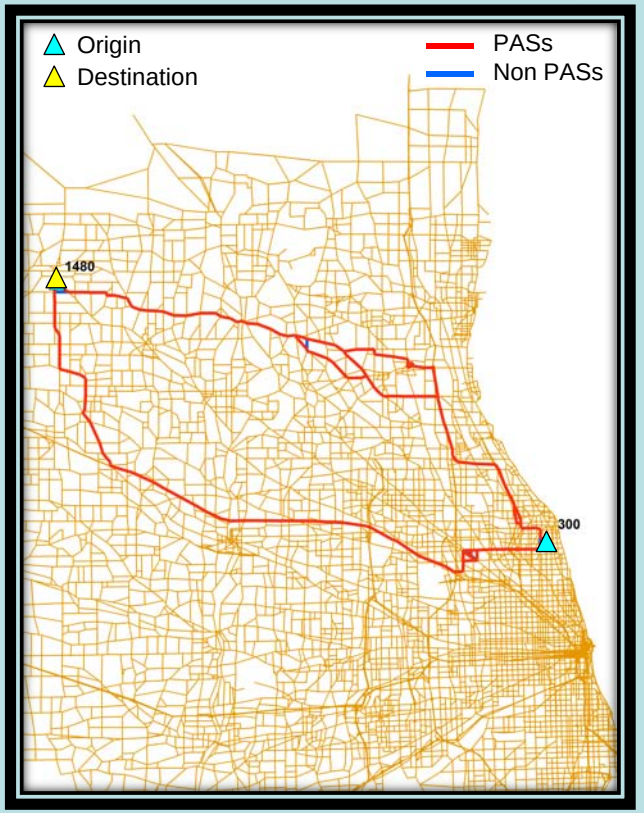
CS-0.20		CS-0.10		CS-0.05	
0 PAS	80.45 min	5 PASs	86.45 min	29 PASs	96.95 min
1 route	71.71 mi	6 routes	65.98 mi	16 routes	67.99 mi
1.09E-9 vph	53.45 mph	0.000222 vph	45.79 mph	0.017206 vph	42.08 mph



OD Pair 300 - 1480



OD Pair 300 - 1480



OD Pair 300 - 1480

Summary of findings for PAS solutions

The following findings are expected to help guide transportation professionals and practitioners in understanding the properties of PASs for solving traffic assignments with unique route flows:

- No active PASs has a segment crossing at a node.
- All active PASs consist of physically unique links.
- Simple PASs formed by three or four links are prevalent.
- Active PASs which are short and local are commonplace.
- Occurrences of PASs which are extremely long are rare.
- Active PASs with small numbers of origins occur most frequently.
- All active PASs relevant to a specific origin are part(s) of a corresponding tree of minimum travel cost routes.

Questions for future research

This research seeks to understand characteristics of user equilibrium solutions to large scale urban traffic networks. Further research is needed on:

- Networks from other regions
- Assignment of multiple classes
- Different trip matrices
- More complete generalized link cost functions including distance term and tolls