Economy of scale and the role of publicly available congestion information for local delivery industry: Agent-based simulation approach

IGERT Seminar, July 9, 2009

Kazuya Kawamura
Associate Professor, University of Illinois, Chicago
Yandan Lu
Wlibur Smith Associates

Outline

1. Background and motivation
2. Overview of study framework
3. Simulation approach
4. Findings
5. Challenges

Real-time/advanced travel information system

In the U.S.

- Travel time information collected from:

detectors, cameras, satellite imaging, cell phones, GPS, etc.

- Distributed via publicly accessible means (radio/TV, Internet, etc.) – direct provision by the government or outsourcing (e.g. Tele Atlas)

- Growth of customized travel information sent via text messages and e-mails (e.g. NAVTEQ-Traffic.com), Westwood One – SmartTraveler, etc.)

"predictive traffic trends, vehicle speeds, congestion levels, travel times, and delay times delivered via Web, wireless device, radio, television, and in-vehicle navigation systems."

Motivation

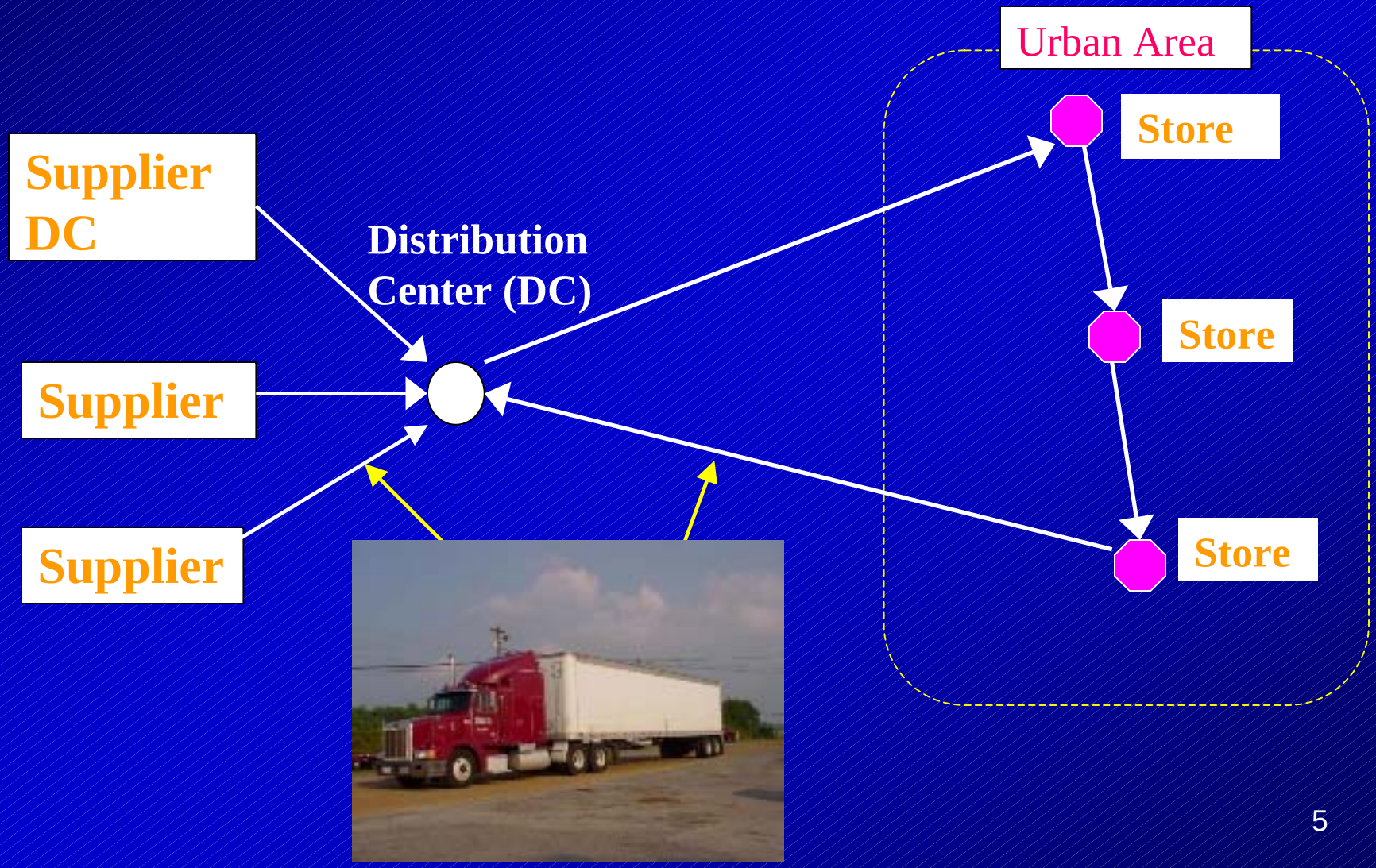
Broad questions:

- Where is the travel information business heading?
- Is there a justification for non-exclusive ("public") provision of travel information?
- Are there positive externalities that are overlooked?

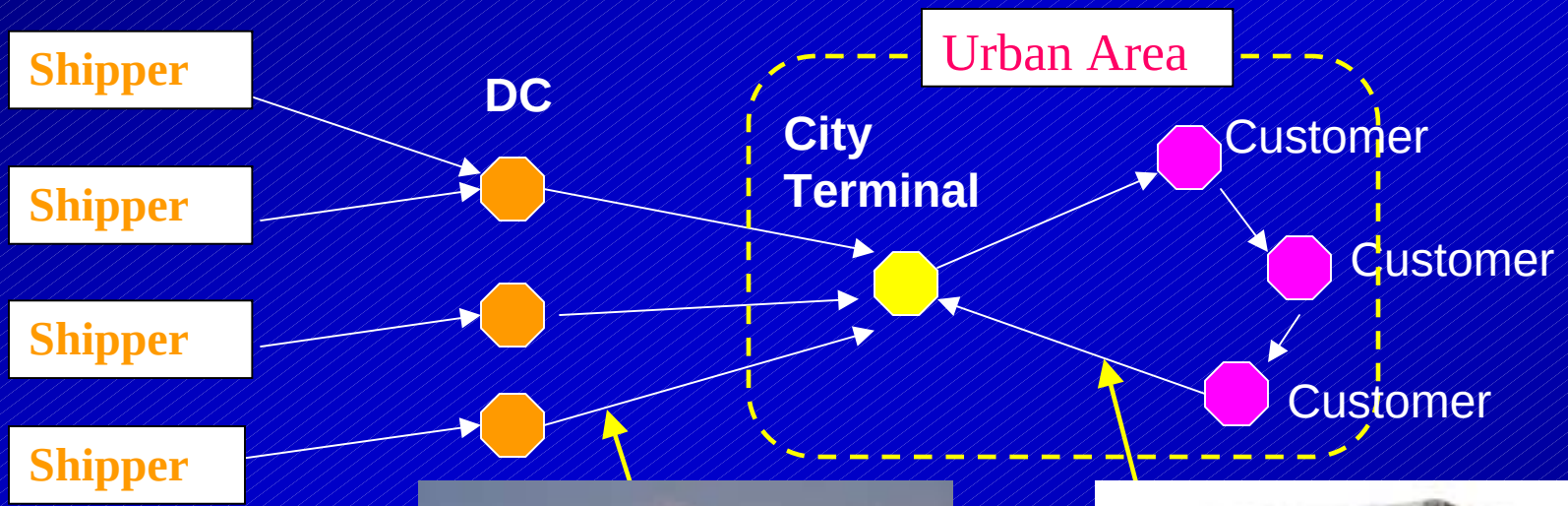
Hypothesis:

Publicly available travel information (or affordable equivalent in the private sector) benefits smaller goods delivery firms by lowering the market entry barrier

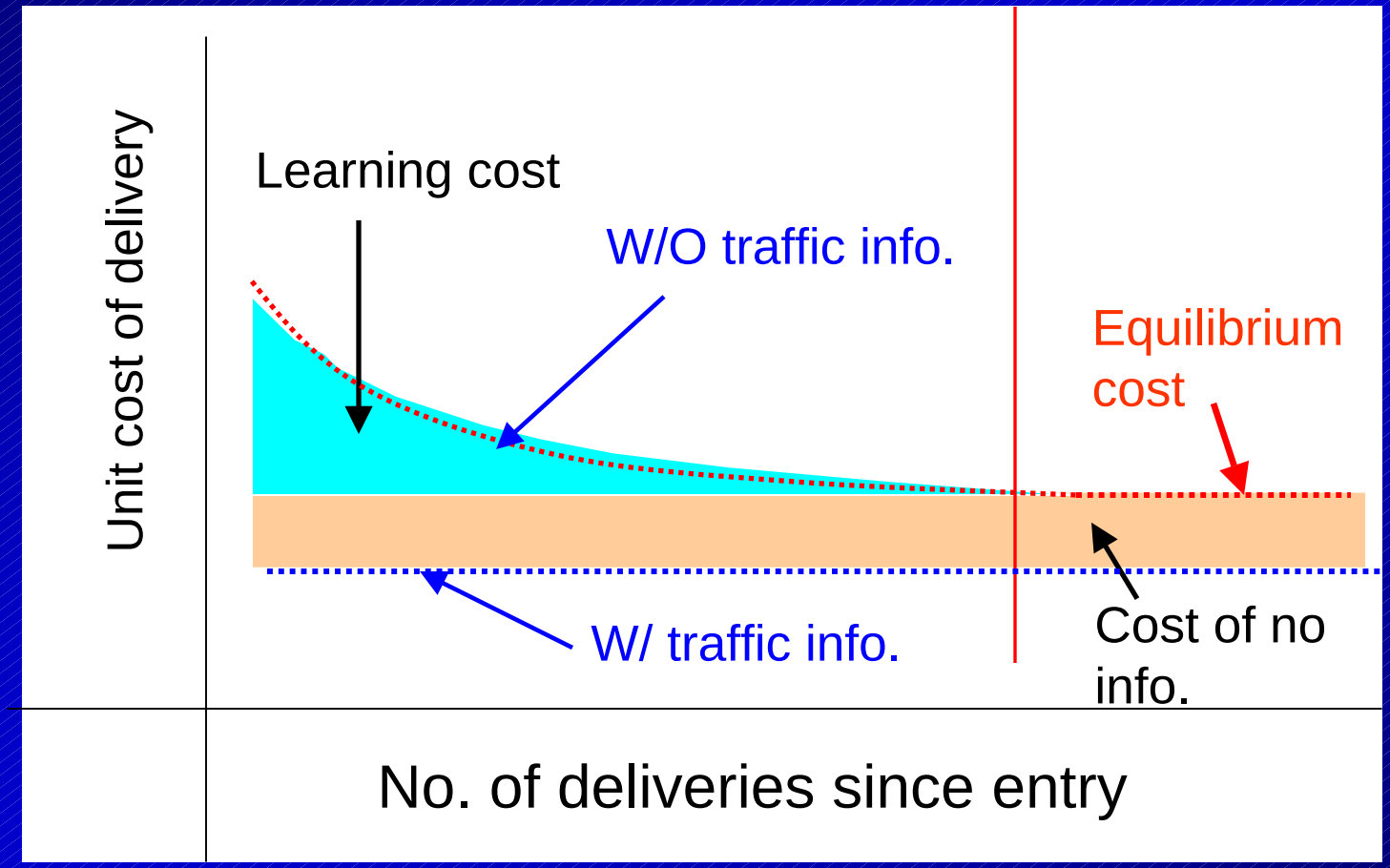
“Peddle run" system commonly used in the U.S. by retail chains



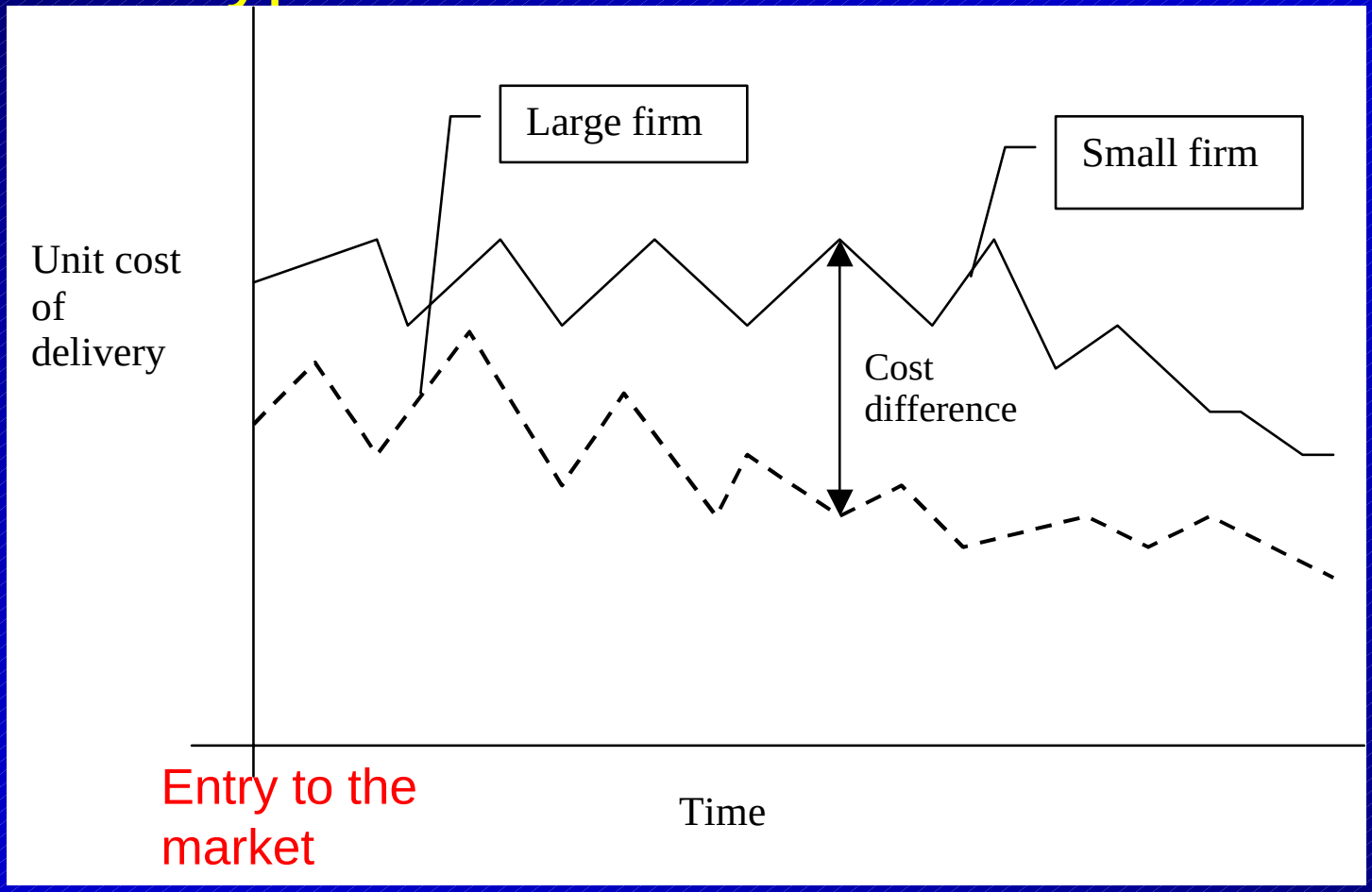
“Single-stage” system commonly used by parcel delivery/pick-up services



For each firm …



Economy of scale at work
- Hypothesis w/o traffic info -



Exploratory examination of an <u>entry into a hypothetical urban area by delivery service firms of different sizes</u>

⇒ Compare efficiency for “with” vs. “without” information cases

Overview of Research

Expected outcomes:

Large firms have shorter learning period (lower entry cost) ⇒ smaller benefit from travel time information ⇒ publicly available traffic information lower entry barrier for smaller firms

However, **magnitude of benefit may depend on various factors:**

- Sizes of competing firms
- Environment (network configuration, congestion level, link travel time variation)

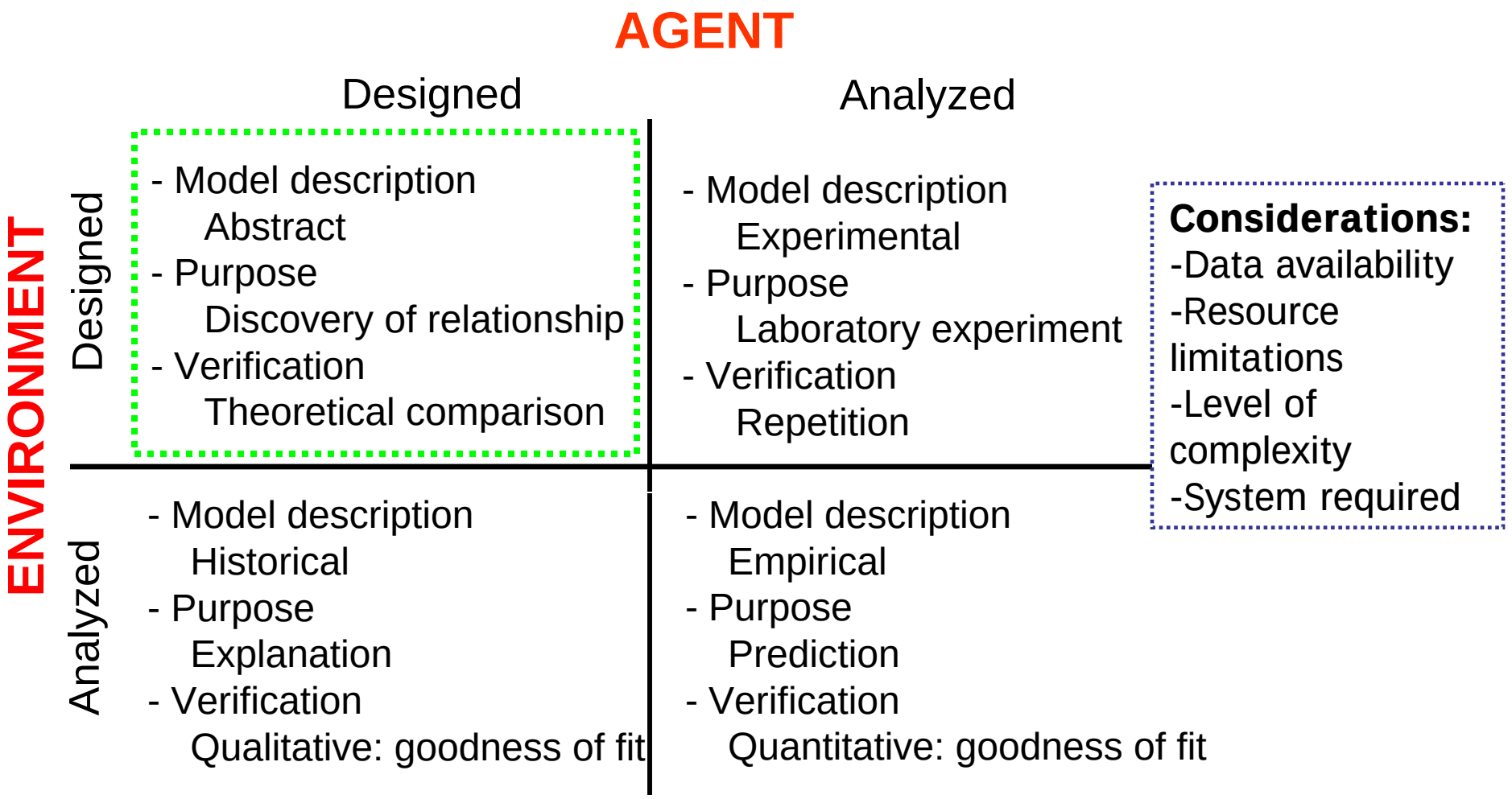
Build an exploratory simulation model of goods delivery to examine the hypothesis under different environment

Agent-based simulation

Agent-based model (ABM)

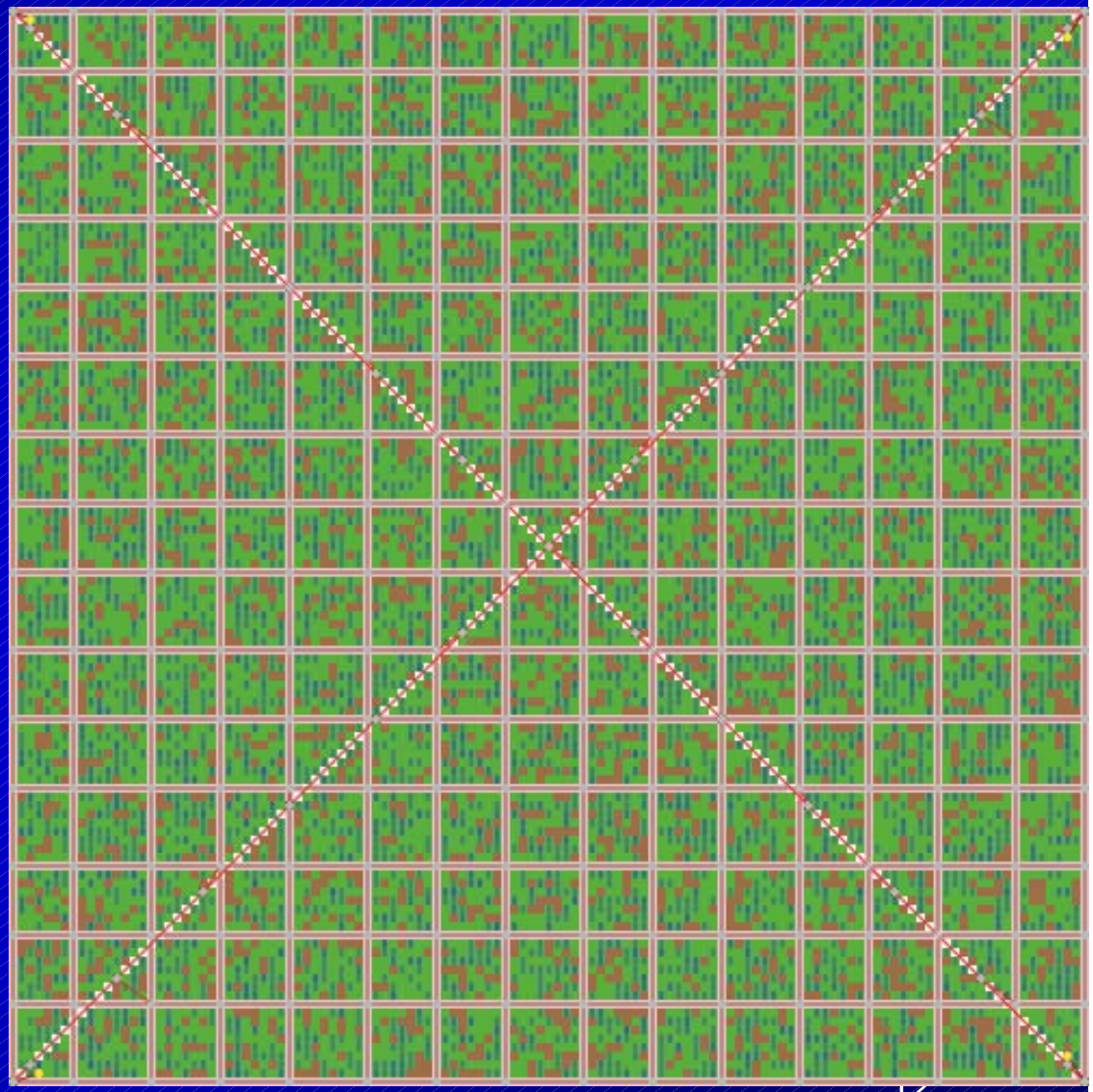
- Derived from complex systems perspective (i.e. emergence of pattern from behaviors and interactions of numerous intelligent agents)
- Behaviors are controlled by a set of rules defined for **each** agent.
- Generally, agents do not act according to global rules.
- Not necessarily suited for forecasting
- Flexible platform to simulate wide-ranging (especially emergent) phenomena
- Key components of simulation: agent, environment

Taxonomy of ABM



Simulation Environment

- City: 18 mile x 18 mile
- Land use: Road, commercial, residential located in 100mx100m Patches
- Land use: Houses & jobs randomly allocated
- Congestion from background traffic



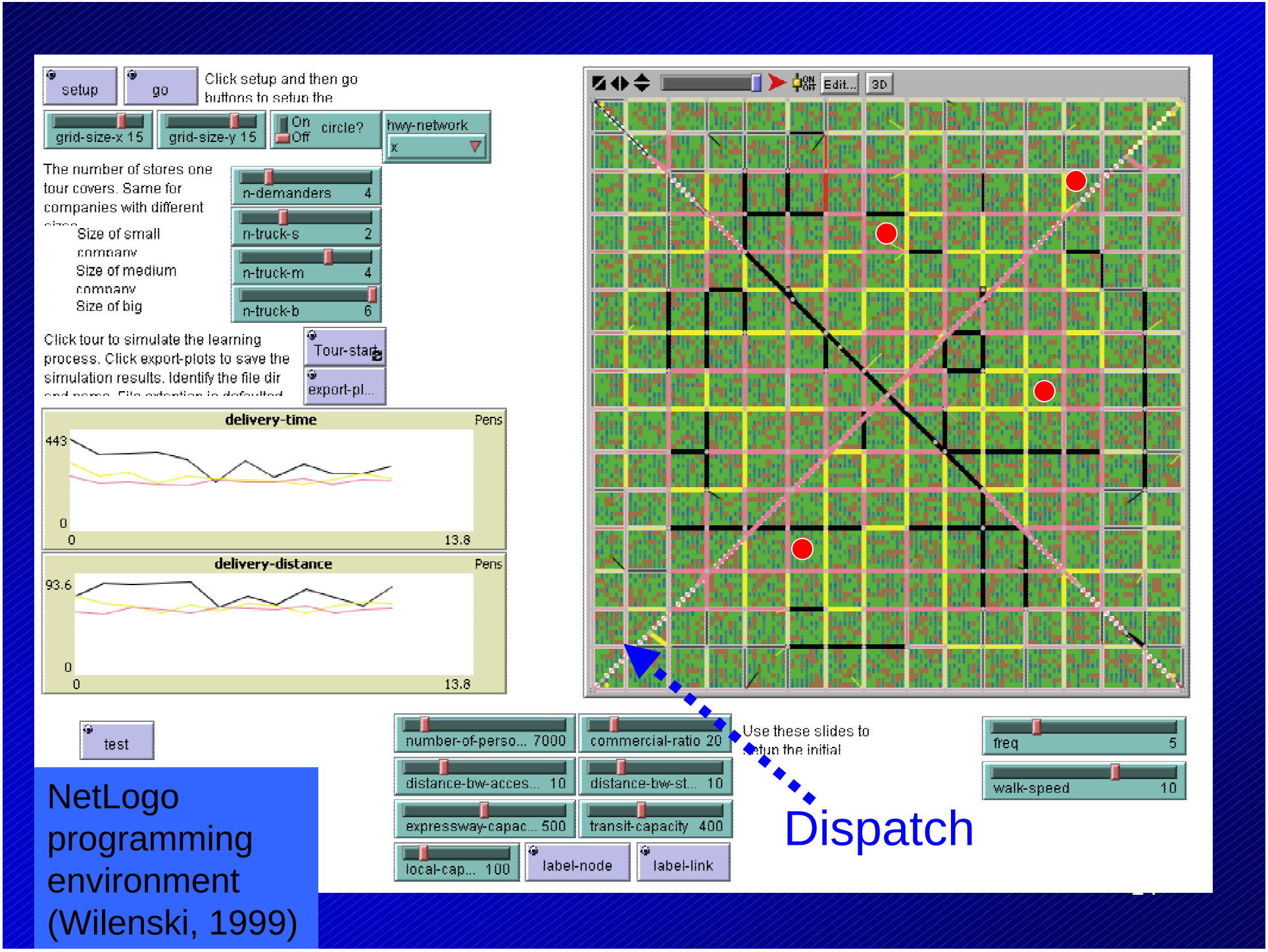
Delivery tour simulation

- Customers are generated randomly across the city
- There is a product differentiation between small, medium, and large firms (i.e. no competition for customers)
- Each tour covers 4 customers
- Firms dispatch trucks from the terminal

  Large: 6 tours/cycle

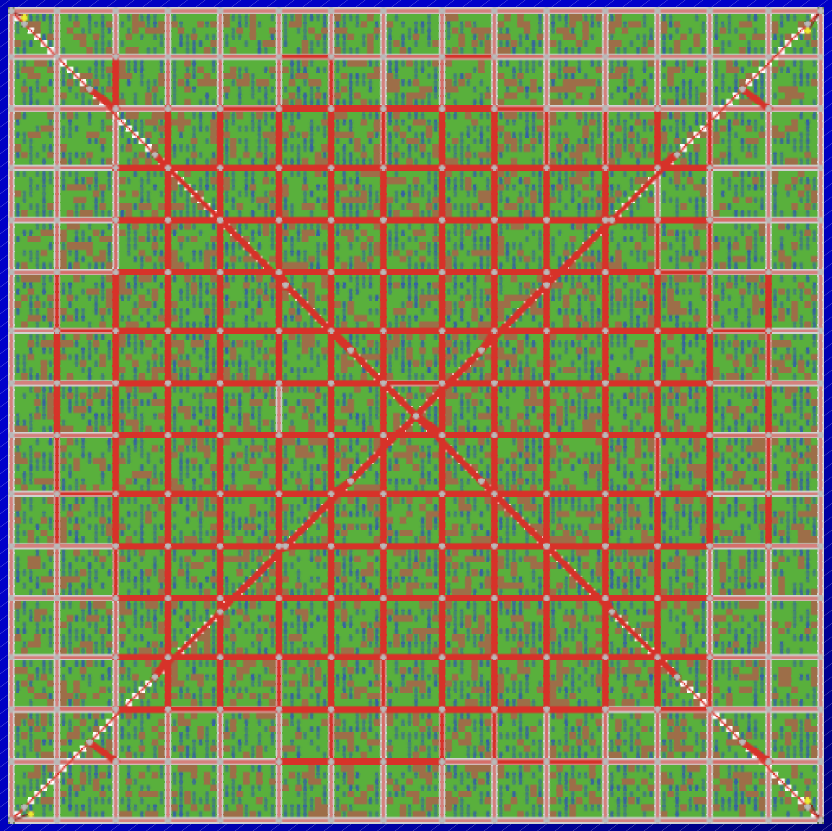
  Medium: 4 tours/cycle

  Small: 2 tours/cycle
- At the end of a cycle, firms update their knowledge of travel time for each link based on the mean of the sample (from the past deliveries)


setup
go
Click setup and then go buttons to setup the
grid-size-x 15
grid-size-y 15
On
Off
circle?
hwy-network
x
The number of stores one tour covers. Same for companies with different
Size of small company
Size of medium company
Size of big
n-demanders 4
n-truck-s 2
n-truck-m 4
n-truck-b 6
Click tour to simulate the learning process. Click export-plots to save the simulation results. Identify the file dir
Tour-start
export-pl...
delivery-time
Pens
443
0
0
13.8
delivery-distance
Pens
93.6
0
0
13.8
Edit...
3D
test
number-of-perso... 7000
commercial-ratio 20
distance-bw-acces... 10
distance-bw-st... 10
expressway-capac... 500
transit-capacity 400
local-cap... 100
label-node
label-link
Use these slides to setup the initial
freq 5
walk-speed 10
Dispatch
NetLogo programming environment (Wilenski, 1999)

Background traffic

- Congestion generated by (shortest-path) home-to-work trips made by the population
- Degree of congestion = f(population, network size, link capacity)



Environment

Parameter	Values tested
Network size	8x8, 15x15, 20x20
Population	6000, 7000, 8000, 9000, 10000
Freeway orientation	Diagonal, parallel
Spacing between ramps	10, 16, 20
Freeway link capacity	400, 500, 600, 700, 800
Street link capacity	75, 100, 125, 150
Stops per delivery tour	3, 4

Values eventually used in scenario simulations

Selection criteria:

- Link V/C ratio must be realistic
- Effect on simulation outcome
- Computation time

Simulation scenarios

Variables: Congestion level, travel time variation, real-time traffic information

Scenario	Population	Expwy capacity	Local capacity	Travel time variation factor	w/ traffic info?
1	7000	500	100	0.5	Y
2	7000	500	100	0.5	N
3	7000	500	100	0.3	Y
4	7000	500	100	0.3	N
5	8000	500	100	0.3	Y
6	8000	500	100	0.3	N
7	6000	500	100	0.3	Y
8	6000	500	100	0.3	N

Adding random delay to link travel time

- For a link i,

TTi = max (Variable congested time, Free-flow time)

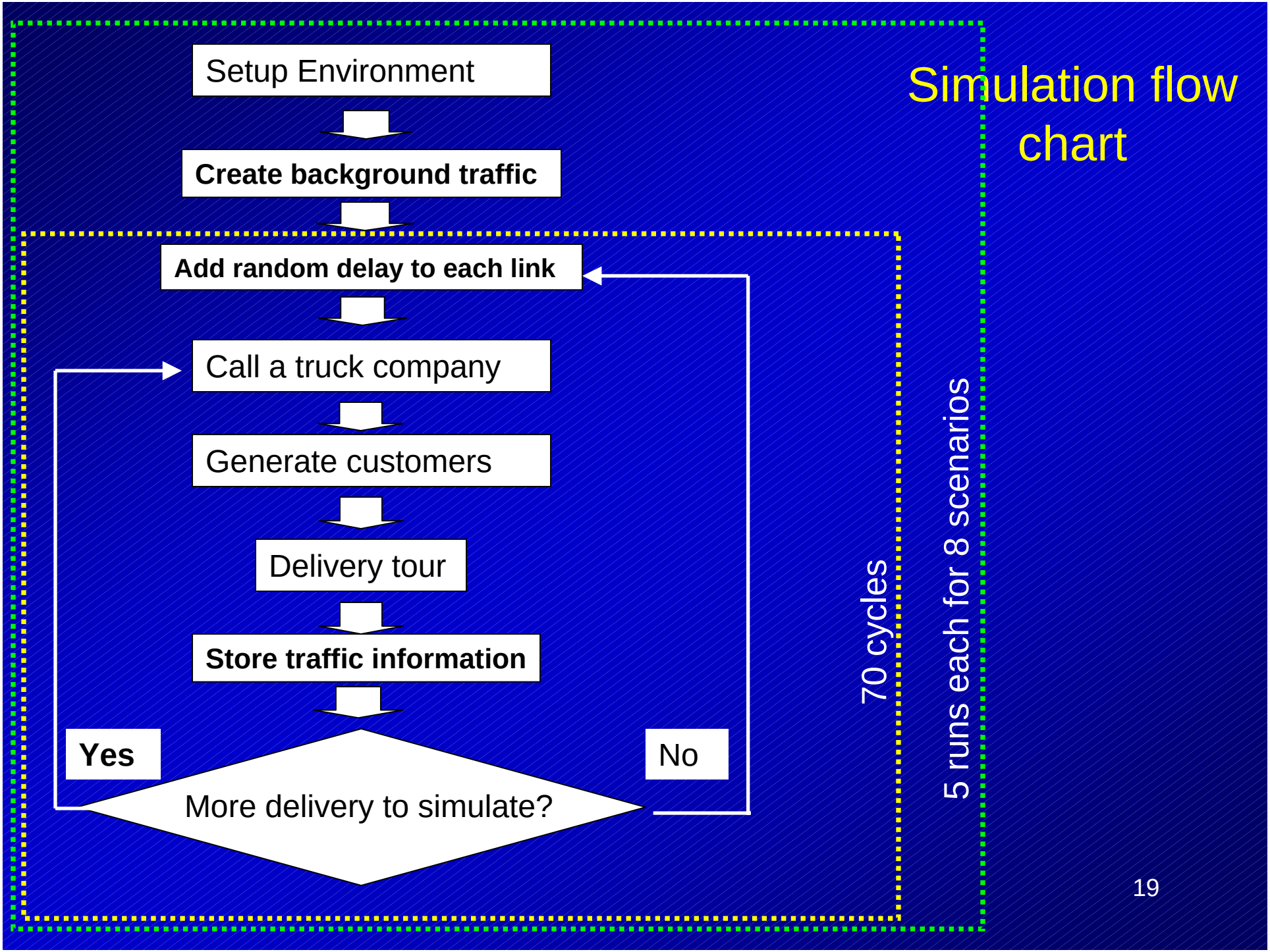
Variable congested time = ~N(μ = Loaded travel time, σ = variability factor x loaded travel time)

Variability factors of 0.3 and 0.5 were used

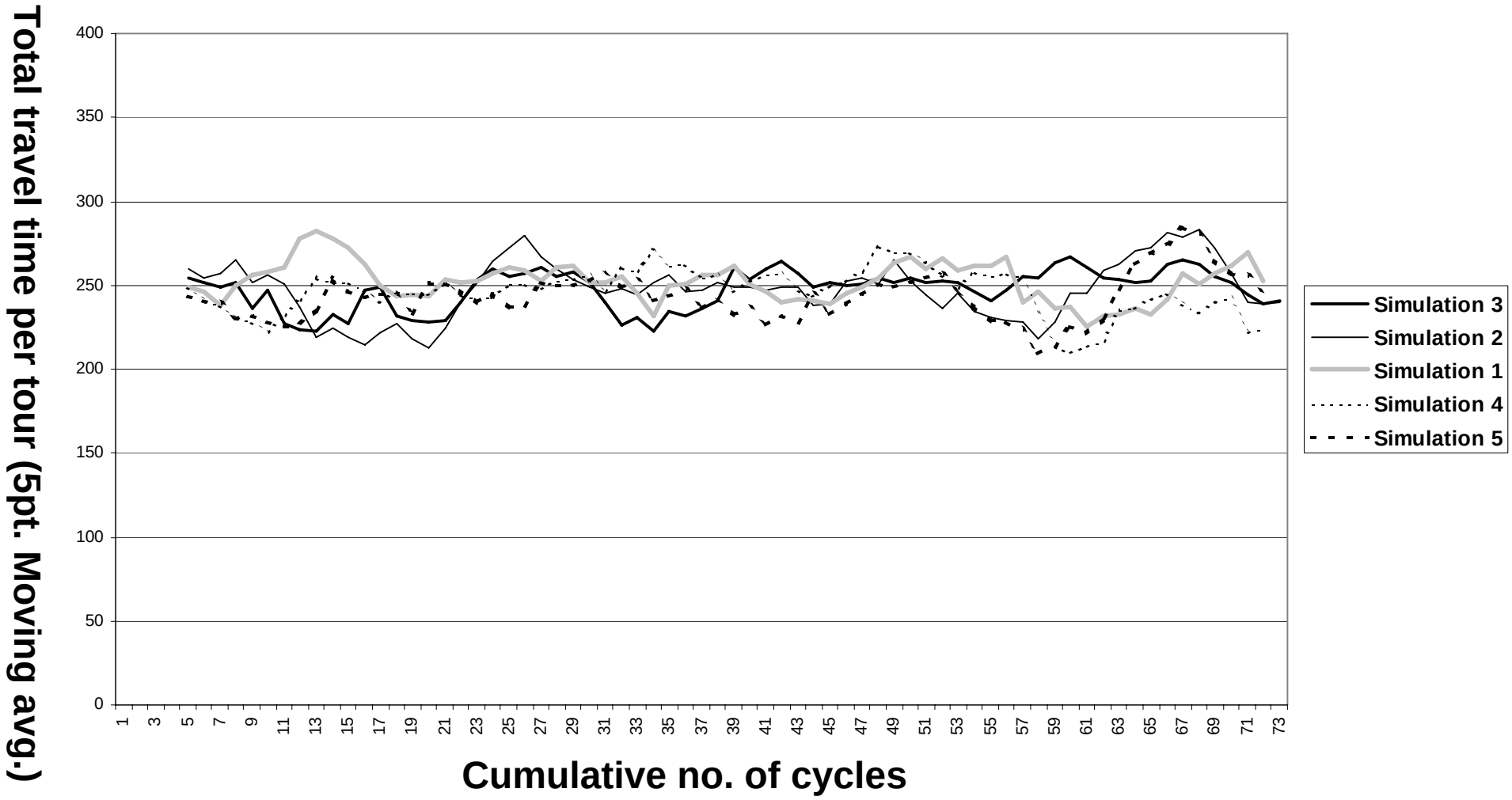
e.g. For a link with loaded travel time = 5 min

Variable congested time = ~N(5, 0.3x5)

Simulation flow chart

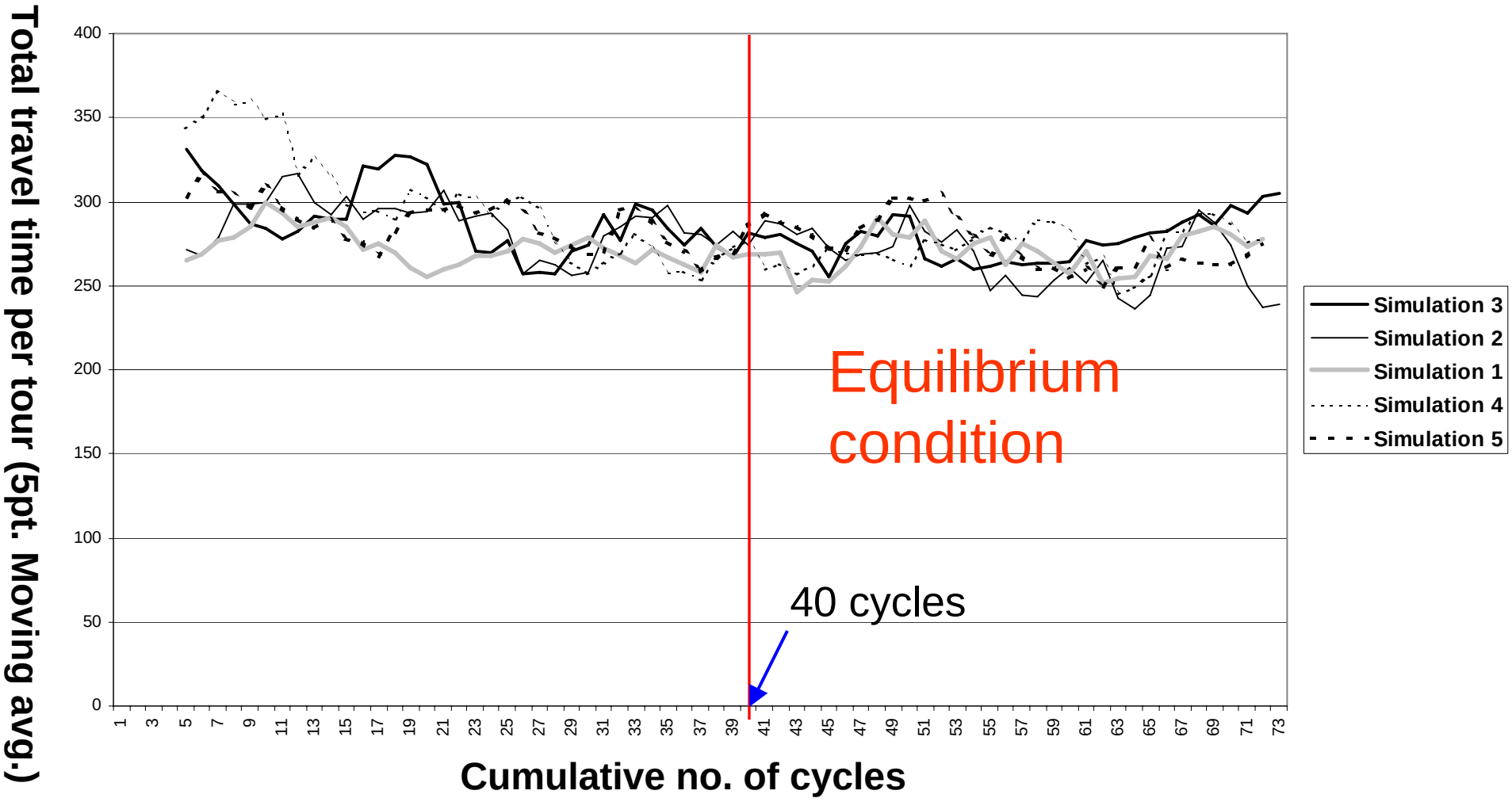


Scenario 1 (Moderate congestion, 0.5 variability factor, **with info.**)



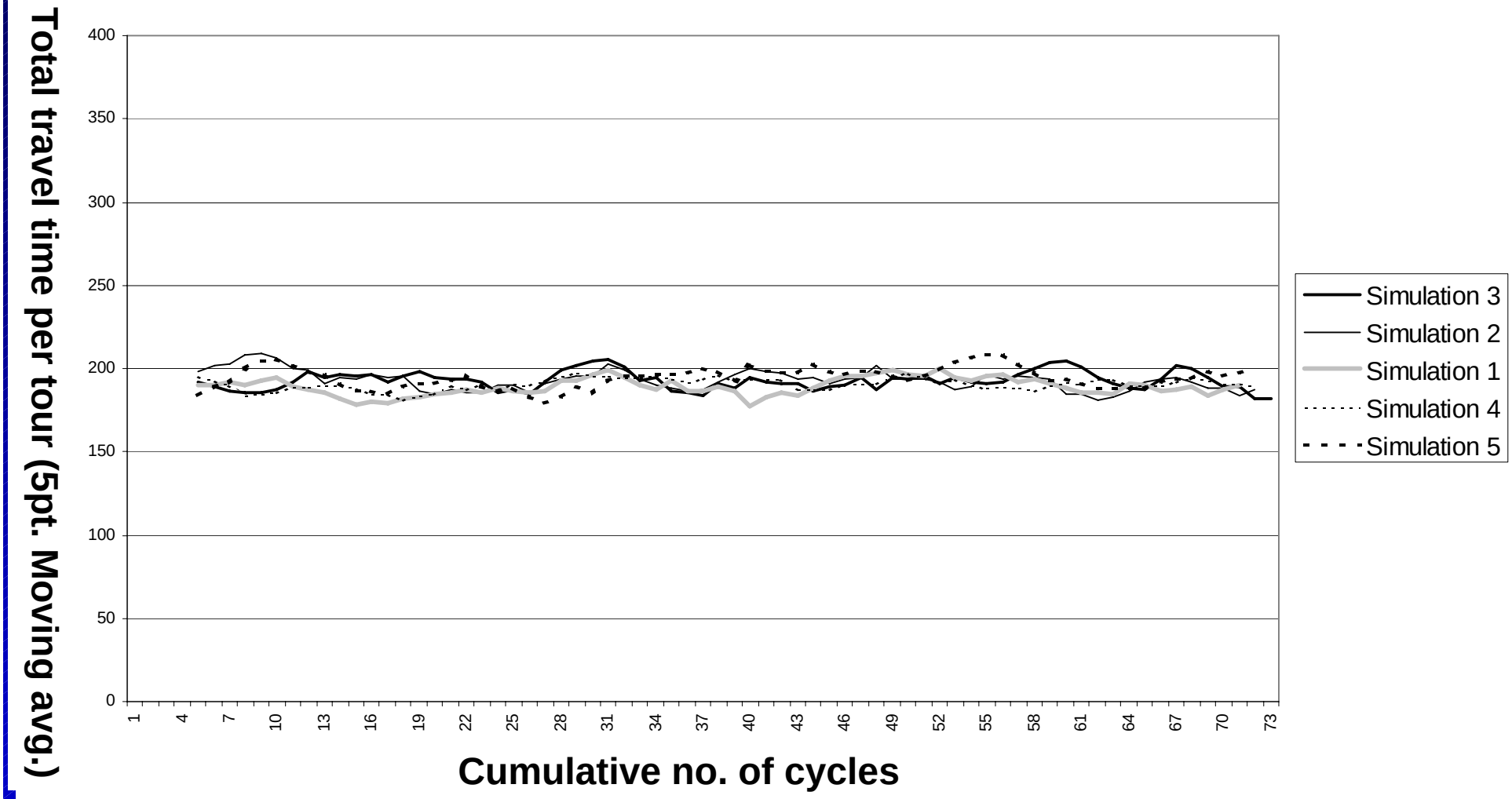
Small firm

Scenario 2 (Moderate congestion, 0.5 variability factor, **without info.**)



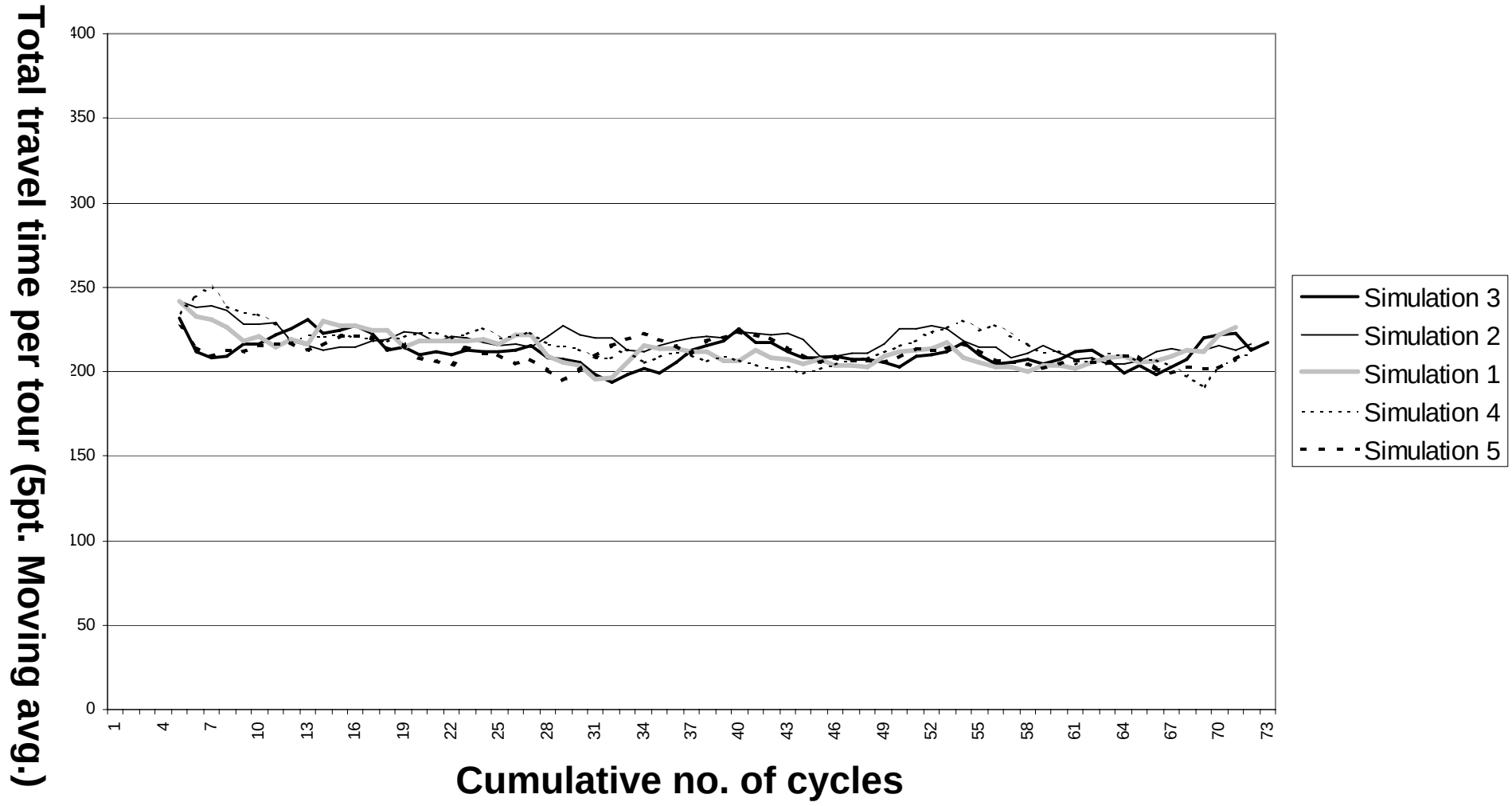
Small firm

Scenario 1 (Moderate congestion, 0.5 variability factor, **with info.**)



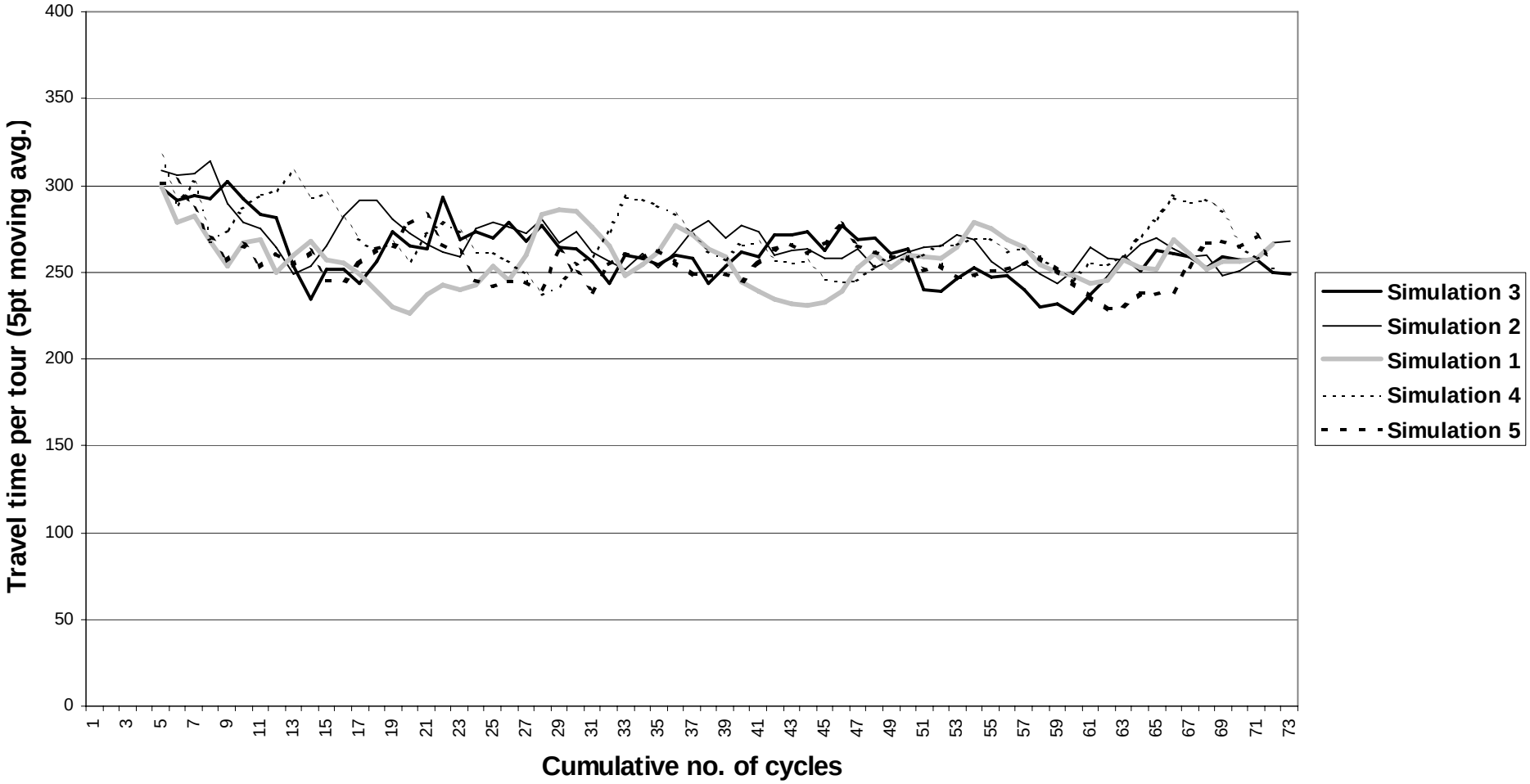
Large firm

Scenario 2 (Moderate congestion, 0.5 variability factor, **without info**)



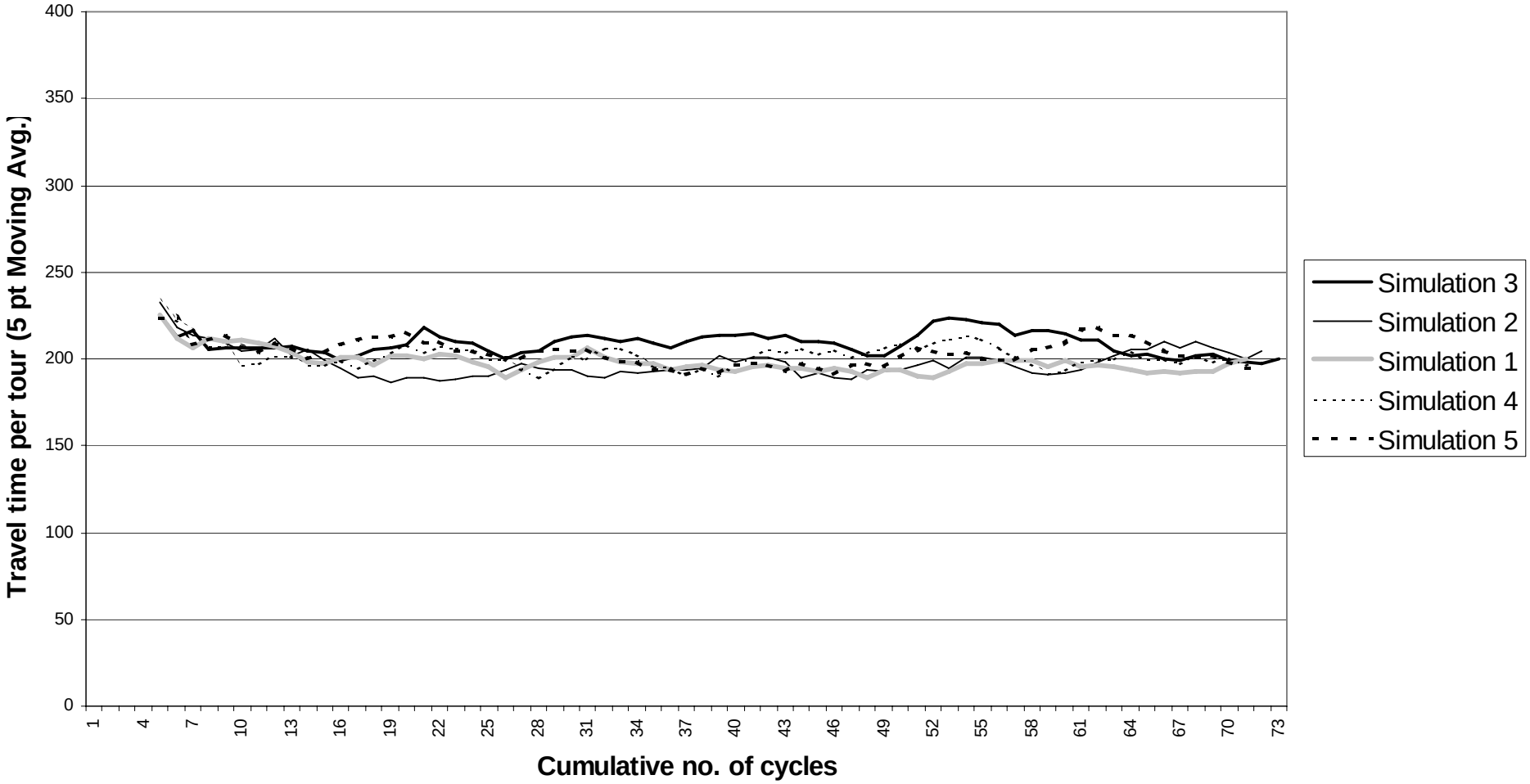
Large firm

Scenario 4 (Moderate congestion, 0.3 variability factor, without info)



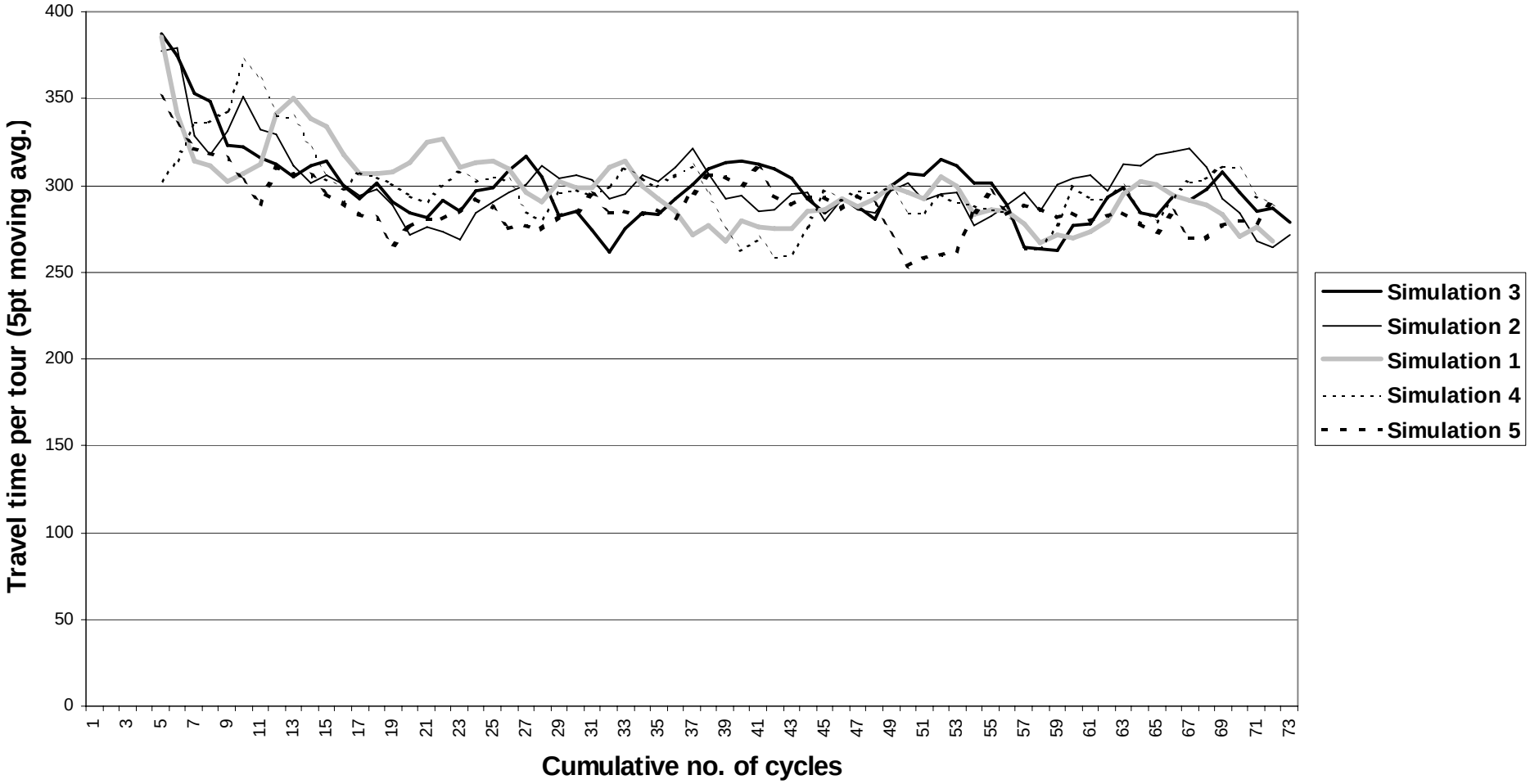
Small firm

Scenario 4 (Moderate congestion, 0.3 variability factor, without info)



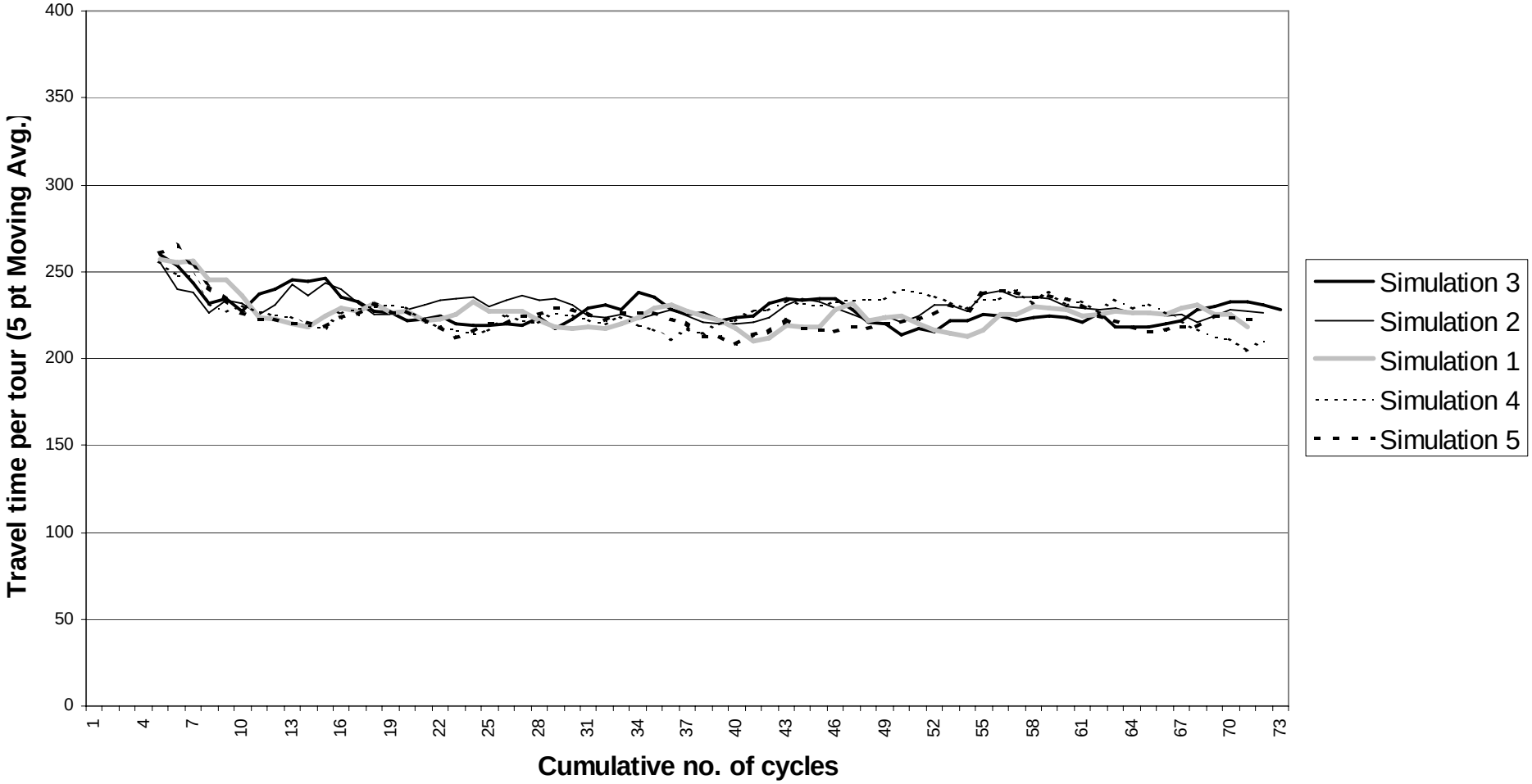
Large firm

Scenario 6 (Severe congestion, 0.3 variability factor, without info)



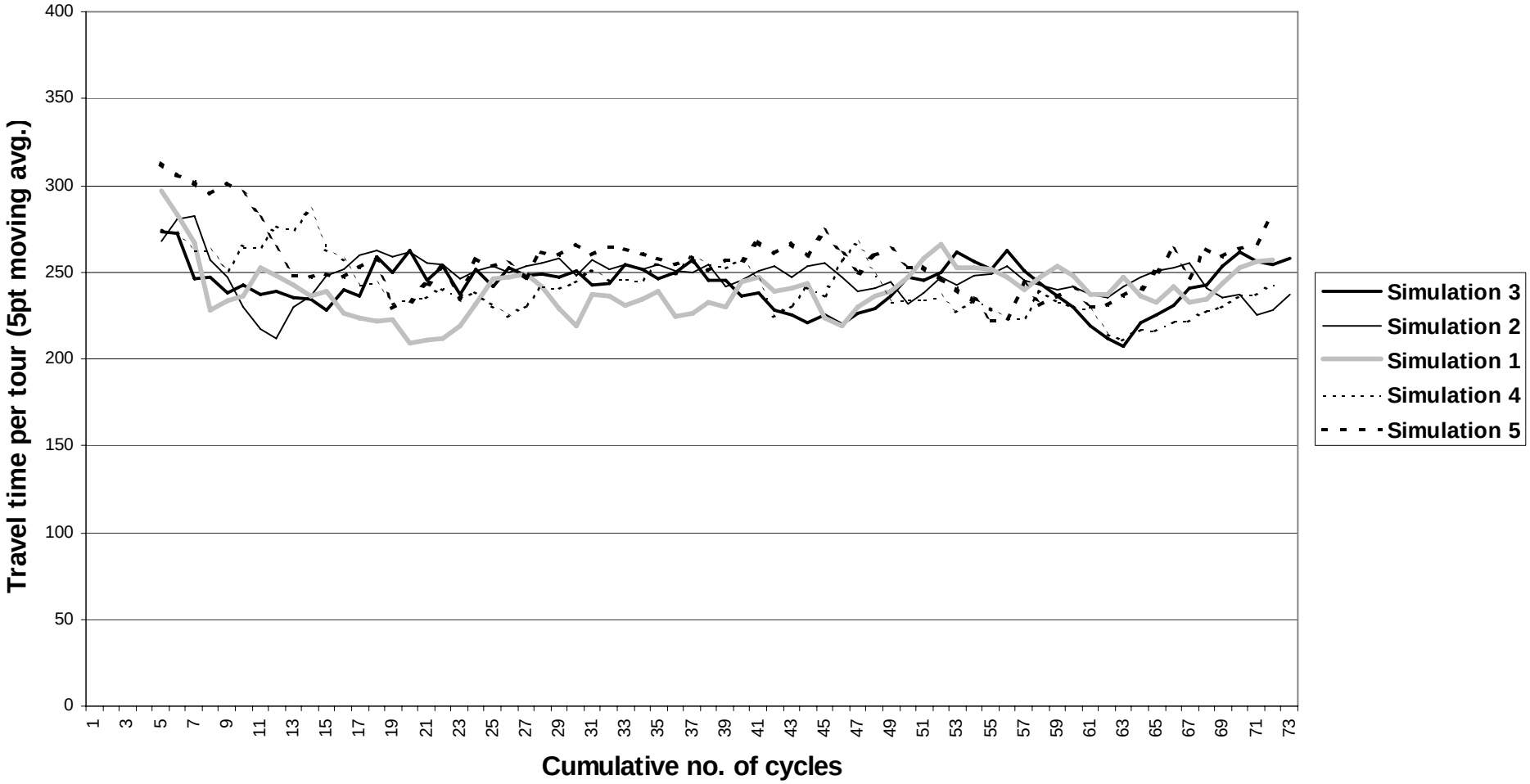
Small firm

Scenario 6 (Severe congestion, 0.3 variability factor, without info)



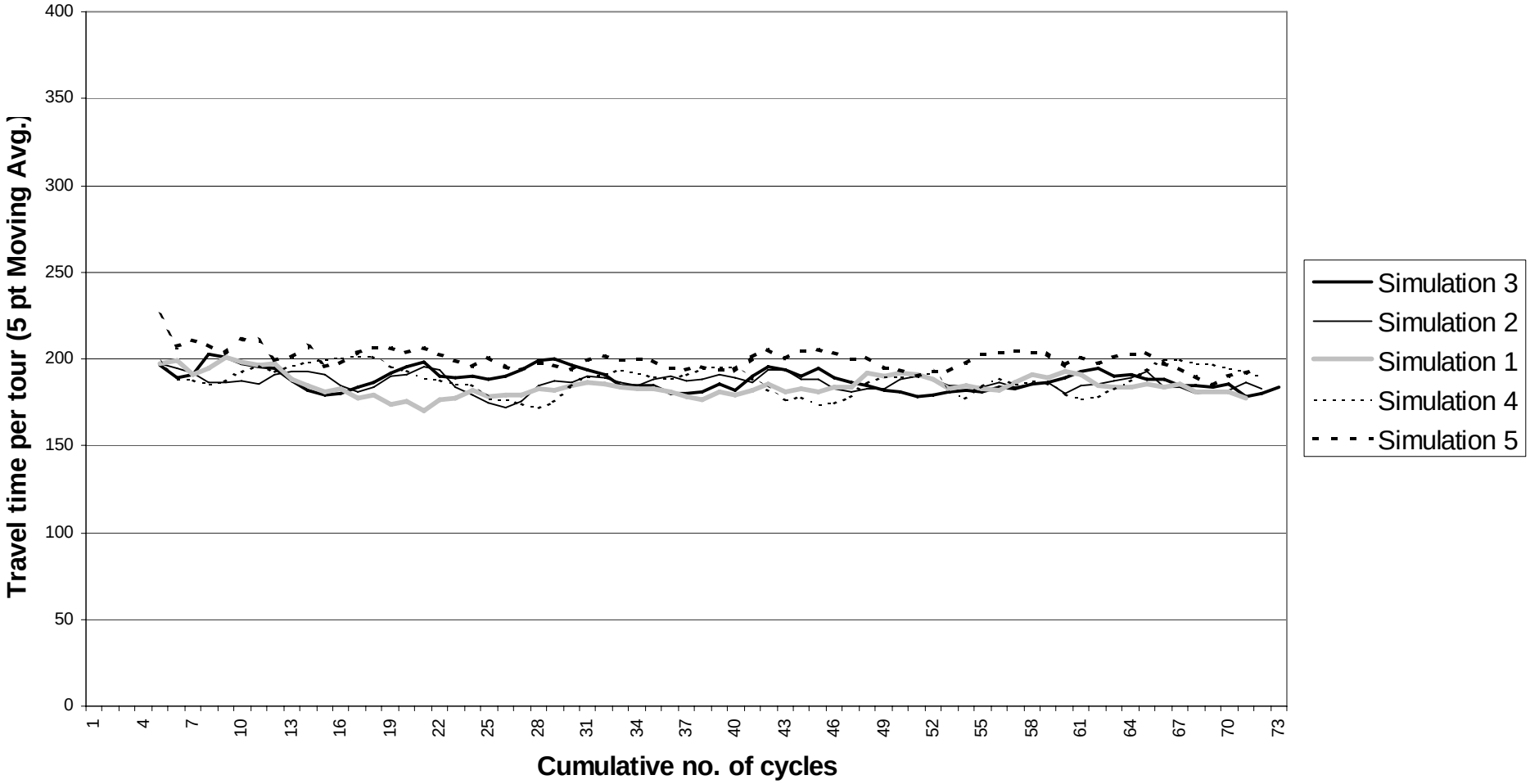
Large firm

Scenario 8 (Light congestion, 0.3 variability factor, without info)

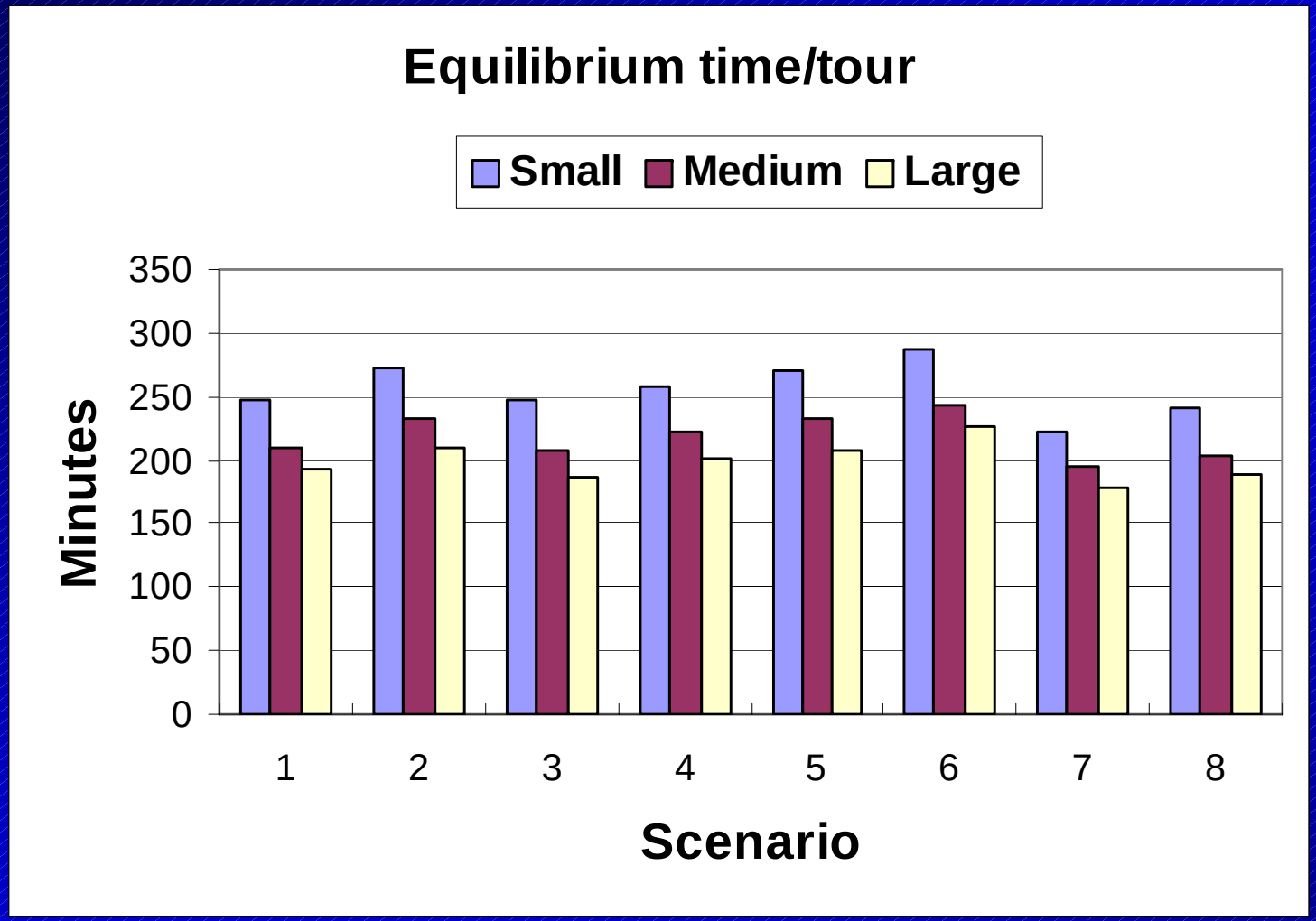


Small firm

Scenario 8 (Light congestion, 0.3 variability factor, without info)

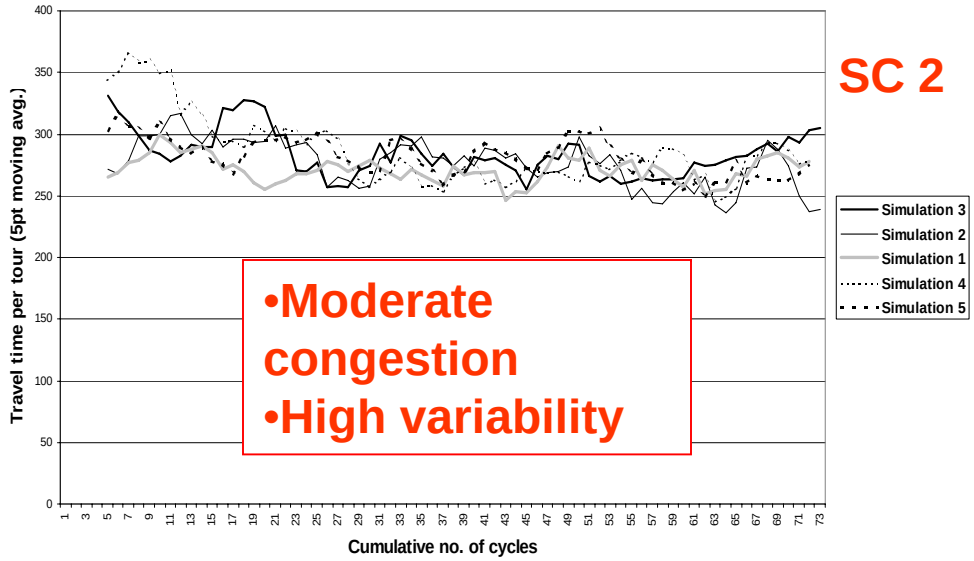


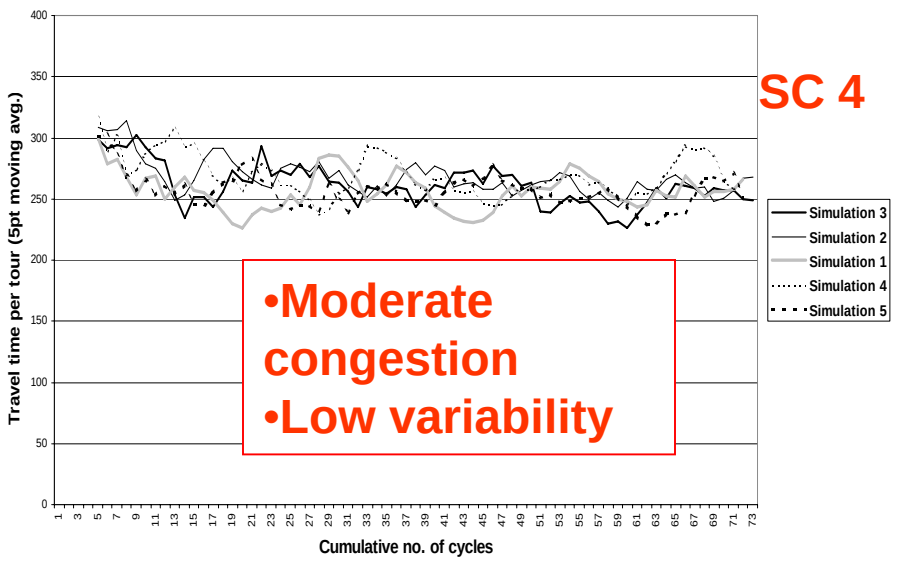
Large firm

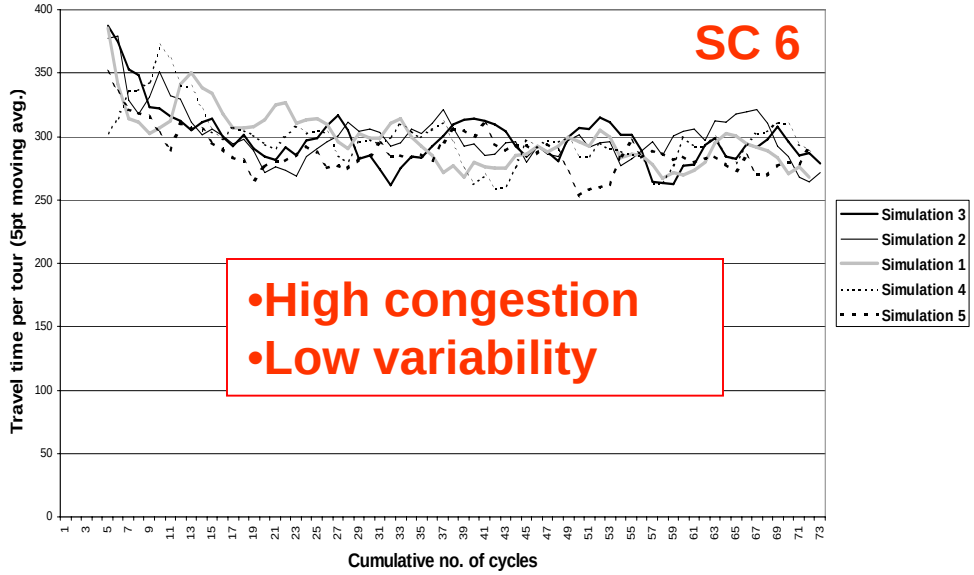


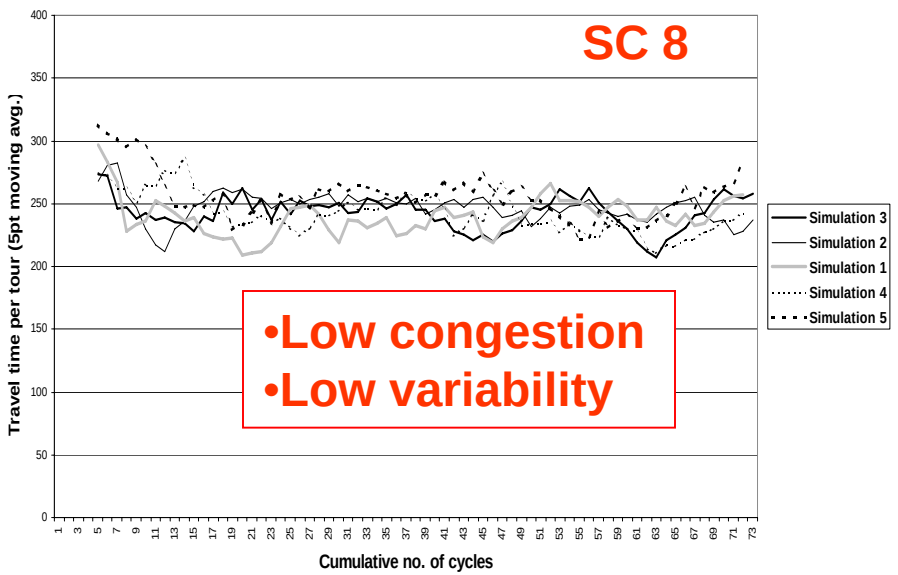
Scenario 1&2 (Moderate congestion, 0.5 variability factor)
Scenario 3&4 (Moderate congestion, 0.3 variability factor)
Scenario 5&6 (Severe congestion, 0.3 variability factor)
Scenario 7&8 (Light congestion, 0.3 variability factor)

Comparison of "without info" scenarios - Small firm -

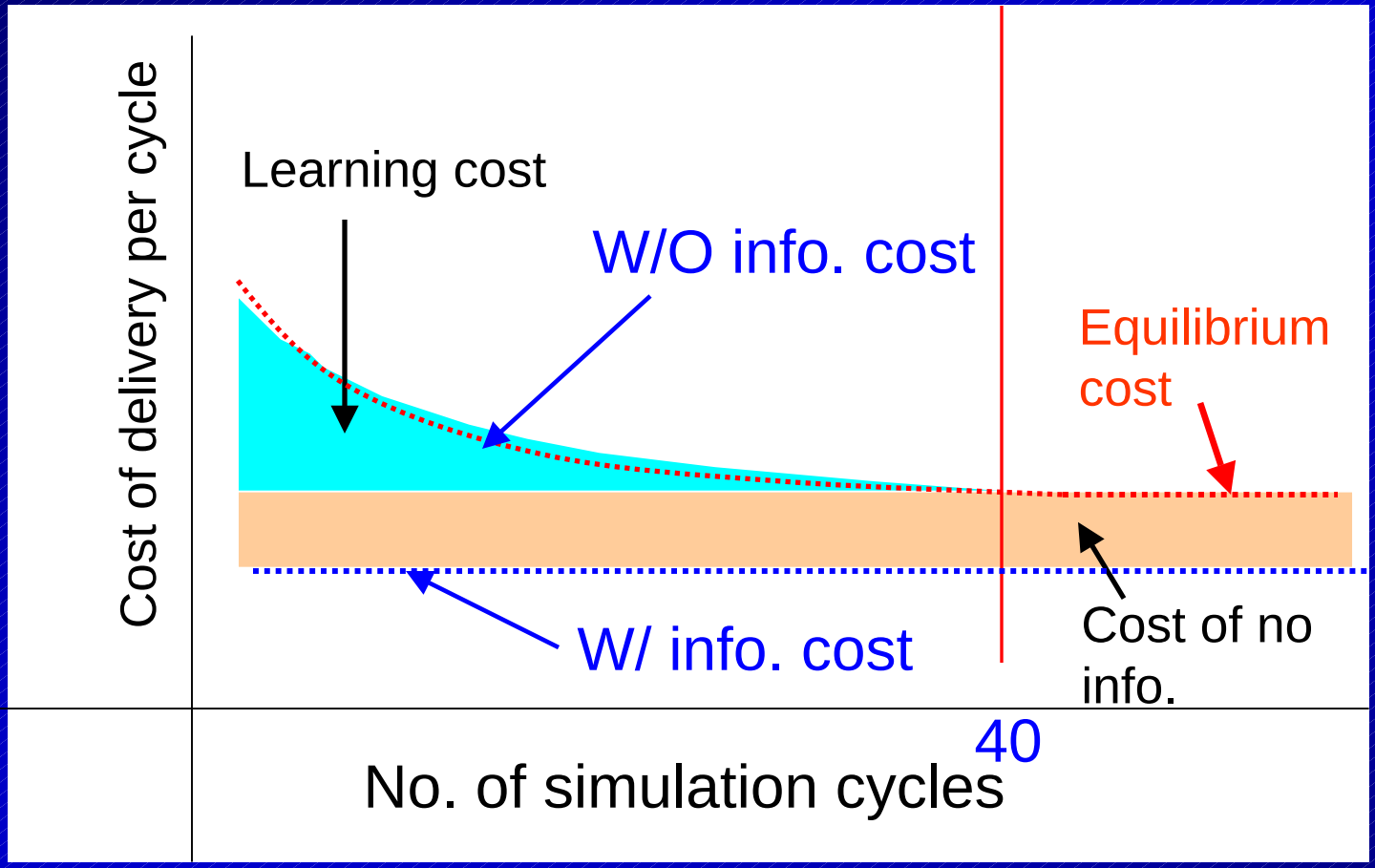








Calculation of costs



$ per mile data from Transport Canada, fuel prices, fuel economy for 2-axle, single unit van

Benefit of Travel Time Information (per tour)

(Avg. of 5 simulation runs)

			Small		Medium		Large	
Scenario	**Median V/C**	**Var. Factor**	**Learning cost**	**Permanent**	**Learning cost**	**Permanent**	**Learning cost**	**Permanent**
1 & 2	0.97	0.5	5.7	13.4	1.7	14.1	2.3	10.0
3 & 4	0.97	0.3	4.0	5.9	1.3	8.3	1.2	7.9
5 & 6	1.21	0.3	7.0	9.8	3.4	6.4	1.1	10.5
7 & 8	0.76	0.3	3.8	11.1	1.6	4.9	1.8	5.8

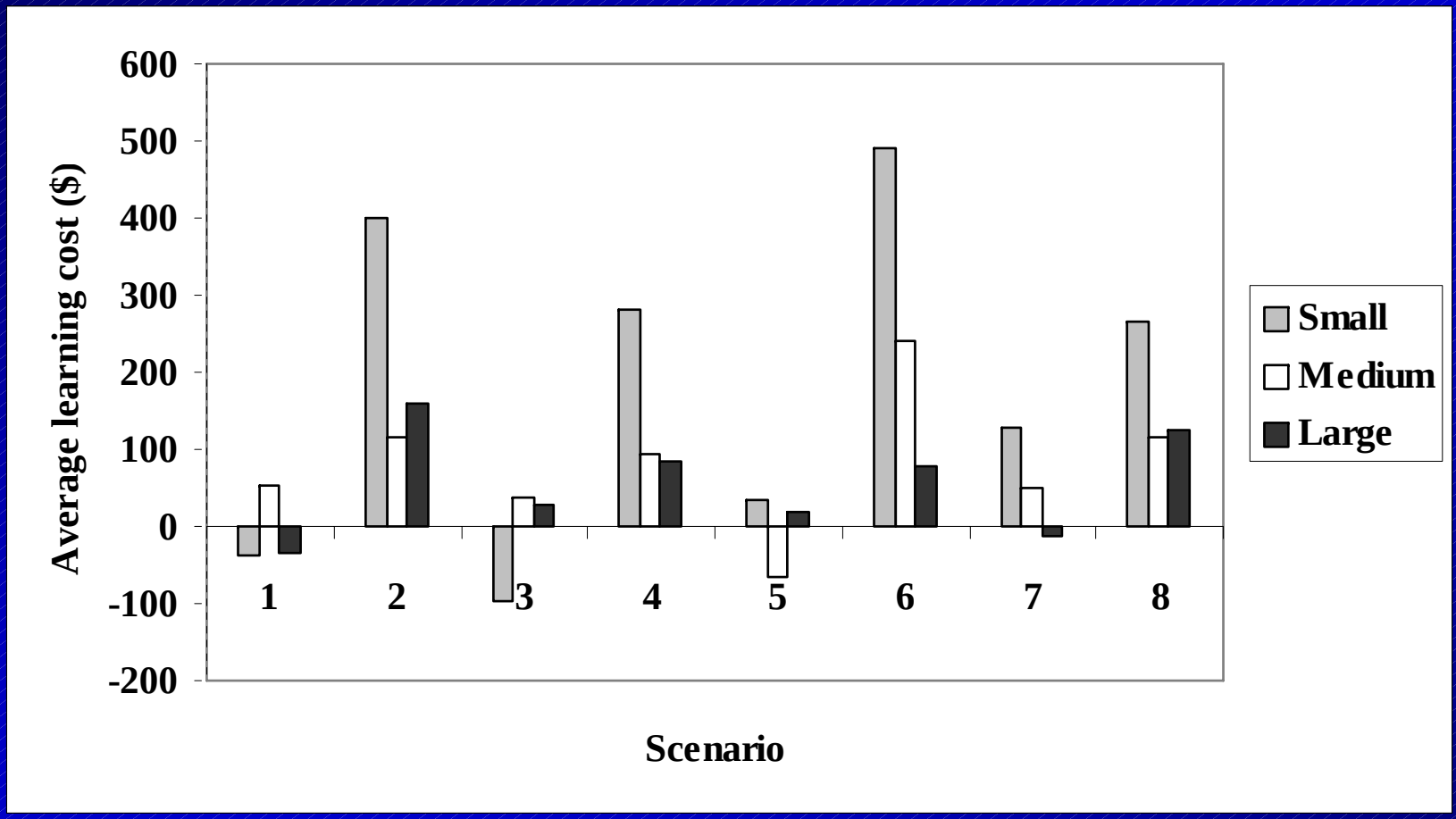
Scenario 1&2 (Moderate congestion, 0.5 variability factor)

Scenario 3&4 (Moderate congestion, 0.3 variability factor)

Scenario 5&6 (Severe congestion, 0.3 variability factor)

Scenario 7&8 (Light congestion, 0.3 variability factor)

Learning Costs Comparisons



Scenario 1&2 (Moderate congestion, 0.5 variability factor)

Scenario 3&4 (Moderate congestion, 0.3 variability factor)

Scenario 5&6 (Severe congestion, 0.3 variability factor)

Scenario 7&8 (Light congestion, 0.3 variability factor)

Conclusions

- Simulation of “learning” traffic conditions was conducted
- Benefit of traffic information increases with the level of congestion & **variability**
- Savings from knowing real link travel time (as opposed to estimating) is often greater than the saving in learning cost
- Without publicly available traffic information…
  - For medium or large firms, learning cost is negligible
  - For small firm, learning cost can be an issue (up to 4.5% of total cost)
- Simulation-to-simulation variability in the benefit is large in some cases

Future work

- Stochastic decision by the trucks
- More simulation runs
- Variations in terminal locations
- Better optimization algorithm
- Simulation of congestion caused by incident
- Larger network
- Real-time (during the tour) updating of traffic data