Agent-Based Modeling in Healthcare Delivery Simulations

A Demonstration Study of Agent-Based Modeling for Predictive Healthcare Delivery Simulations

Steckley & Associates

Introduction

- Proof of concept work demonstrating the kinds of problems that can be studied and results obtain obtained in modeling and simulation of healthcare delivery

- Commissioned by

  Paul Woods, M.D.

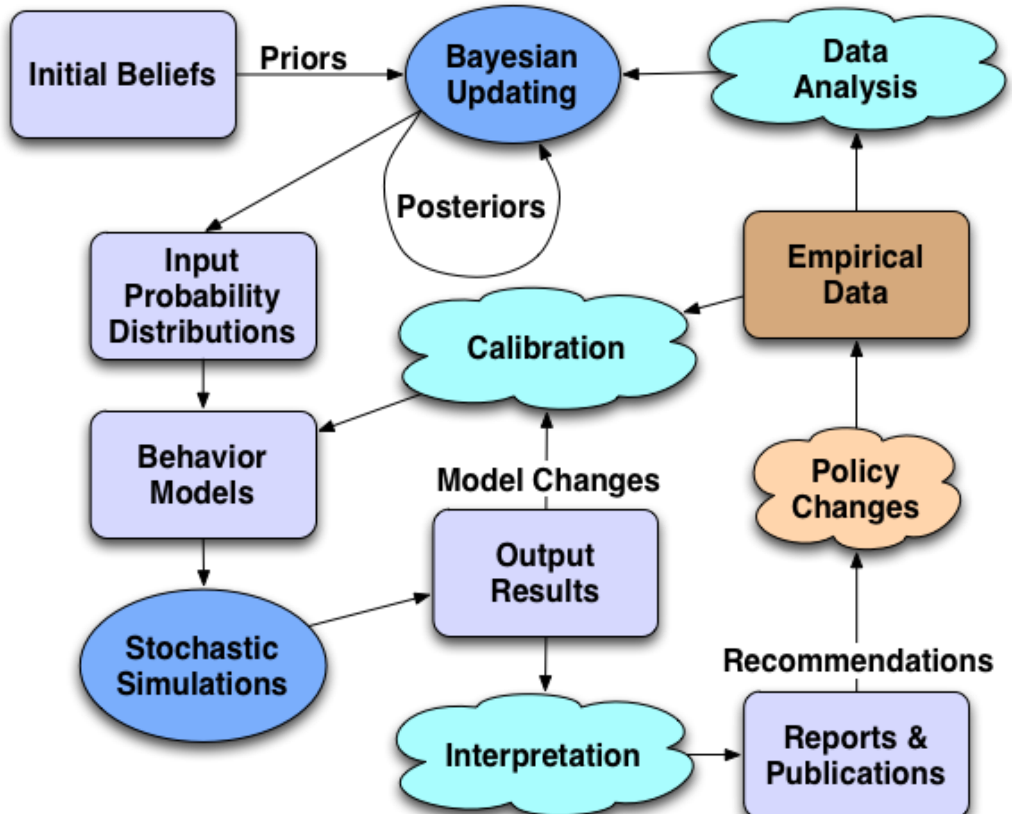
- Department Chief for Primary Care with large integrated health care organization
  - •Non-profit health care delivery system in the Midwest
  - •Operates 11 hospitals and over 60 ambulatory sites
  - •Deals with over 700 providers

Healthcare Delivery is a "Complex System"

- Simple autonomous entities interacting with each other can produce surprisingly complex aggregate behavior
- Alternative "heuristic" modeling approaches can produce incomplete or misleading results
- Better approach: Agent-Based Modeling and Simulation

Continuous Improvement Modeling

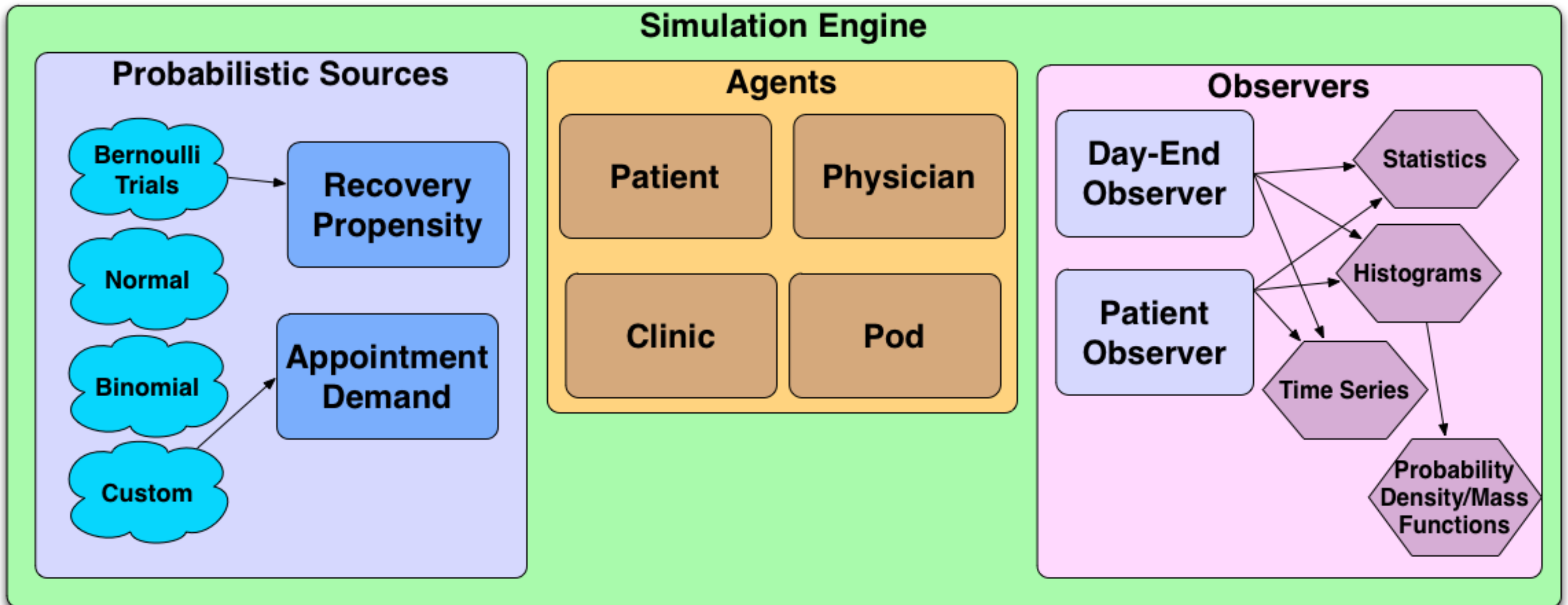
- Agent-Based Modeling and Simulation combined with continuous improvement with real-world data
  - Behavior Models are developed to simulate the key elements of the system
  - Monte Carlo and time history simulations emulate real-world activities
  - Empirical data is used to calibrate and improve input models



Some Proof of Concept Study Results

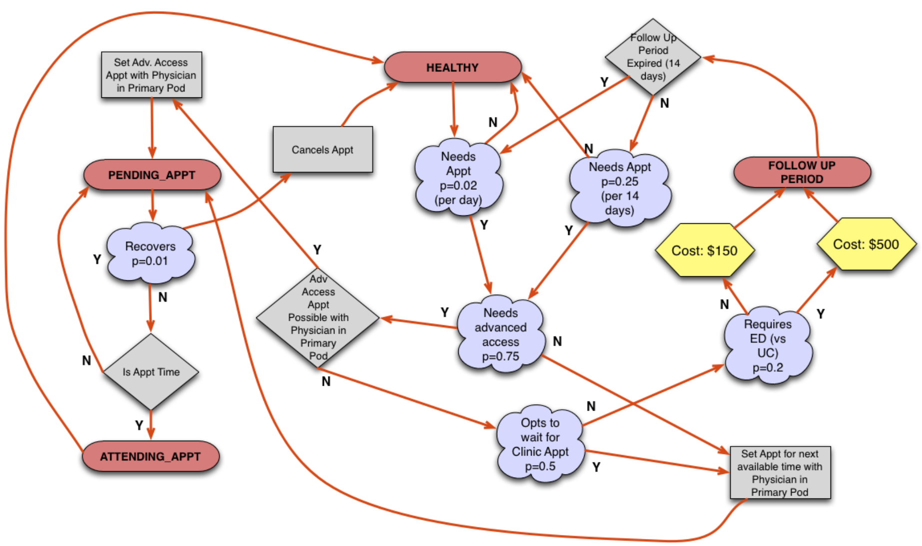
- Developed Simple Behavior Model for Primary Care Facility
  - 12 Physicians, organized in teams from size 1 to 6
  - Varying Patient Panel Size
  - 24 “normal” appointment slots each day, Monday-Friday 8am-4pm
  - 1 “overtime” appointment slot each day per physician
  - Advanced Access ➔ Appointment for same or next day
- Ran Agent-Based Simulations, looking at:
  - Quality of Service for various patient panel sizes
  - Effect of certain model enhancements
  - Effect of physician team size

Simulation Engine Entities

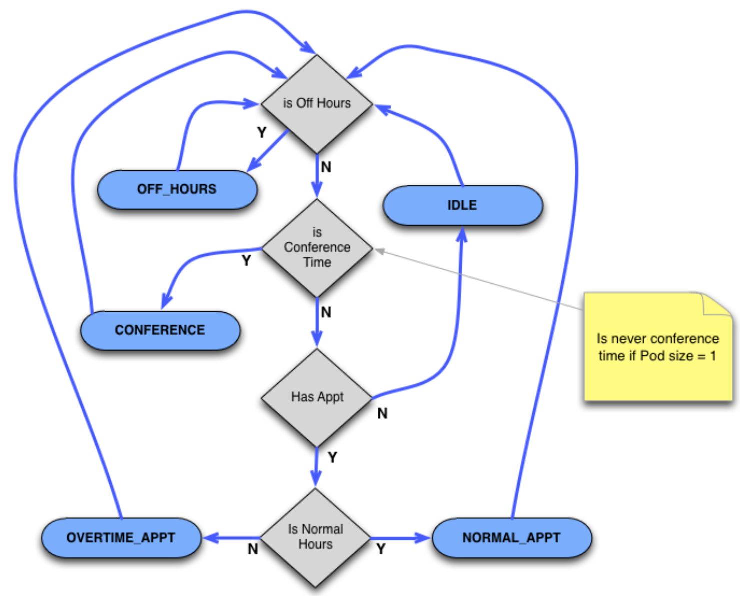


Patients, Physicians, Clinic, and Pods Simulated as Autonomous Agents

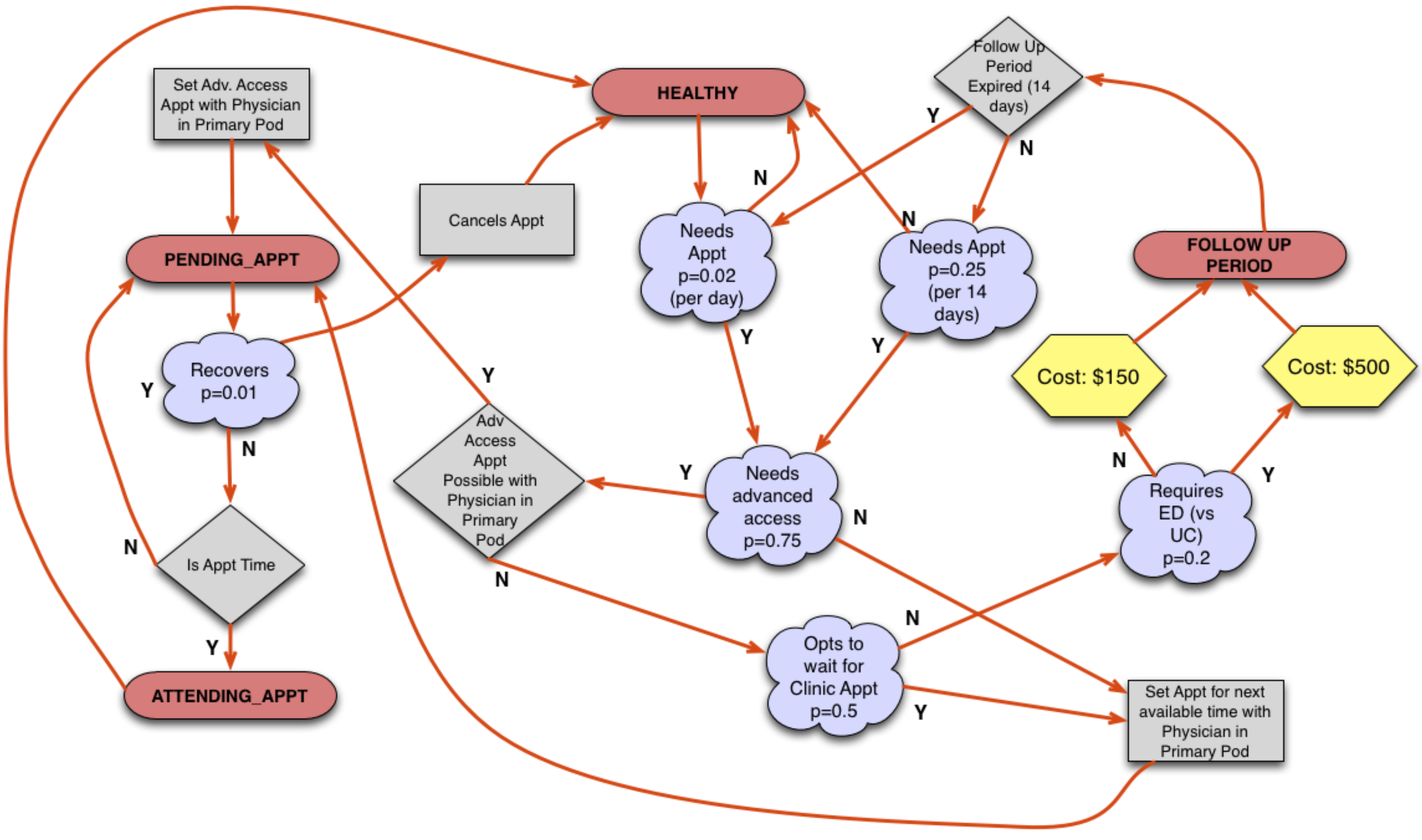
Each Patient Acts at Each Time Step



Each Physician Acts at Each Time Step



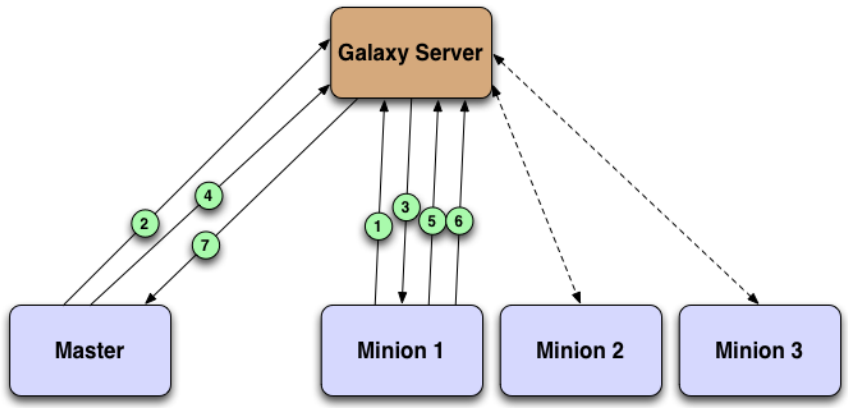
Patient Model



Software System for Distributing Work

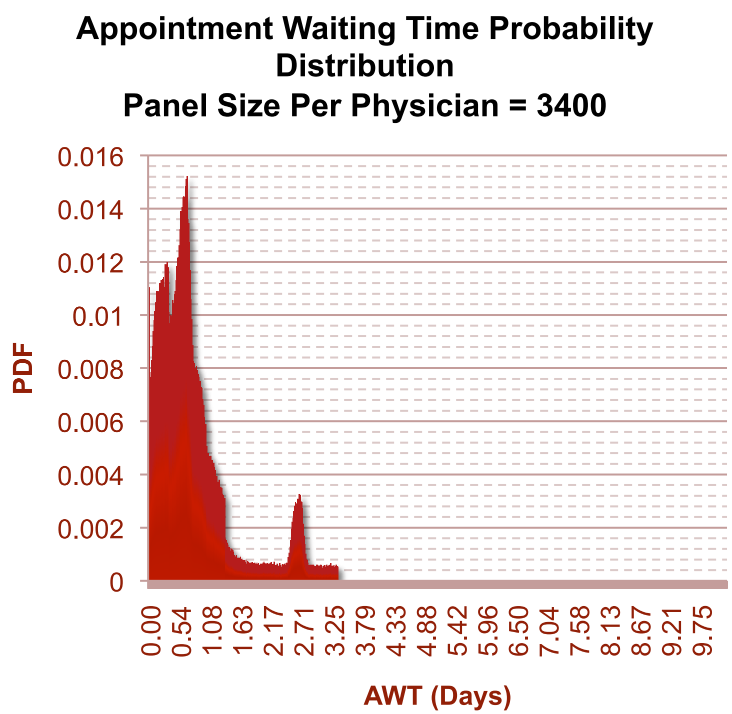
Distributes and Manages
Computations across multiple servers

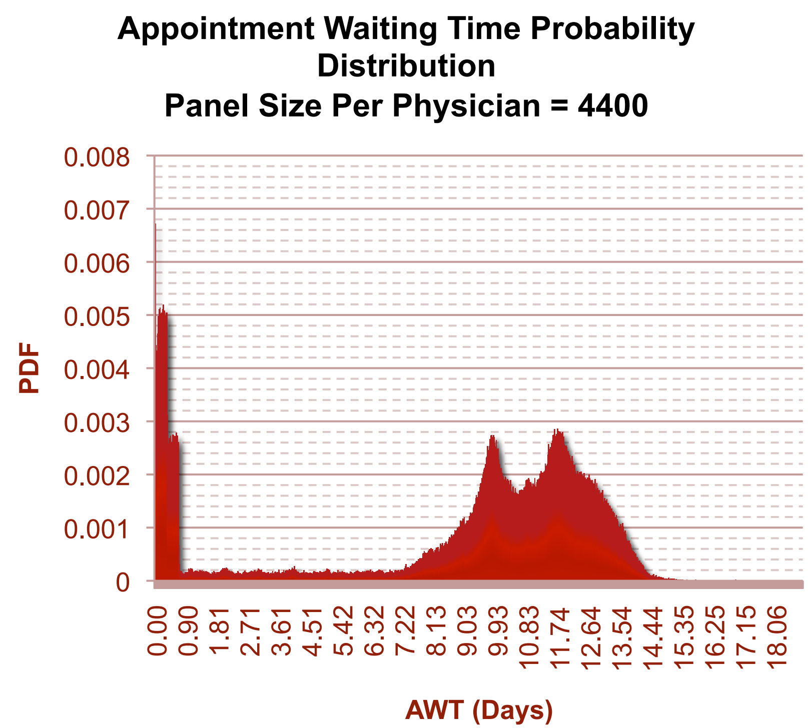
- Masters & Minions
- Coordinated by Central Web Server
- Supports:
  - Straight Time-based Simulations
  - Parametric Studies
  - Monte Carlo Distributions
  - Optimization Analyses
  - Burn-in



Detailed Statistics Can be Gathered

- Agent-Based Simulations produce detailed statistical observations on numerous system attributes

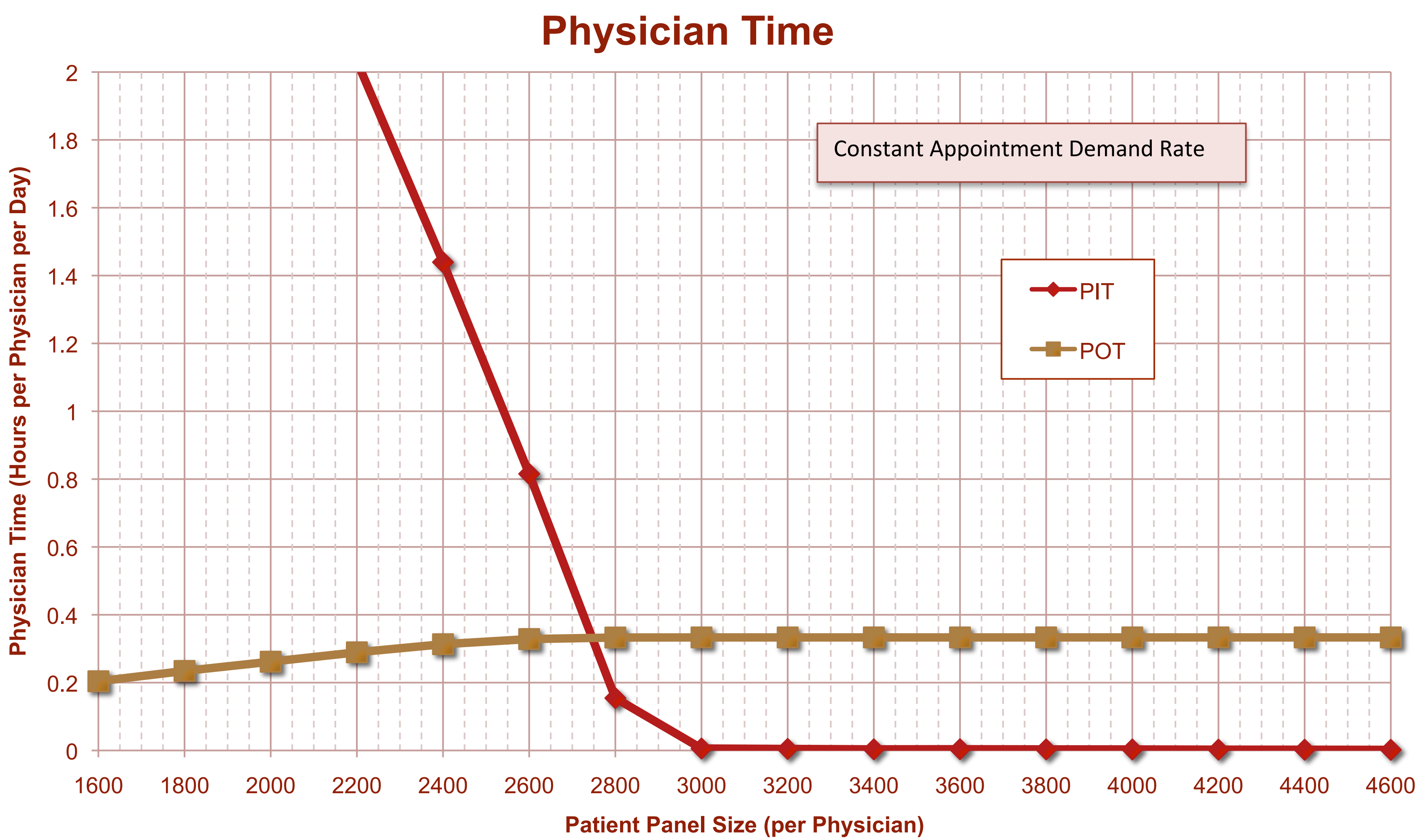




Competing "Quality of System" Measures

- (AWT) Appointment Waiting Time
  - Time between appointment request and delivery
- (AAU) Advanced Access Unmet
  - Number of Advanced Access appointments requested, but not able to be delivered (scheduled out further than a day)
- (PIT) Physician Idle Time
  - Time during normal office hours that Physician has no appointment scheduled
- (POT) Physician Overtime
  - Time above the 8 normal office hours each day required to fulfill appointments

Physician Time by Panel Size



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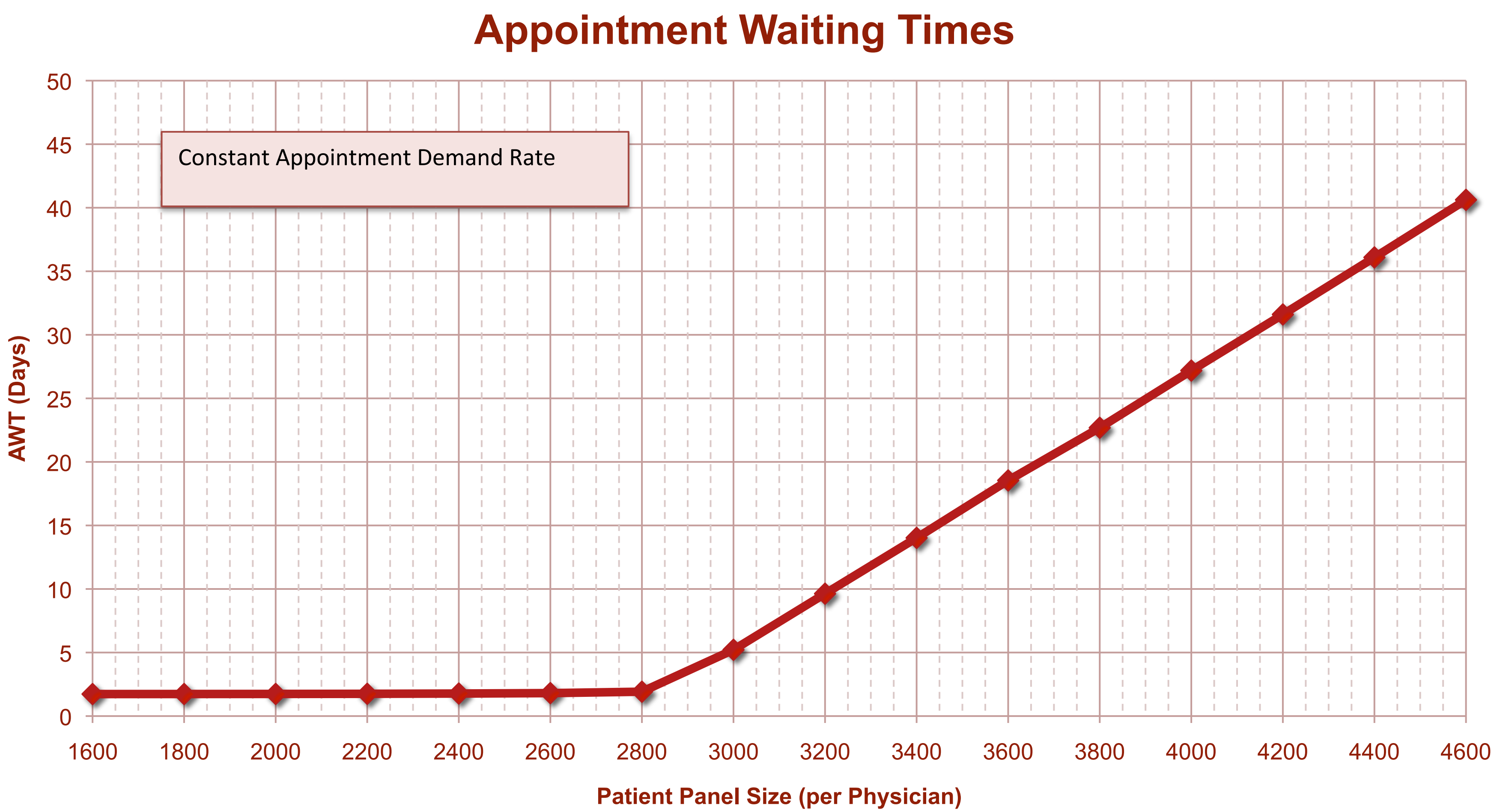
Appointment Waiting Times by Panel Size



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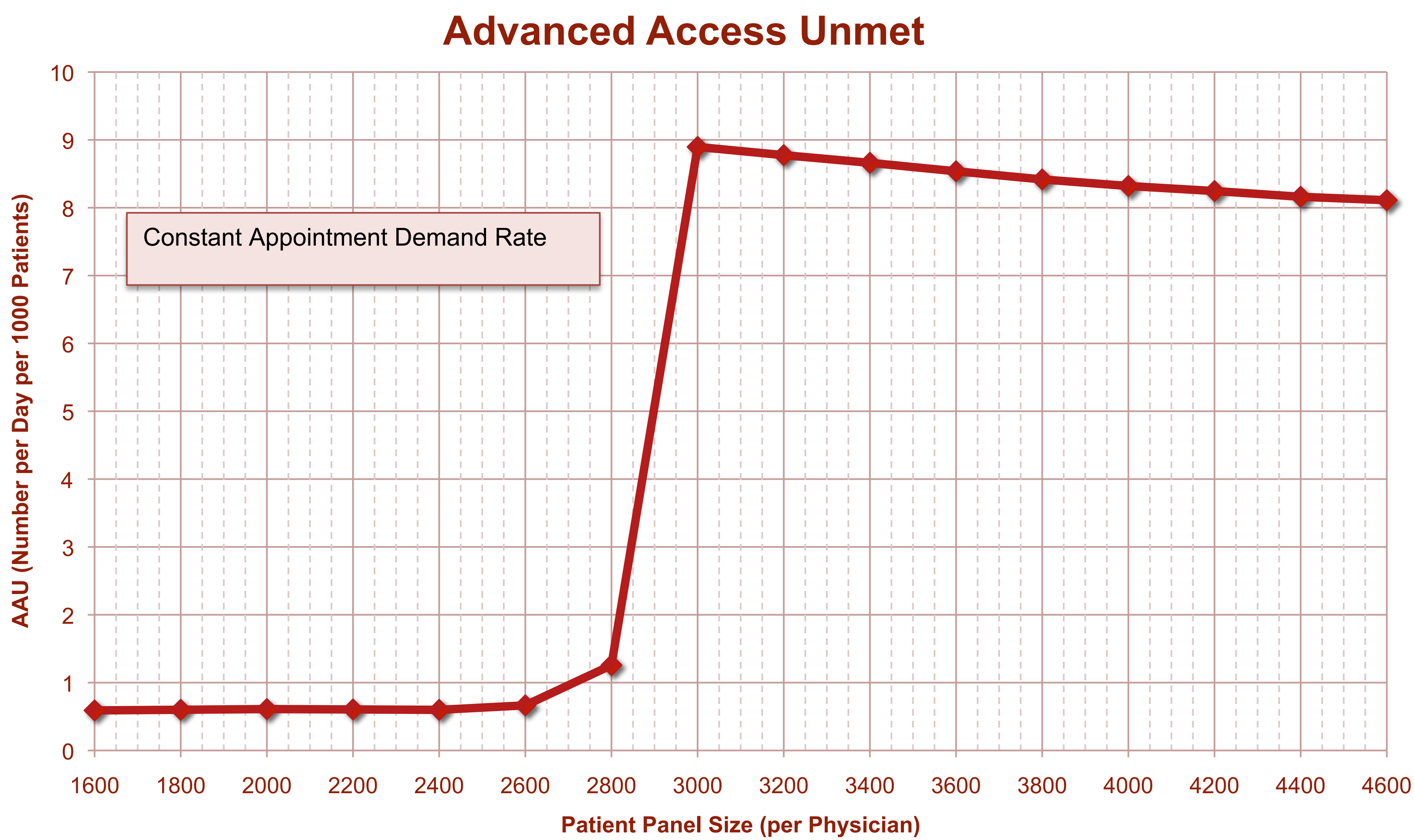
Advanced Access Unmet by Panel Size



What is Optimal Panel Size?

- Trade-offs between competing Quality of System measures

$$QoS = \frac{1}{1 + A \cdot AWT + B \cdot AAU + C \cdot PIT + D \cdot POT}$$

where A, B, C, D are relative weighting factors

- Wish to maximize QoS

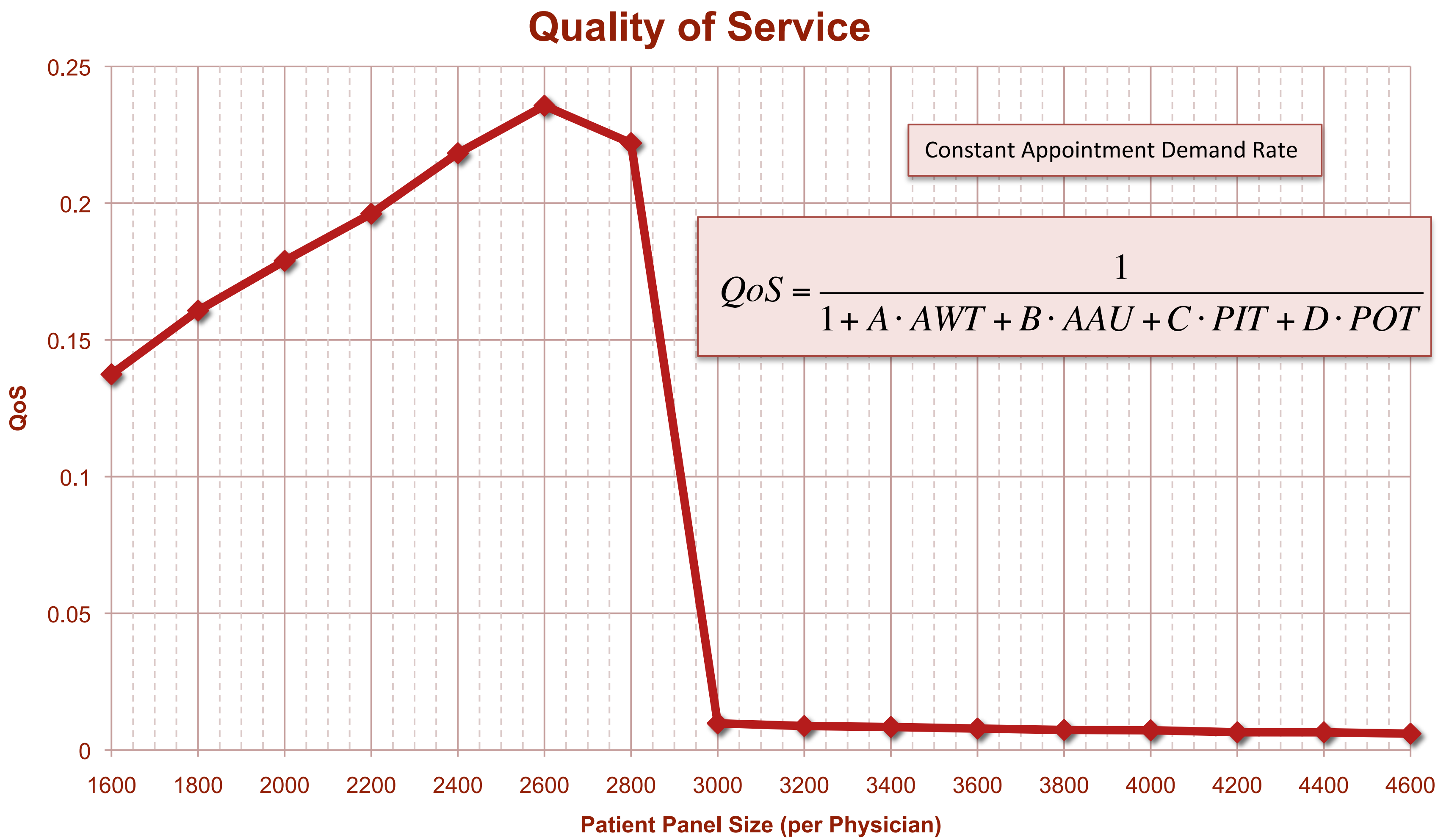
- Answering the panel size question requires first determining appropriate weighting factors A, B, C, D

Quantification of Quality

- Consider ALL Stakeholders
- Tally the "value" of each quality measure to each stakeholder
- In practice, consider "classes" of stakeholders and evaluate vicariously

	Performance Metric											
	AWT			AAU			PIT			POT		
Survey Question	How much would you pay to avoid patient waiting 1 day extra for appointment?			How much would you pay to ensure patient gets Advanced Access appointment?			How much would you pay to avoid physician having 1 hour of idle appointment time?			How much would you pay to avoid physician doing 1 hour of overtime?		
Stakeholder	**Amount**	**# Agents**	**Total**	**Amount**	**# Agents**	**Total**	**Amount**	**# Agents**	**Total**	**Amount**	**# Agents**	**Total**
Physician Directly Impacted							$10.00	1	$10.00	$80.00	1	$80.00
Physician Indirectly Impacted	$3.00	10	$30.00	$5.00	10	$50.00	$15.00	9	$135.00	$30.00	9	$270.00
Patient Directly Impacted	$5.00	1	$5.00	$20.00	1	$20.00						
Patient Indirectly Impacted	$0.01	(N-1)	(N-1)*$0.01	$0.10	(N-1)	(N-1)*$0.1	$0.05	N	N*$0.05	$0.25	N	N*$0.25
Clinic Mngmt. Directly Impacted												
Clinic Mngmt. Indirectly Impacted	$2.00	1	$2.00	$10.00	1	$10.00	$30.00	1	$30.00	$60.00	1	$60.00
TOTAL	(N-1)*$0.01 +$37.00			(N-1)*$0.1 +$80.00			N*$0.05 +$175.00			N*$0.25 +$410.00		

"Optimal" Panel Size

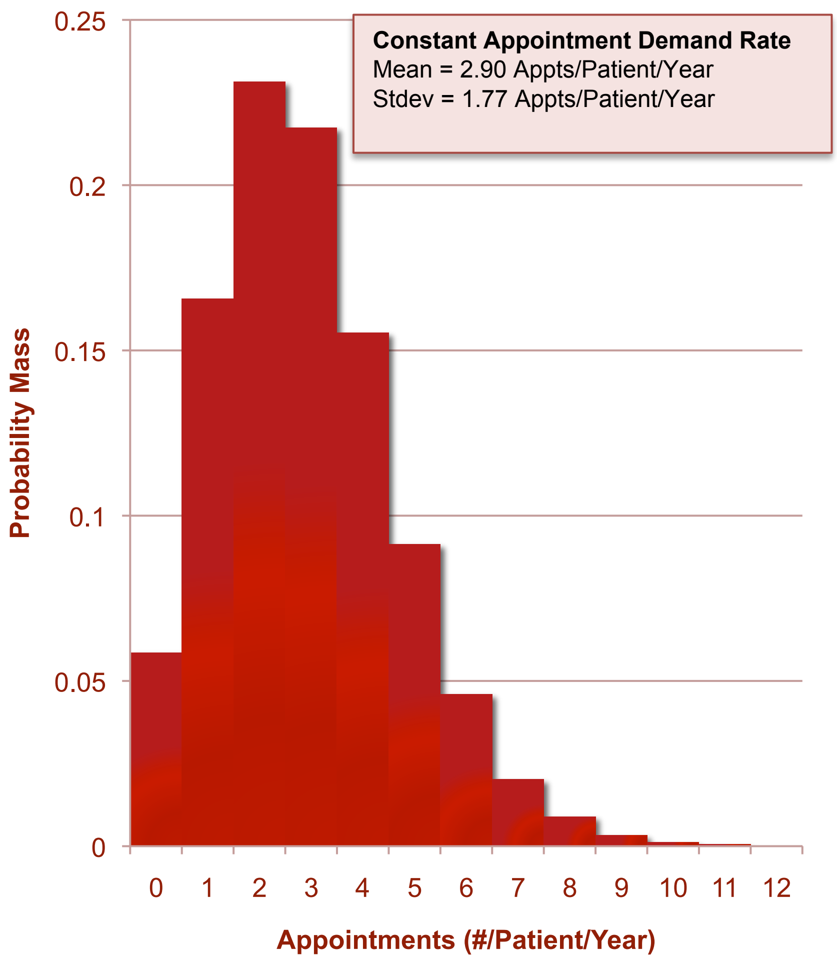


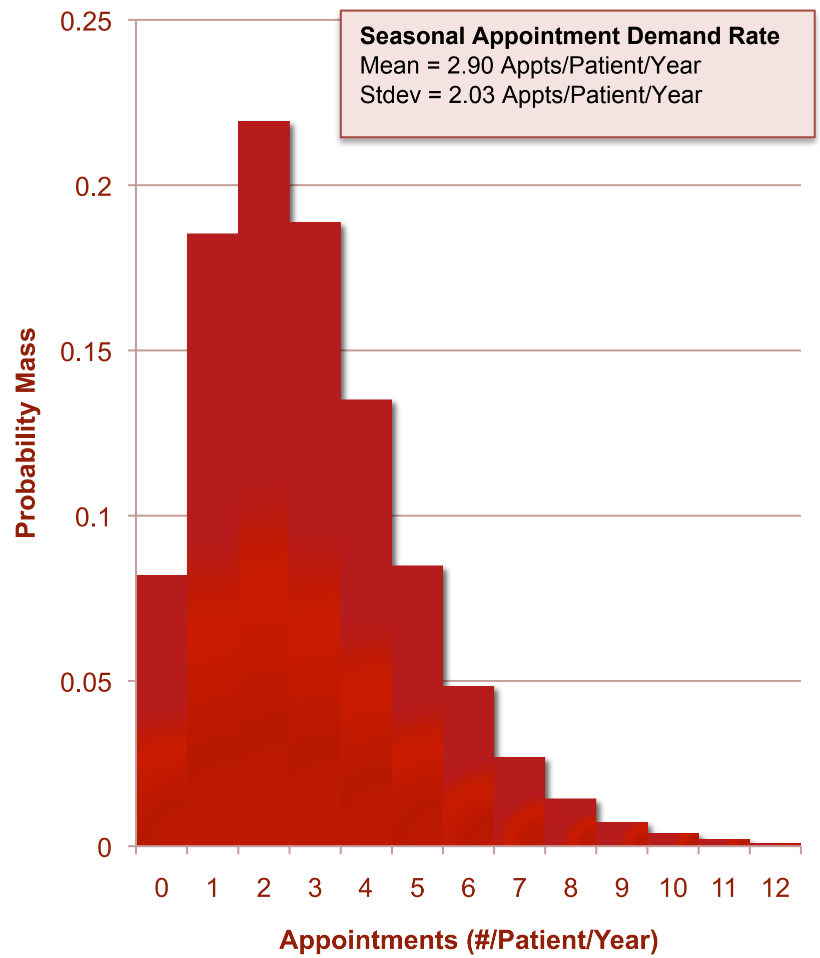
$$QoS = \frac{1}{1 + A \cdot AWT + B \cdot AAU + C \cdot PIT + D \cdot POT}$$

Introducing Seasonal Variation in Appointment Demand Rate

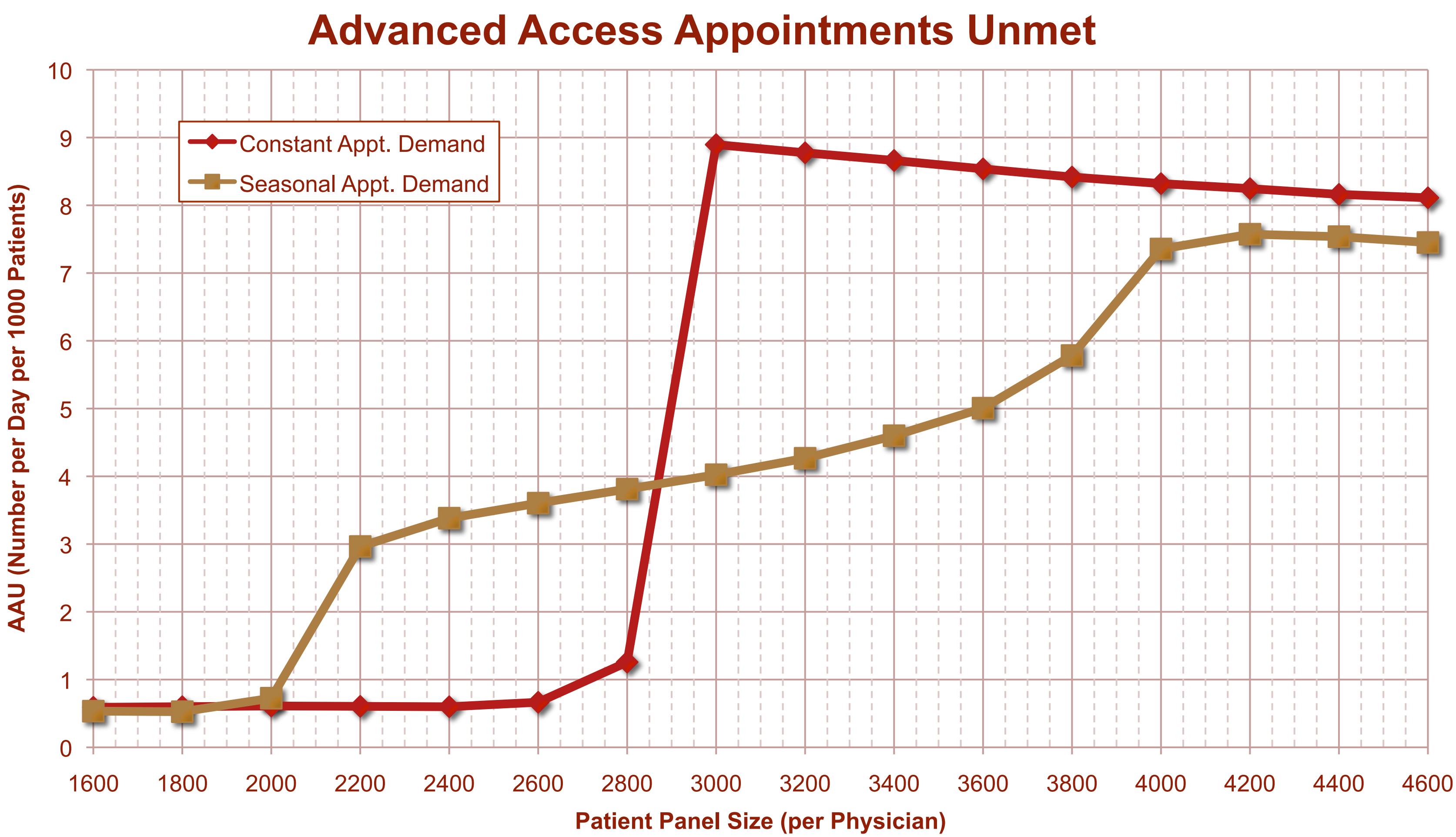
- Previous Behavior Model simulated appointment demand as a constant probability on all days
- Modify Behavior Model to simulate seasonal variation:
  - Higher demand rate during "winter" months (Dec, Jan, Feb)
  - Shift probability of appointments from summer to winter
  - Keeping same long term appointment demand rate

Both Models Simulate Similar Annual Appointment Demands



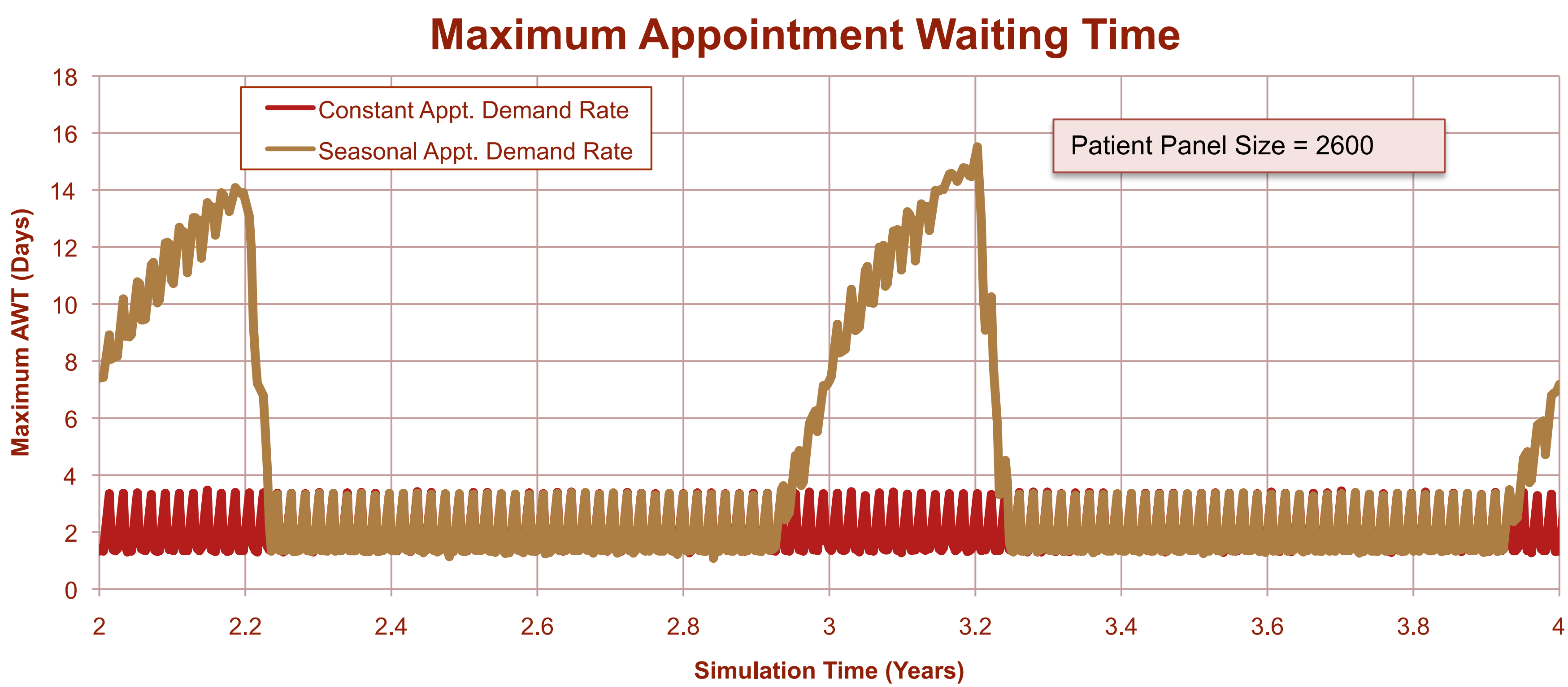


But Dramatically Different Results



Agent-Based Modeling reveals "Details"

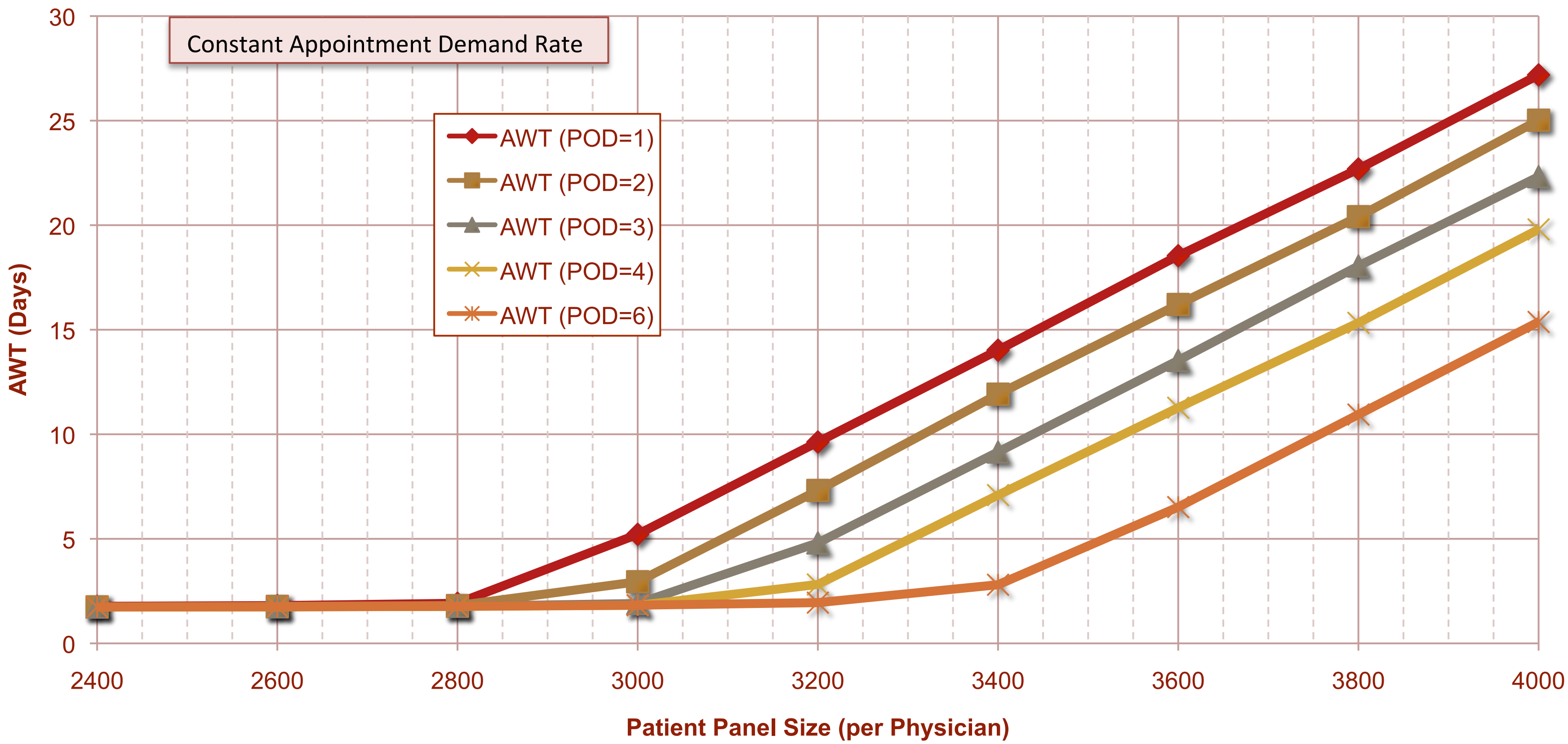
- Agent-Based Modeling can reveal complex behavior patterns over time that is lost when applying a more heuristic modeling approach



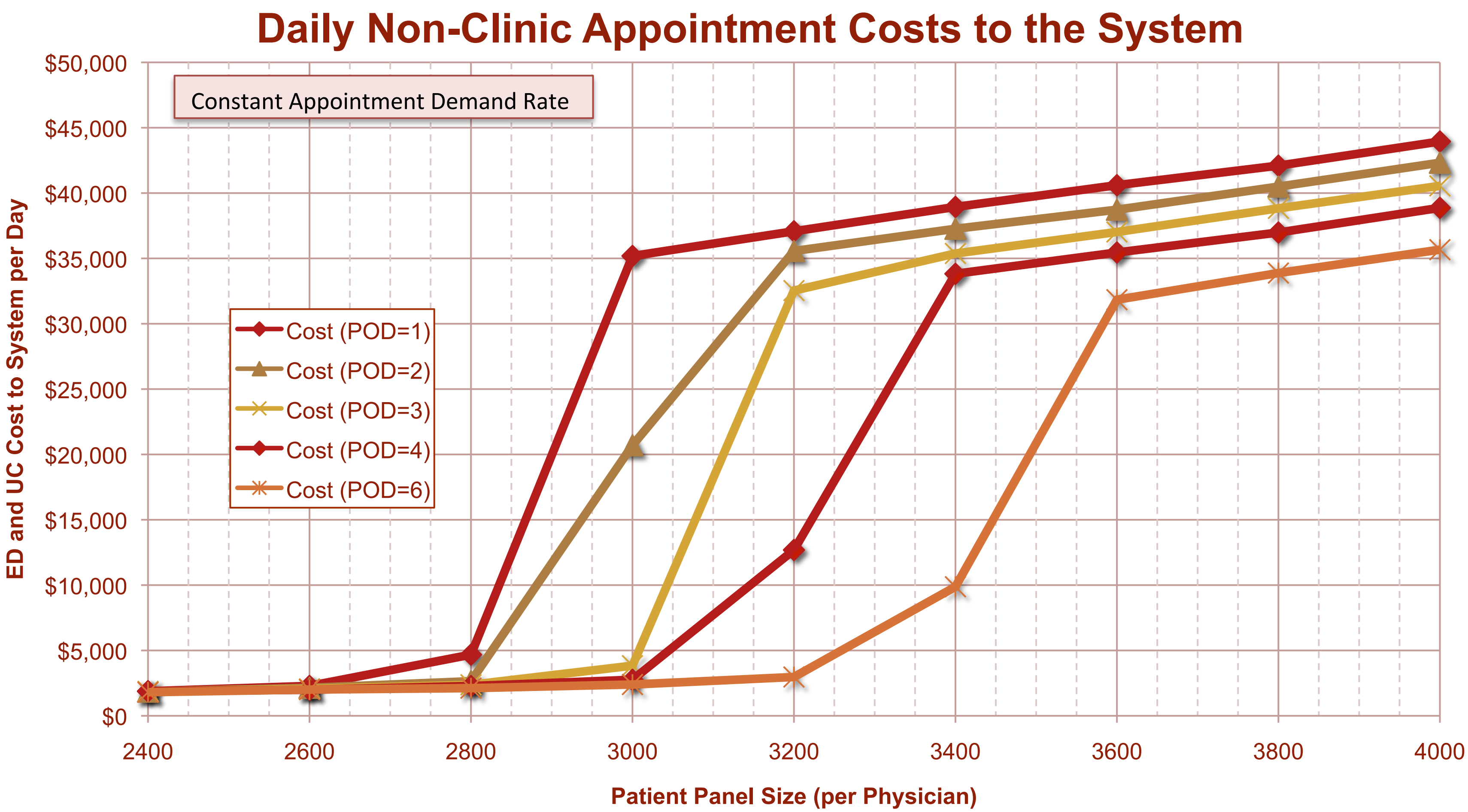
Introducing Team-Based Care via “Pods”

- Each patient has a primary team or “Pod” of physicians
- Each day, one physician in the pod is responsible for all overtime appointments
- Physicians within pod take turns doing overtime
  - Physician in pod of size 3, is responsible for up to 3 overtime appointments every third day

Appointment Waiting Times



Costs to the Overall System Due to ED and UC Visits



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What we've learned

- When patient panel size is less than critical value, the clinic is able to keep up just fine.
  - Patients are served, but daily fluctuations in demand result in trade-offs between physician idle-time and physician overtime
- When patient panel size exceeds critical value, clinic never catches up → advance appointments are unmet, waiting times increase, ED/UC costs increase
  - Avoiding this can save the system up to $30,000 per day
- Longer-term (seasonal) variations in demand cause the optimal panel size to be a moving target
- Team-based Pods can increase the patient capacity of the clinic and reduce overall system costs

An Operational Policy to Study

- Pods can help absorb the short-term (daily) fluctuations in appointment demand
- Effect of longer-term (seasonal) variations in appointment demand governed by clinic resources (available appointments, physicians)
- Suggests a combination of varying office-hours during year AND using team-based physician pods

Longer winter office-hours + Pod size=2

may result in better quality and performance than

Pod size=3

Heuristic Vs. Agent-Based Modeling

- Agent-Based Modeling allows one to model details that would be impractical to include in an heuristic analysis
- Can generate statistics and time histories for numerous attributes of interest
- Simulated time histories can reveal complex and surprising behaviors before real-world policy changes are tried
- Effects of small changes in system or environment can be modeled (e.g. What happens if there is flu epidemic this season?)
- Sensitivity of results to uncertain input assumptions can be modeled (e.g. What if our guess for recovery rates is too low?)
- Implications of newly obtained empirical observations can be assessed (e.g. Should this new data be used to modify our models?)
- Models of a system can be simple or very detailed depending on one's knowledge of component factors and on empirical data available

Agent-Based Modeling Also Requires Great Care !

- Development of effective behavior models requires expert knowledge and keen sense of "what is important"
- Models for autonomous agents can model internally consistent, but unrealistic, behavior just as easily as they can model actual real-world behavior
- Models need to be kept <u>as simple as possible while still capturing any essential behavior that governs the problem at hand</u>
- Calibrations against empirical data, sanity checks, and expert intuition all play significant roles

Contact Informaton

Andrew Steckley, PhD
Steckley & Associates
Vancouver, WA
asteckley@asteckley.com
(360)-713-3907