A Bottom-up Simulation Method to Quantitatively Predict Integrated Care System Performance

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Motivation

1

Prediction, explanation & optimization are challenging for a *complex system* like *Integrated Care system*.

For example, **healthcare operations management**, for which we want to:

Predict system performance for a specific configuration, cost and benefit for a proposed change.

Explain factors influencing performance, how the prediction is made and why it performs like this.

Optimize changes to the system with constrain like budget.

2

1. A **platform** to study healthcare system related problems, like bacteria propagation. (e.g., MRSA infection).
2. To study disordered system behavior based on integration of first-principles model and data-driven model (real operation data). *Every decision we make is based on information, stop guess.*

The way to achieve to goal:

First-principles modeling to capture details of system behavior from the interaction of system components.

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The way to achieve to goal:

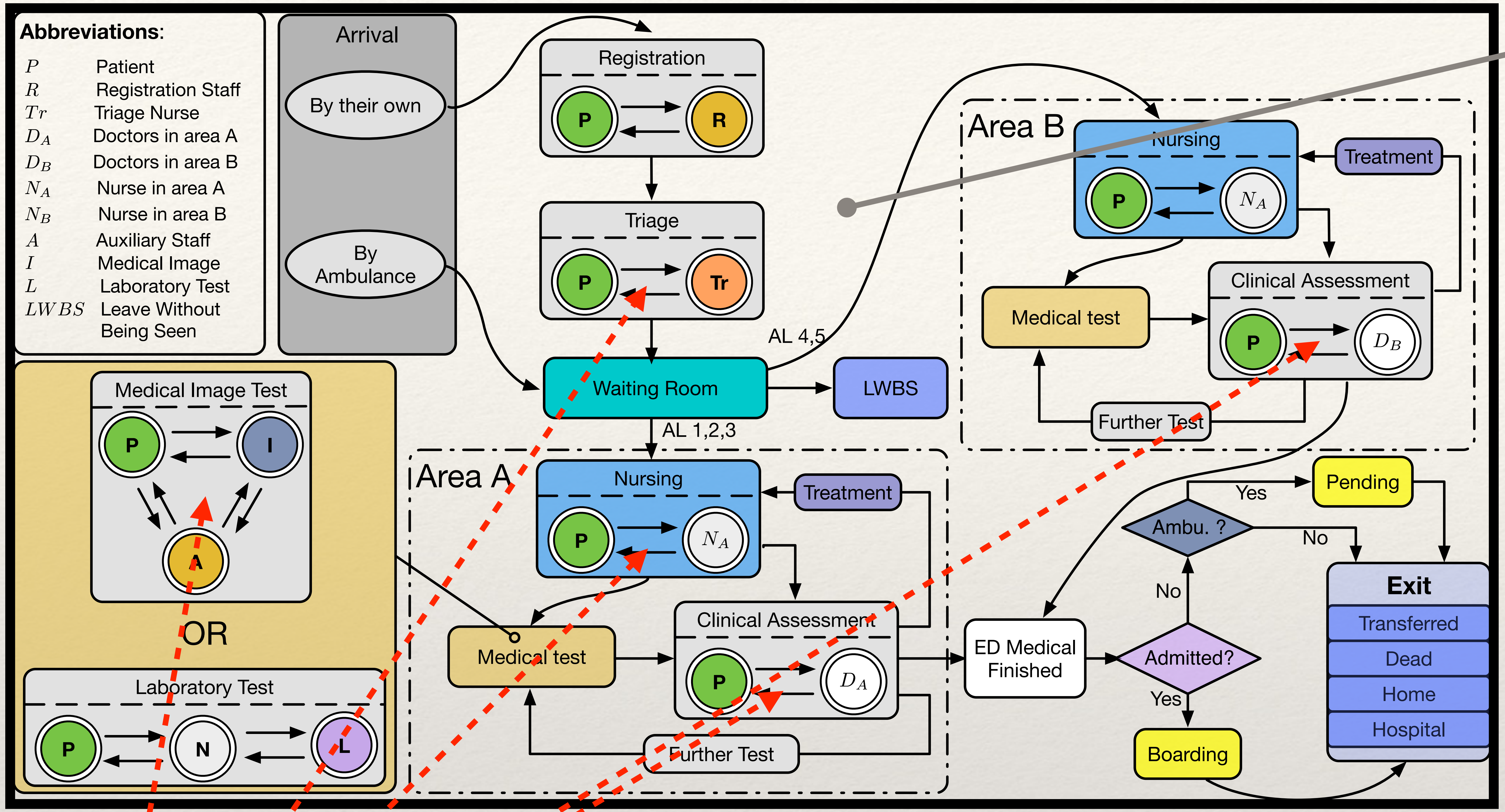
First-principles modeling to capture details of system behavior from the interaction of system components. **Start with simulating the emergency departments.**

My Agenda

- Introduction
- The Emergency Department Simulator
- Use of the Simulator
- Model Parameters Calibration Tool
- Demo applications
- Conclusion and Future work

How it works (Rules + State Variables => state)

Conceptual Model

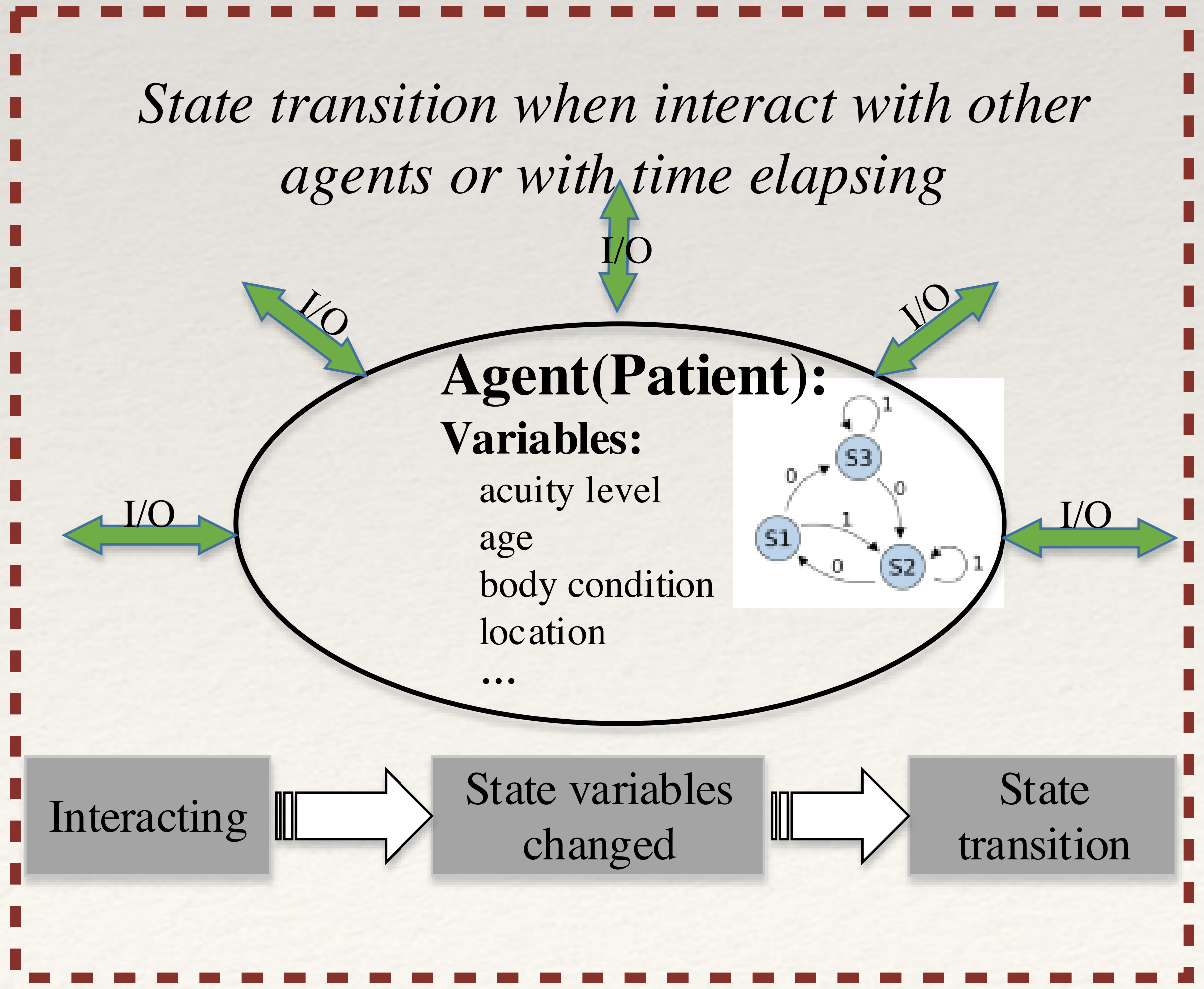


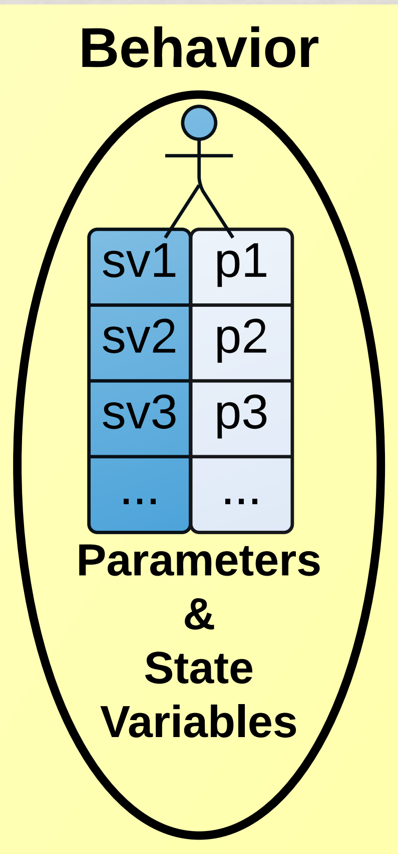
Interaction

emulate the **system behavior**

via

mimic **individual's behavior**

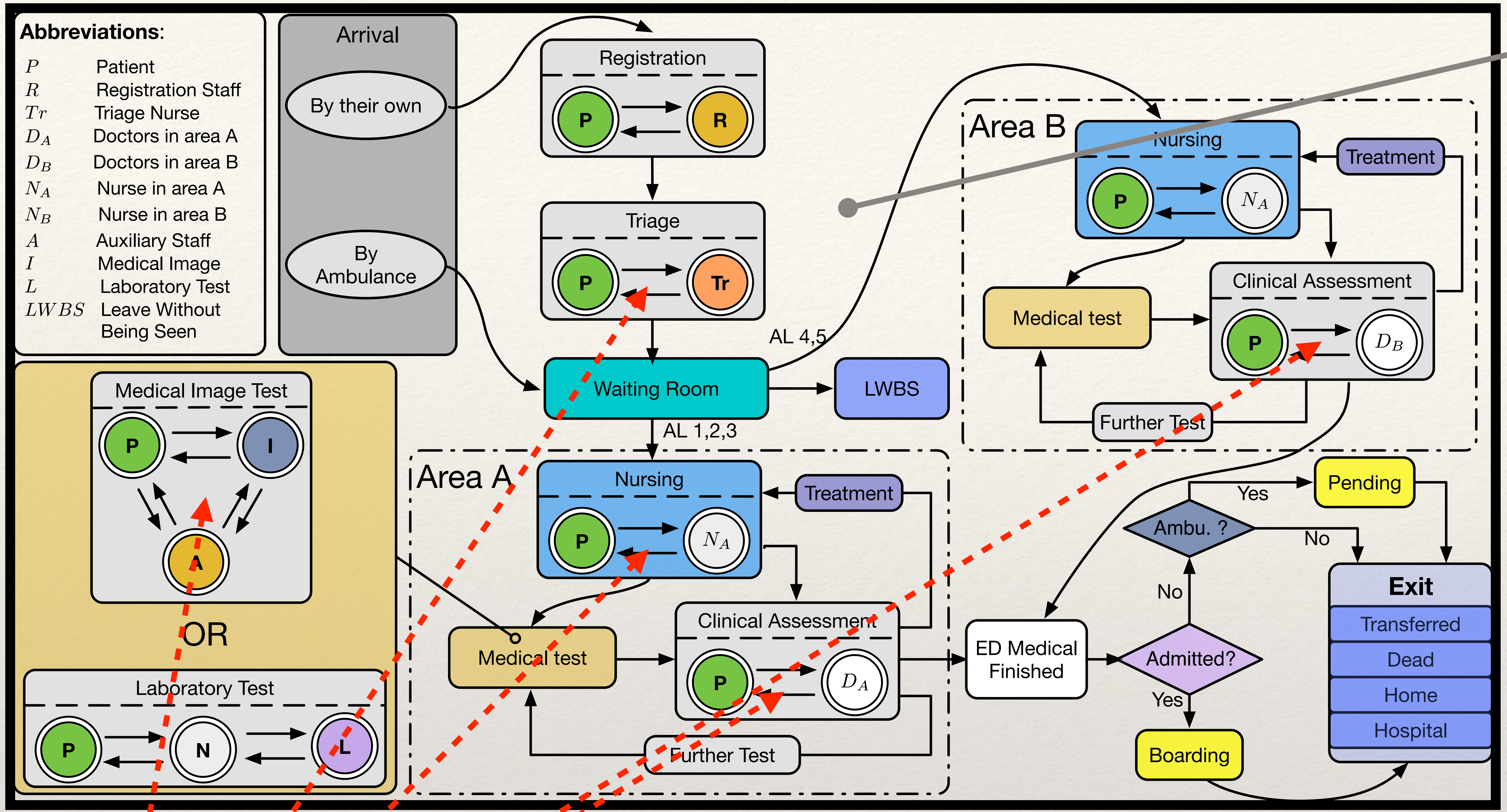




Note: Every patient who comes through the door is an unknown, with a condition that unfolds over time in a functionally non-deterministic way. Theoretically speaking, **no two paths through this "system" are the same for any two patients**.

How it works (Rules + State Variables => state)

Conceptual Model



First-Principle Models

They are not as quick and easy to build, but they have many advantages. In terms of simulation, first-principle models provide **extrapolation in addition to the interpolation provided by data-driven models**. They also can be used for **prediction**, **explanation** and **optimization**.

Interaction

emulate the **system behavior**

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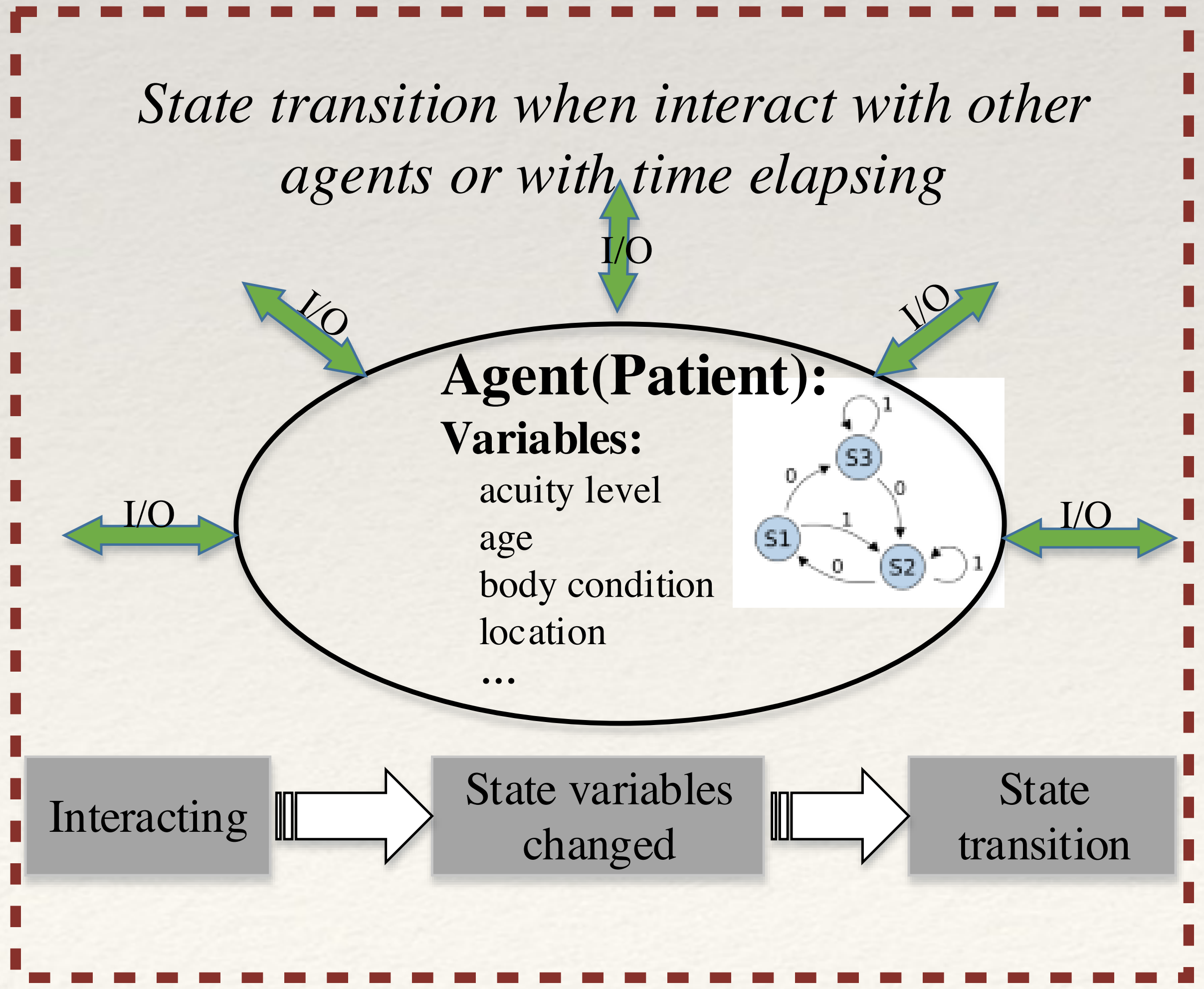
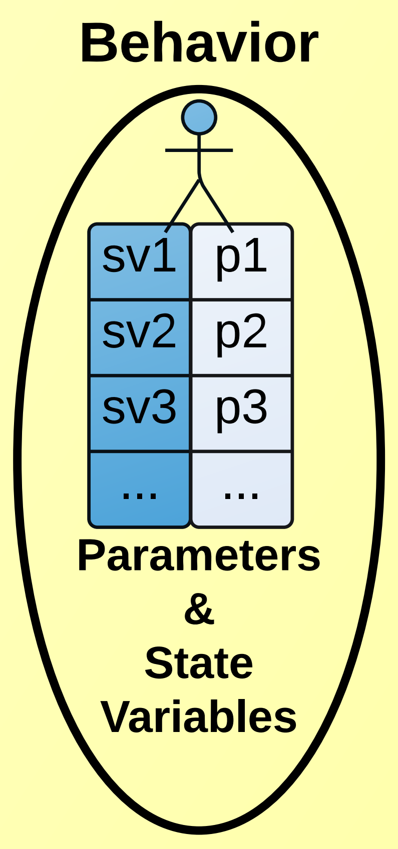




Note: Every patient who comes through the door is an unknown, with a condition that unfolds over time in a functionally non-deterministic way. Theoretically speaking, **no two paths through this "system" are the same for any two patients**.

How it works? - Simulation Input Organization

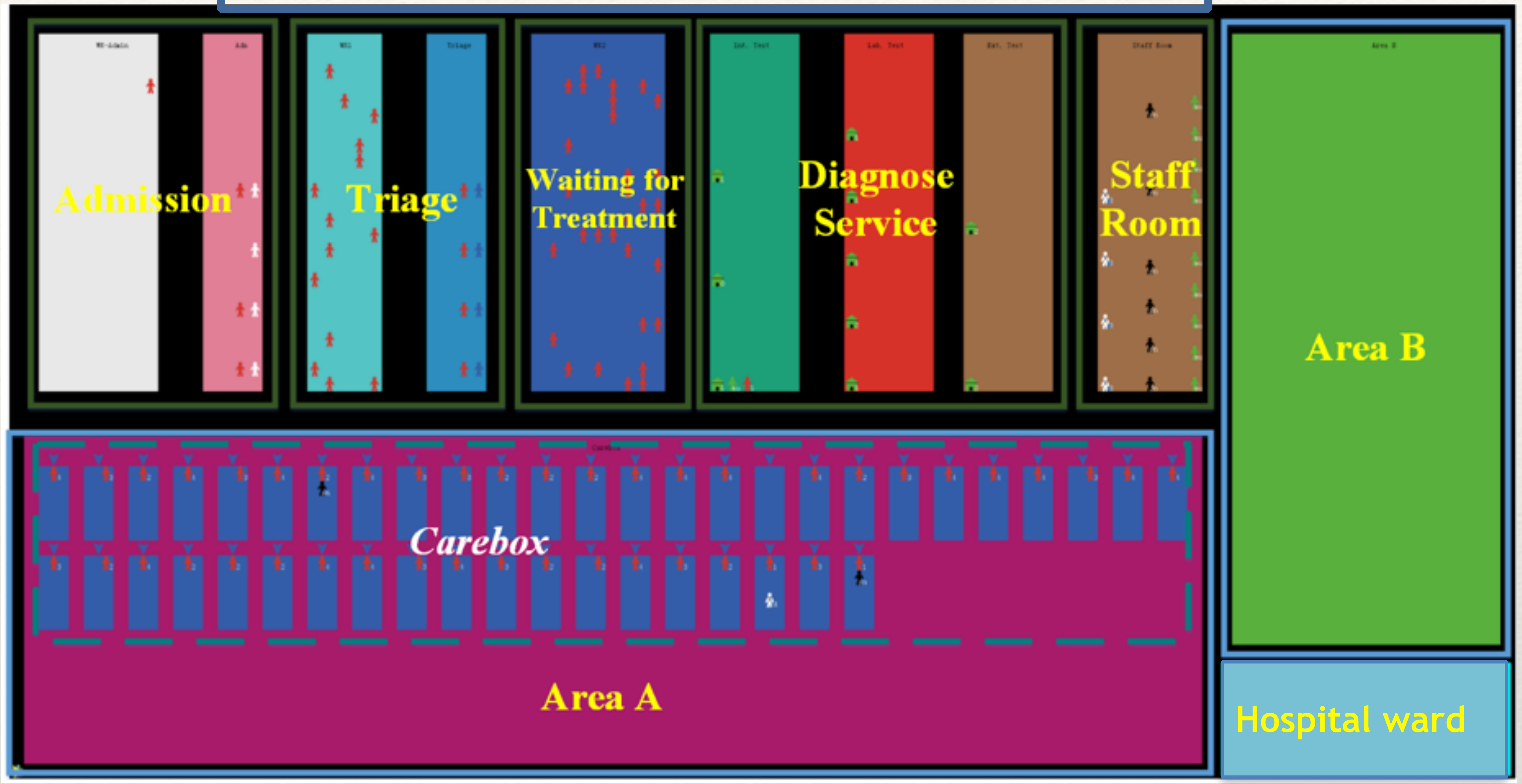
configuration

- ✓admission staff
- ✓triage nurse
- ✓nurse
- ✓doctor
- ✓auxiliary
- ✓carebox
- ✓laboratory test
- ✓internal test
- ✓external test
- ✓hospital ward
- ✓ambulance.
- ✓…

patient(input)

scenario

Two areas: A and B for different patients



Version 2.0

CTAS: 1 → 5

Patient:

Scenario = ED-Model-Configuration + Input (Patient)

CTAS: Canadian Triage and Acuity Scale

How it works? - Simulation Input Organization

configuration

- ✓admission staff
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- ✓nurse
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- ✓auxiliary
- ✓carebox
- ✓laboratory test
- ✓internal test
- ✓external test
- ✓hospital ward
- ✓ambulance.
- ✓...

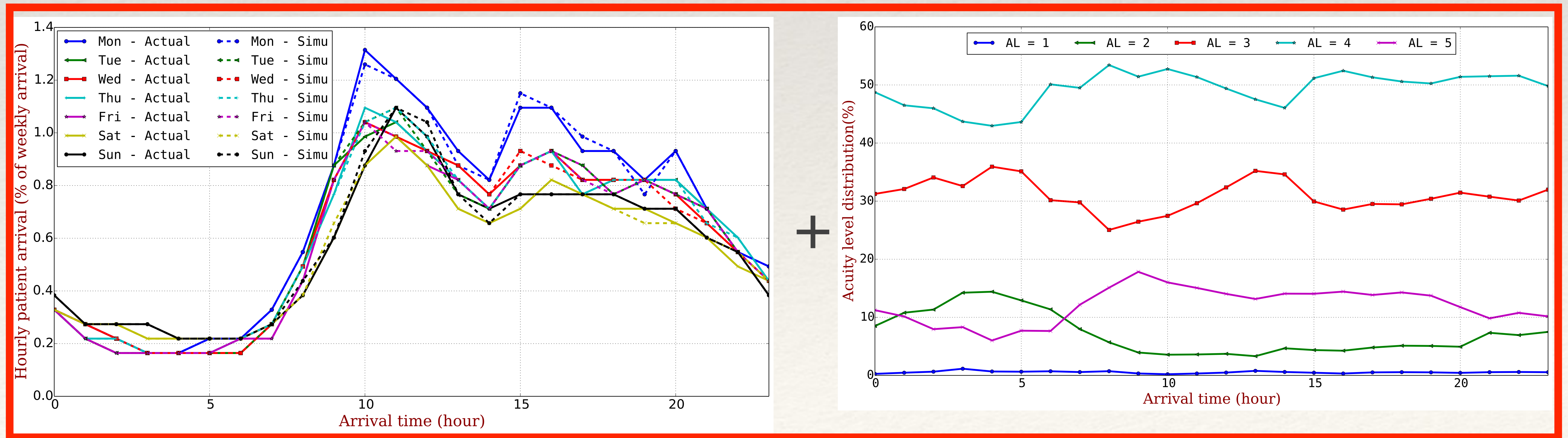
patient(input)

scenario

Resource	Capacity (#) day	Capacity (#) night	Avg. Attention Time (AT, minutes) first interaction	Avg. Attention Time (AT, minutes) follow-up	AT Distributic
junior admission staff	3	2	5		Gamma
senior admission staff	2	0	3		Gamma
junior triage nurse	3	1	8		Gamma
senior triage nurse	2	1	6		Gamma
junior doctor in area A	2		20	15	exponential
senior doctor in area A	4		15	13	exponential
junior nurse in area A	5		25	18	exponential
senior nurse in area A	5		20	14	exponential
junior doctor in area B	2		8	7	exponential
senior doctor in area B	5		6	5	exponential
junior nurse in area B	4		11	7	exponential
senior nurse in area B	4		7	5	exponential
medical imaging test room	5	2	45		Beta
laboratory test place	4	2	30		Beta
carebox in area A	50		-		-
chair in area B	60		-		-
auxiliary nursing staff	3		15		exponential

Should Execute Many Times for One Scenario

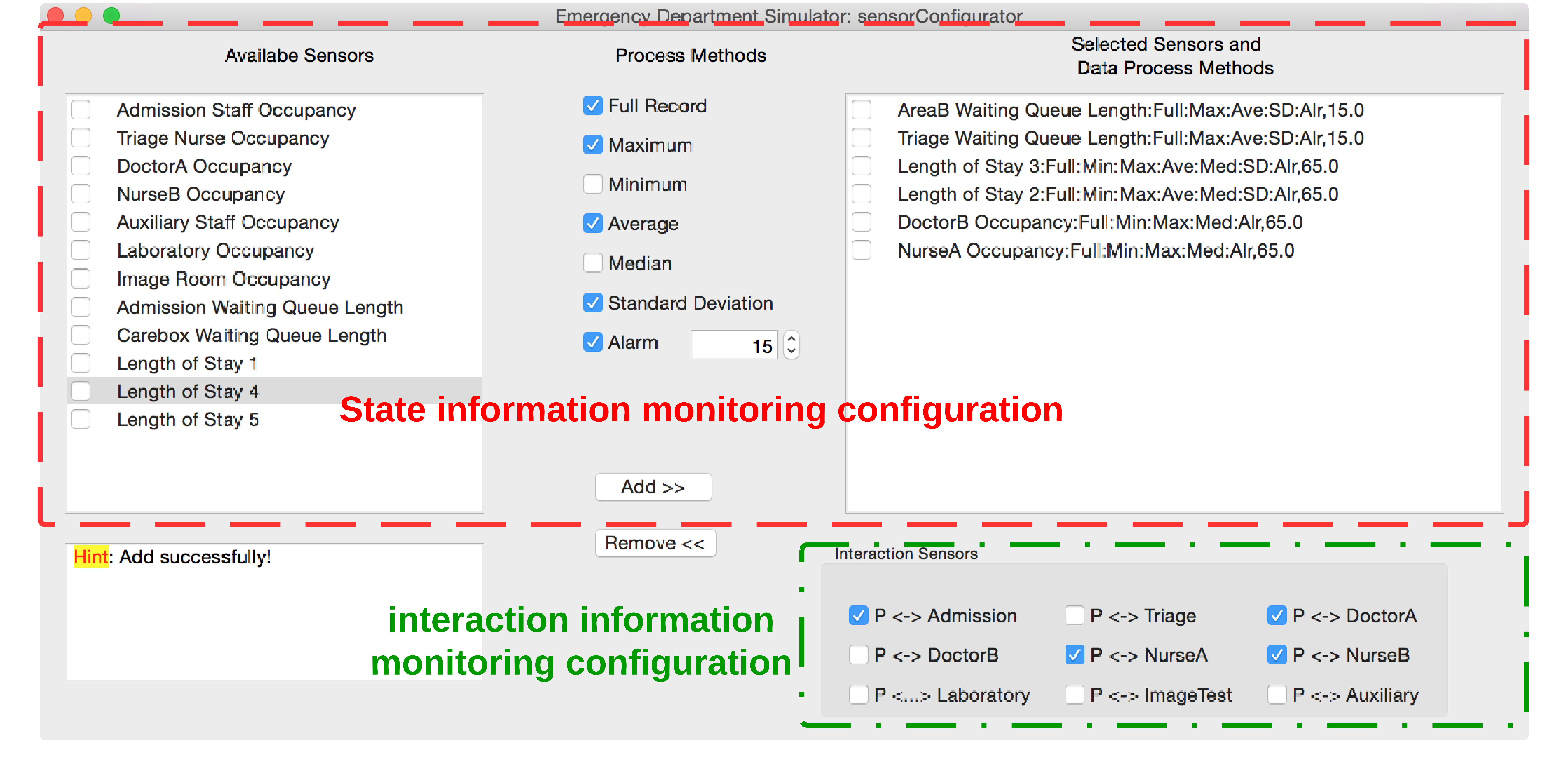
Statistical Model



Scenario = ED-Model-Configuration + Input (Patient)

CTAS: Canadian Triage and Acuity Scale

HOW IT WORKS? - SIMULATION OUTPUT CONFIGURATION



It is like: we could put a device (*sensor*) on *each* of the individuals to monitor their ***detailed activities***. sensors are customizable and have process capability.

How it works? - Direct Simulation Data

1	who	what	when(minute)	where	why	how long(second)
86179	(doctorb 76) and (patient 16279)	first-visit	70446	doctorB's room	default	1200
86180	(doctorb 74) and (patient 16283)	first-visit	70447	doctorB's room	default	900
86181	(nursea 80) and (patient 16158)	go-home	70447.5	carebox	default	150
86182	(doctorb 75) and (patient 16277)	first-visit	70448	doctorB's room	default	210
86183	(doctorb 78) and (patient 16222)	treatment-finished	70449	doctorB's room	default	1320
86184	(doctora 69) and (patient 16211)	test-result-review	70449.5	carebox	default	330
86185	(doctorb 73) and (patient 16281)	first-visit	70449.5	doctorB's room	default	1290
86186	(admission 1) and (patient 16285)	admission	70451.5	admission desk	default	300
86187	(doctora 67) and (patient 16199)	test-result-review	70451.5	carebox	default	120
86188	(nursea 80) and (patient 16199)	laboratory test	70453.5	carebox	default	1080
86189	(nursea 84) and (patient 16211)	go-hospital	70455	carebox	default	1290
86190	(doctora 69) and (patient 16262)	test-result-review	70455.5	carebox	default	450
86191	(doctorb 77) and (patient 16154)	treatment-finished	70455.5	doctorB's room	default	510
86192	(doctora 66) and (patient 16033)	test-result-review	70456.5	carebox	default	300
86193	(doctorb 72) and (patient 16247)	test-result-review	70457	doctorB's room	default	360
86194	(admission 2) and (patient 16288)	admission	70460	admission desk	default	240
86195	(doctora 71) and (patient 16236)	treatment-finished	70462	carebox	default	390
86196	(doctorb 74) and (patient 16180)	test-result-review	70462.5	doctorB's room	default	360
86197	(doctora 70) and (patient 16284)	first-visit	70464.5	carebox	default	480
86198	(doctorb 72) and (patient 16285)	first-visit	70465.5	doctorB's room	default	300
86199	(doctorb 77) and (patient 16228)	treatment-finished	70465.5	doctorB's room	default	180

Extract

Length of Stay, Occupancy, Length of Waiting, Efficiency, …

CALIBRATION - AUTOMATIC TOOL

Purpose: Setting up a general model for the target system simulation; I.E., a general computational model TO specific ED simulator.

Motivation: Enable the simulation users, e.g., ED manager, to calibrate parameters for their own ED system ***without*** the involvement of model developers. => ***promoting*** the application of simulation in ED studies.

Challenge: Data Scarcity, Out the scope of Information System;

Solution: Formed as an optimization problem;

Process: selection of inputs, specifying the objective function, searching, and evaluating the calibration results

CALIBRATION - SET UP YOUR OWN SIMULATOR (WHAT INFO. YOU NEED TO PROVIDE)

from your **information system**

Patient: arrival hour, day, acuity level, discharge time(date-time)

System configuration: #doctor, #nurse, #labs (machine), #medical image, … (all about *resource* you have)

from your **experience**

Table 1: The parameters to be calibrated for the general agent-based model of emergency departments, in order to imitate the emergency department of Hospital of Sabadell . Note: **LB** and **UB** denotes Lower and Upper Boundary respectively, **TV** represents the Typical Value; all the units of time are in minutes. The **Identity** column corresponds to the circled numbers in Figure 1 denote the type of service.

Identity	**Notation**	**Description**	**LB**	**UB**	**TV**
1	$T^{register}_{service}$	the parameter for registration service-time distribution model.	2	15	5
2	$T^{triage}_{service}$	the parameter for triage service-time distribution model.	5	20	10
3	$T^{nurseA}_{service}$	the average duration of service of nurses in area A.	8	30	16
4	$T^{doctorA}_{service}$	the average duration of service of doctors in area A.	8	30	18
5	$T^{nurseB}_{service}$	the average duration of service of nurses in area B.	5	20	12
6	$T^{doctorB}_{service}$	the average duration of service of doctors in area B.	5	20	15
7	$T^{imaging}_{service}$	the average duration for taking medical imaging.	20	40	25
8	$T^{lab}_{service}$	the average duration for taking laboratory test sample.	10	30	15

+

Our tool and general model

=

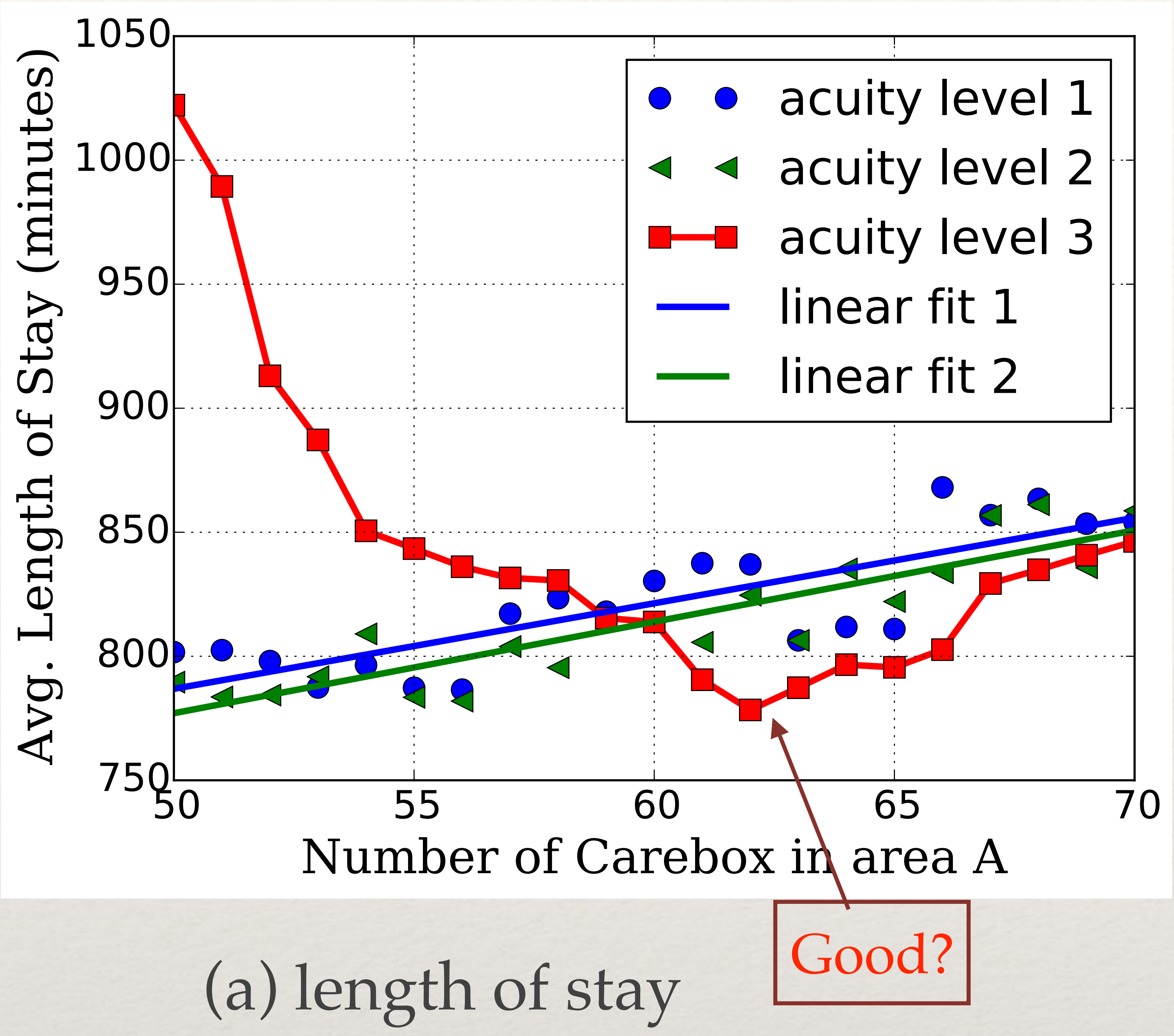
value of parameters to set up your simulator (for your system)

Example of uses, No. 1

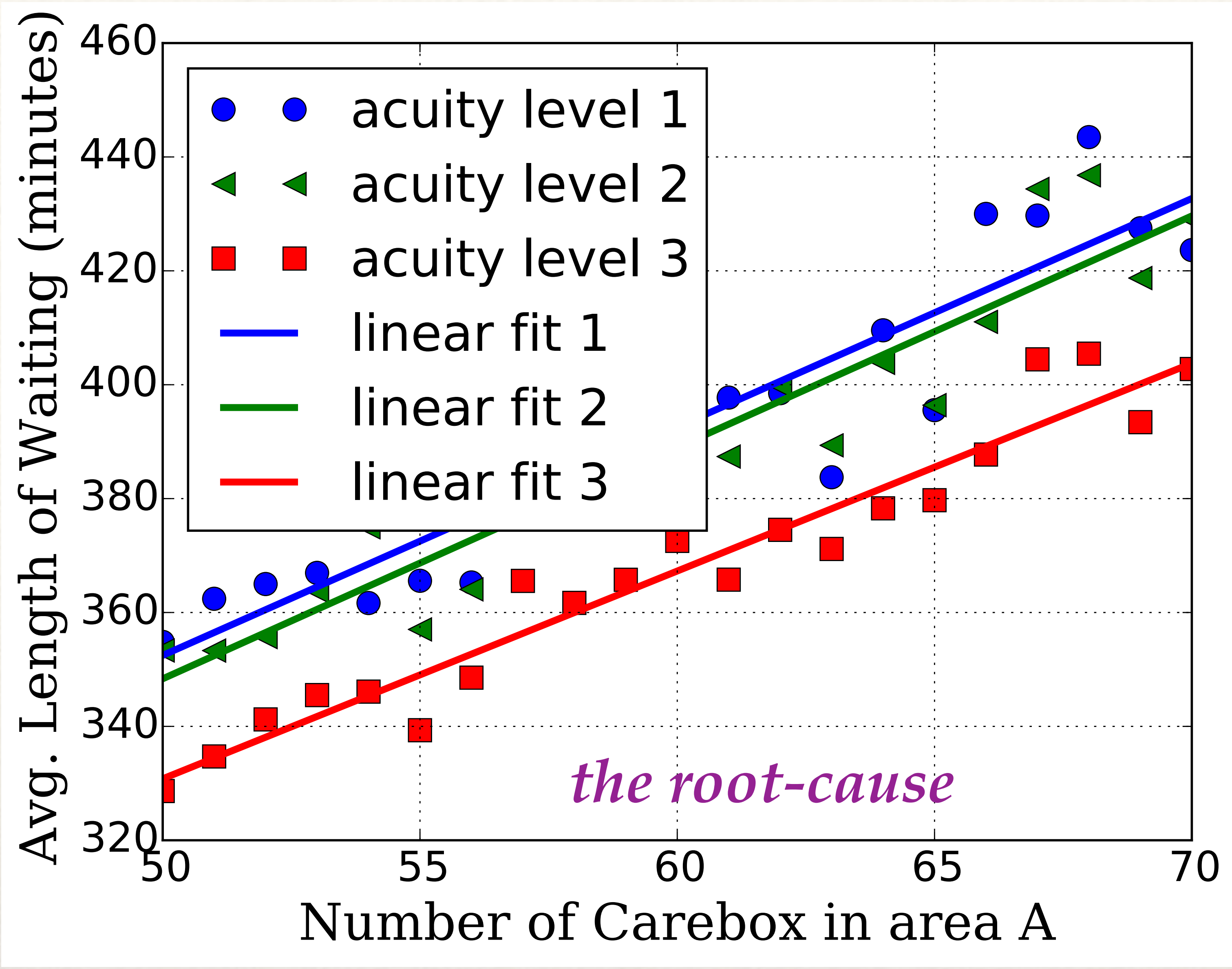
The emergency department system is **overcrowding**,
WHAT-IF
we add 20 careboxes to the system?

Every decision we make is based on information, stop guess.

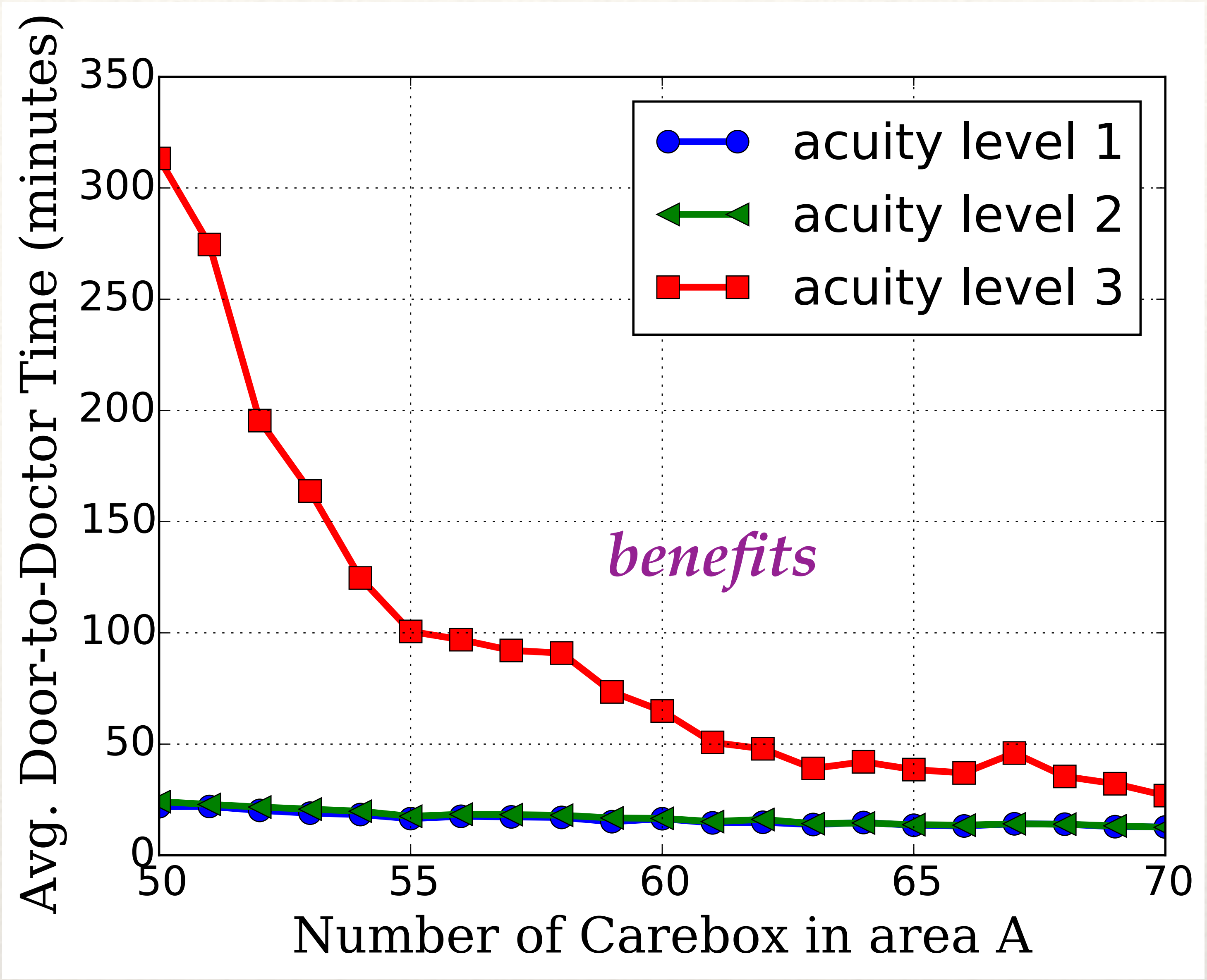
The influence of additional carebox on patients' behavior (Area A).



(a) length of stay

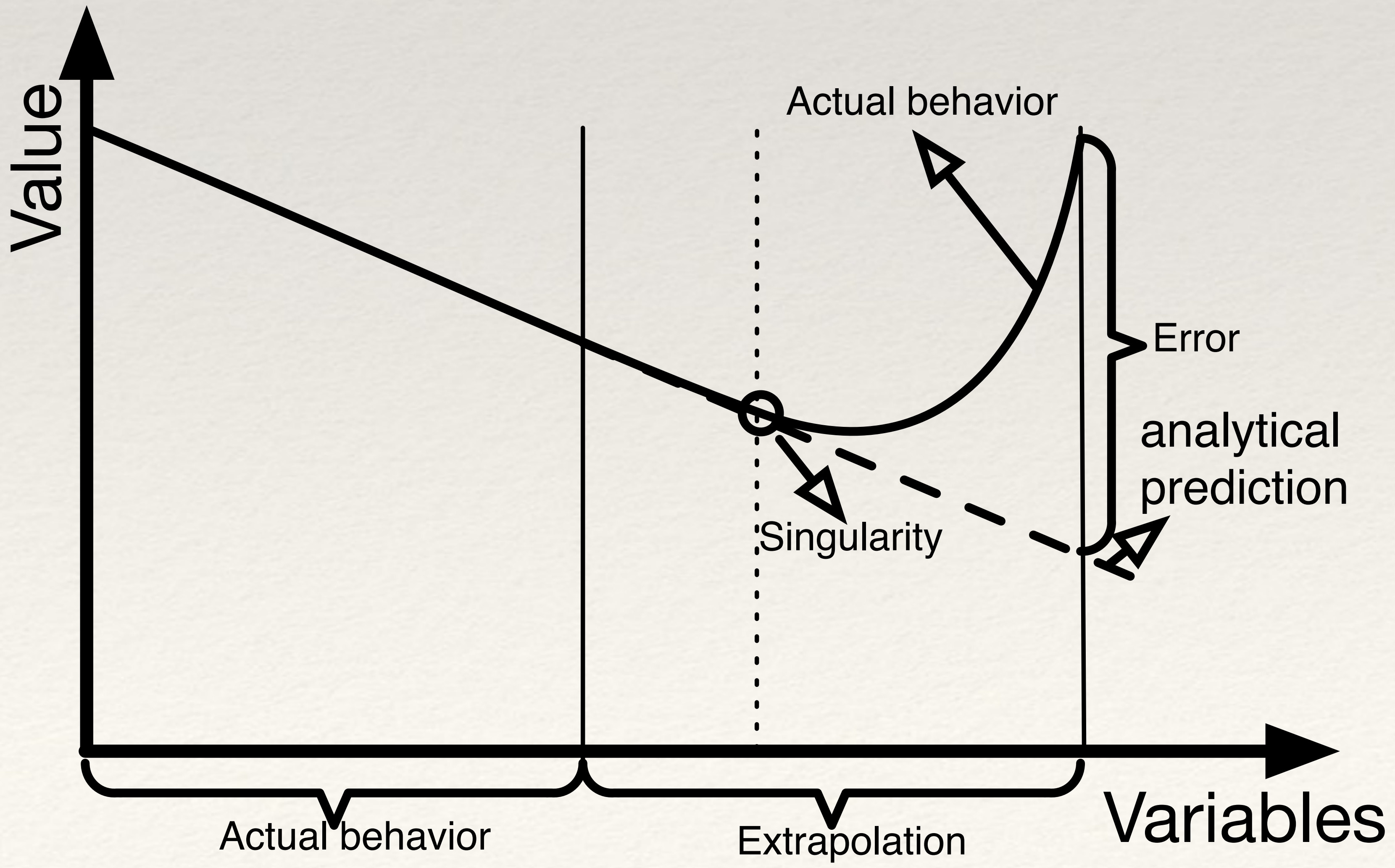


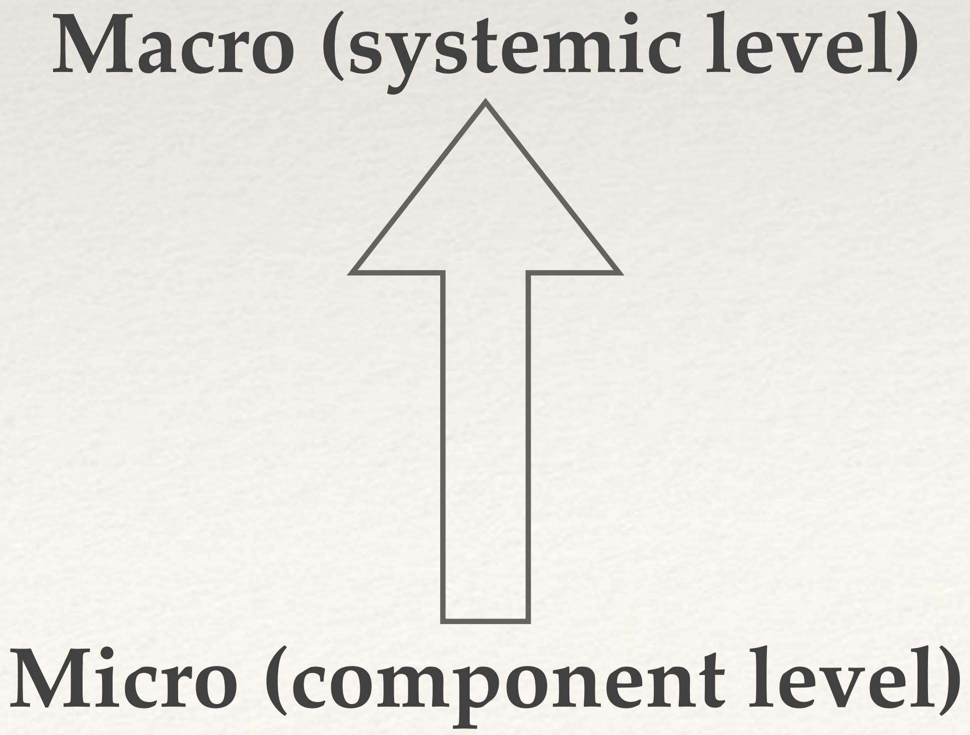
(b) length of waiting time
(in treatment area)



(c) door-to-doctor time

Our world is nonlinear



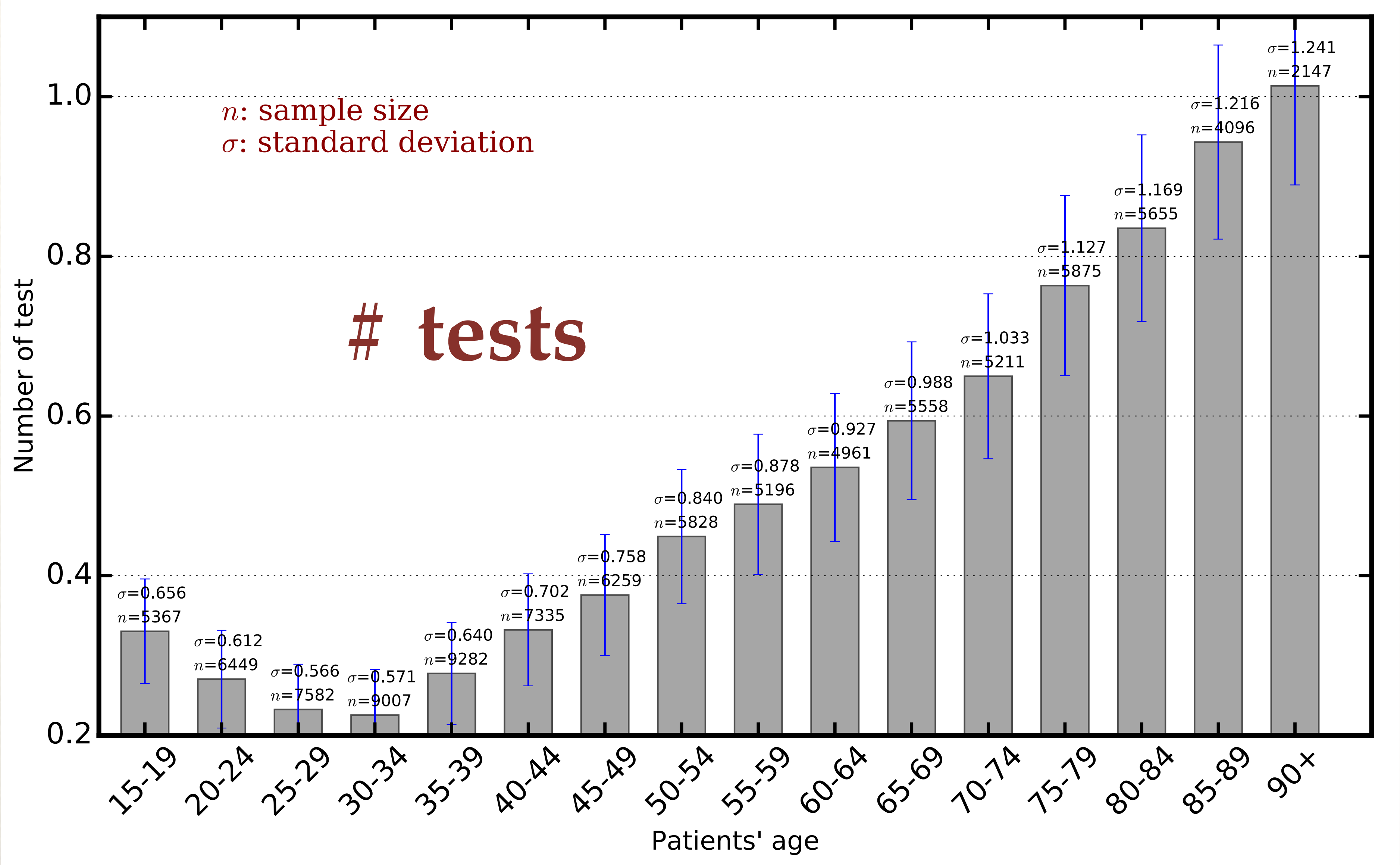


Example of uses, No. 2

How can emergency departments respond to **population aging**: a simulation study.

1. **Predict** the effects of population aging on emergency department.
2. Make longterm plans and **quantify** their costs and benefits with the ED simulator. (**explain**)
3. **Optimize** changes to the ED system with constrain.

Information retrieved from **real data** (2014)



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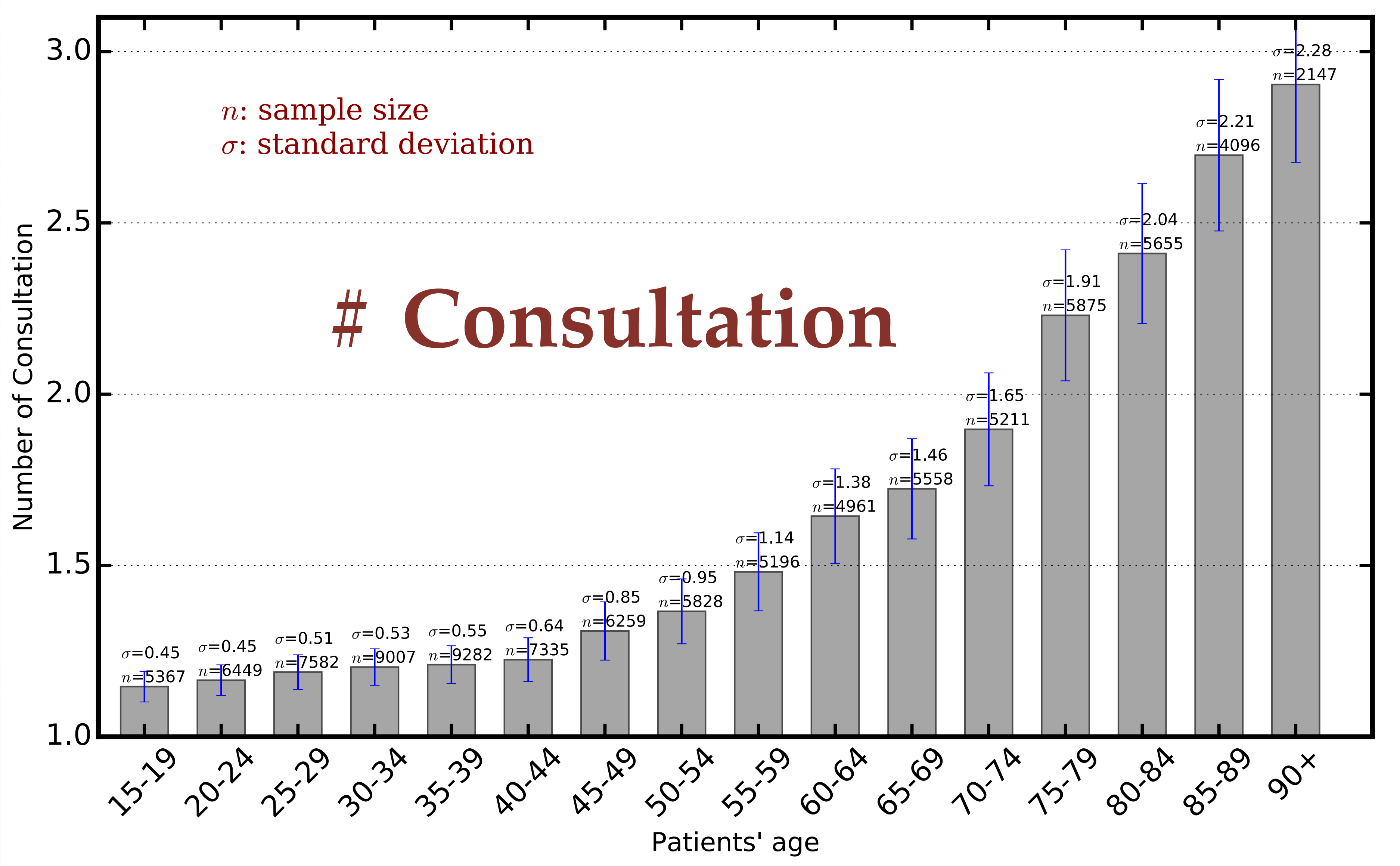

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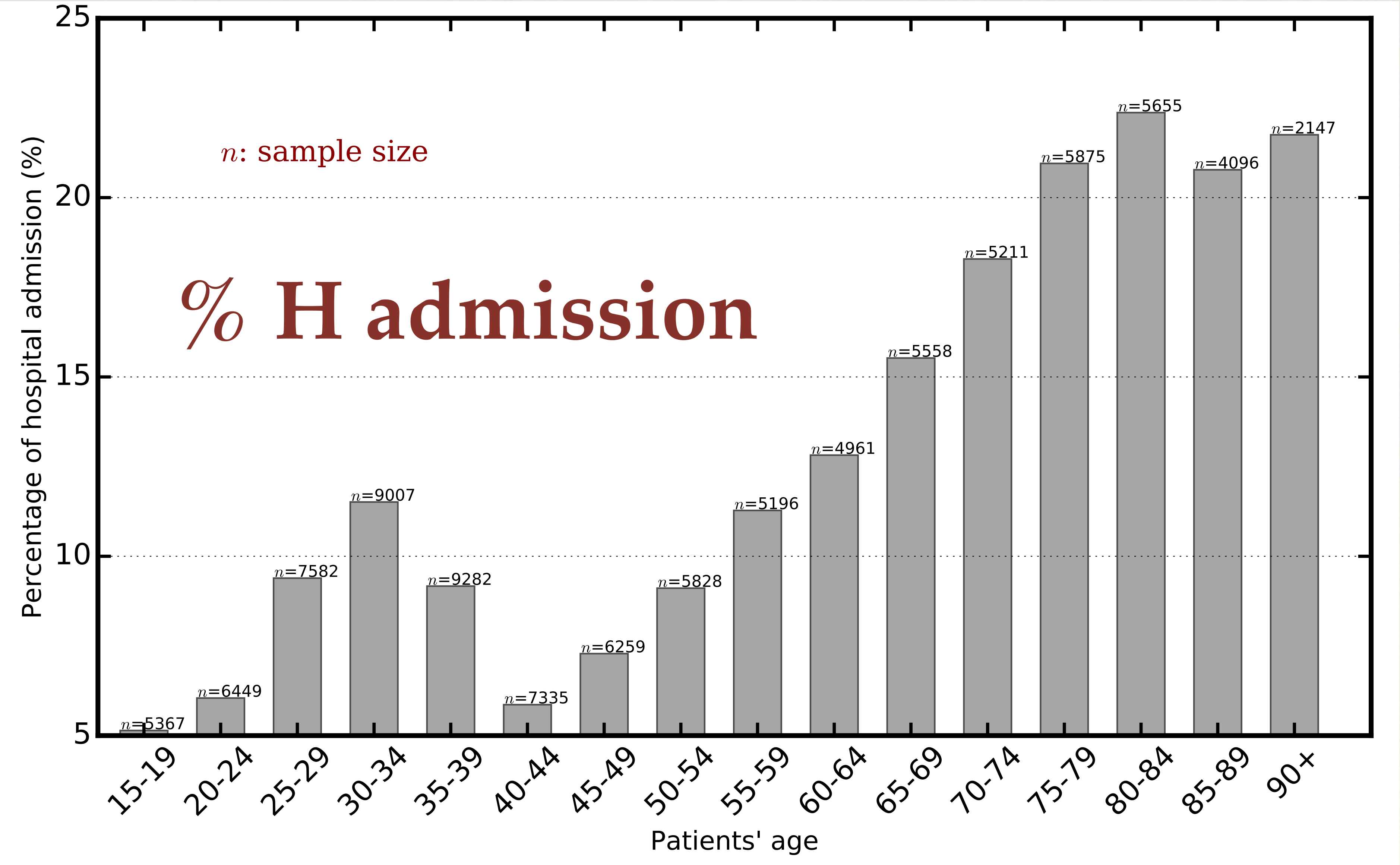
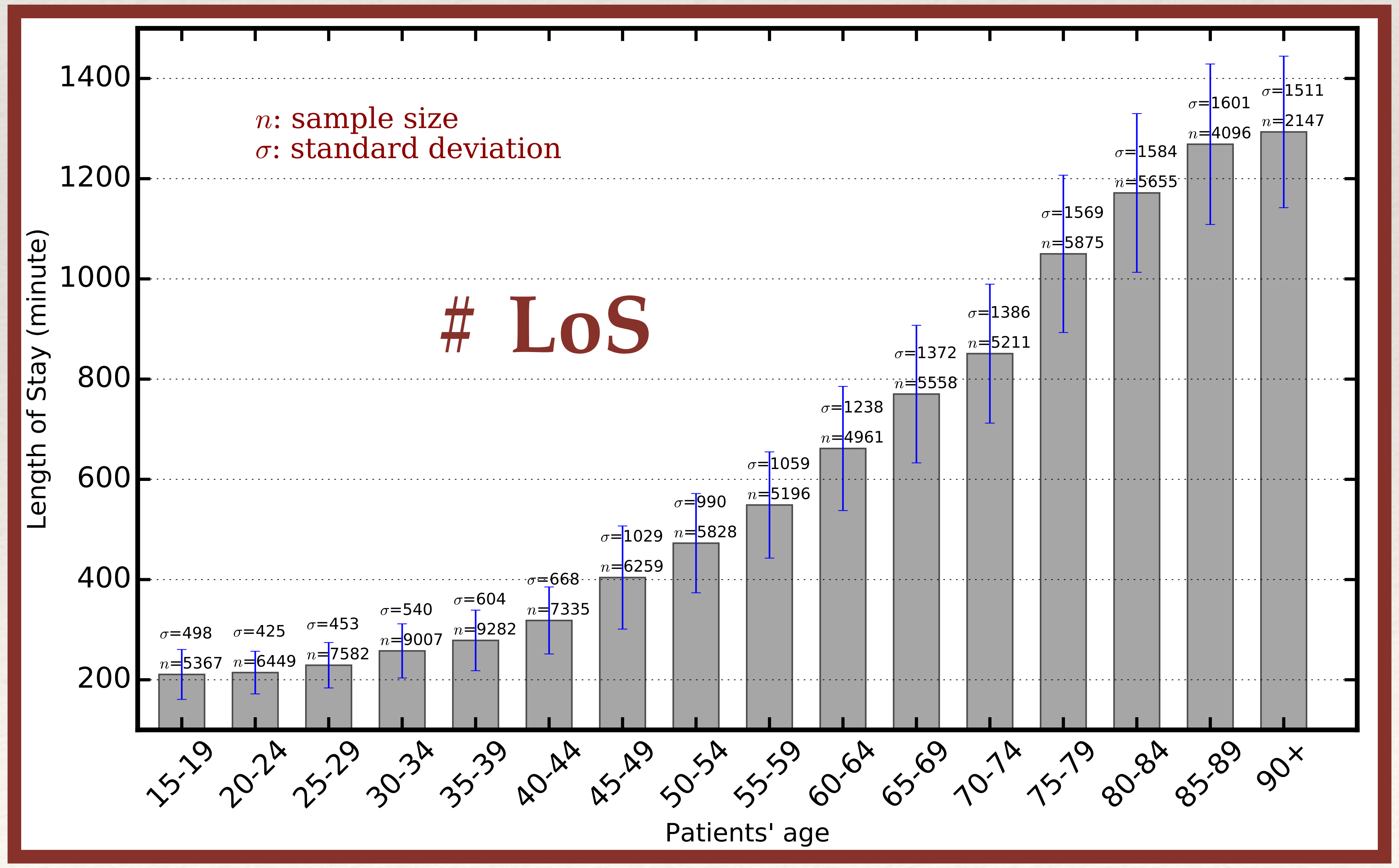


=>



Knowledge from actual data analysis: Elder patients need more care service and stay longer in ED.

Patients' age distribution prediction model

$$N_{ED}^{age}(year) = P_{ED}^{age} \cdot N_{ref} \cdot P_{rate}^{year} \cdot D_{age}^{year} \quad (1)$$

Regarding that

$$P_{ED}^{age} = \frac{\overline{N_{ED}^{age}}}{N_{ref} \cdot D_{age}^{ref}} \quad (2)$$

Replace P_{ED}^{age} in Equation 1 with Equation 2, we get:

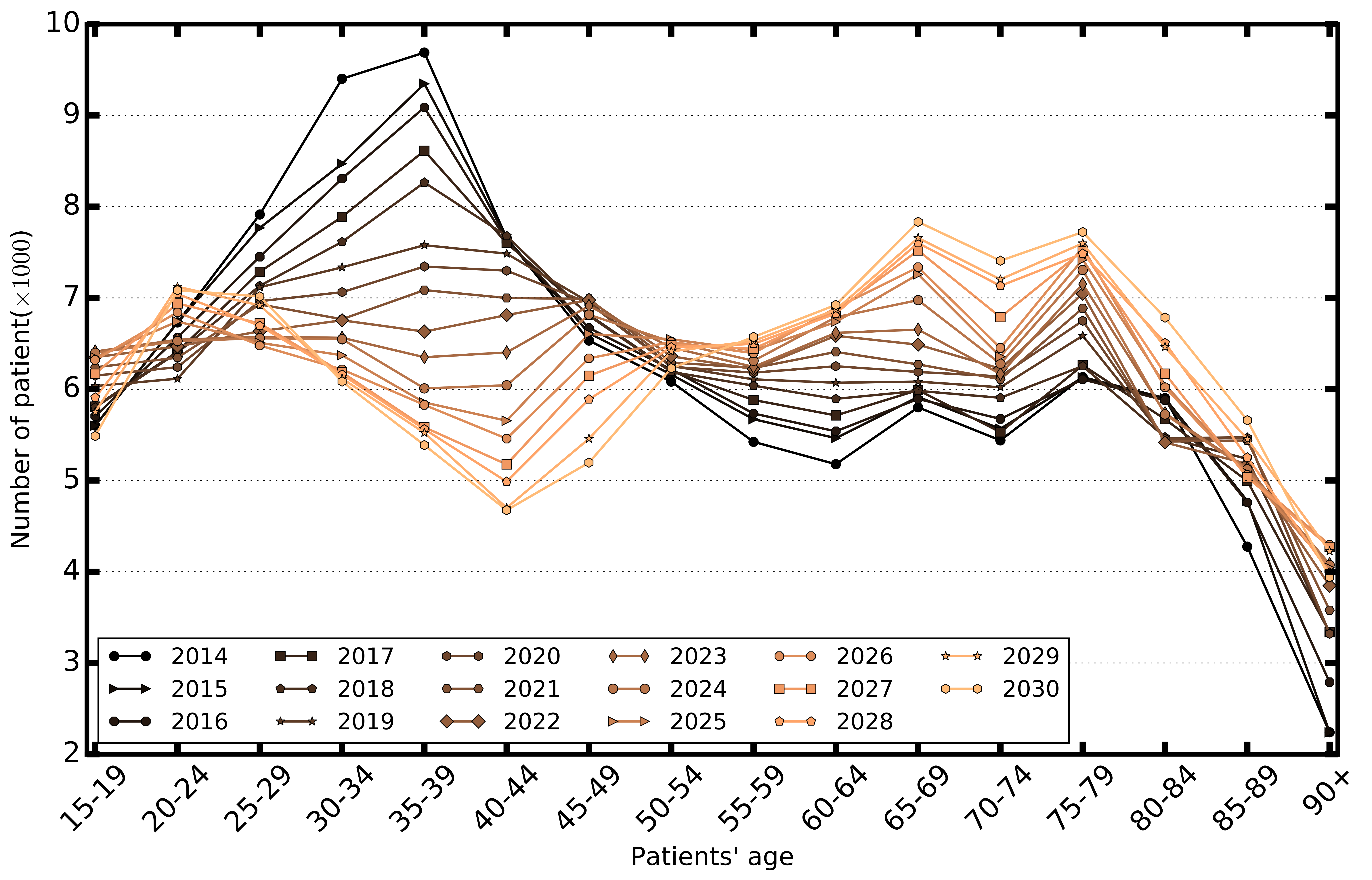
$$N_{ED}^{age}(year) = \frac{D_{age}^{year}}{D_{age}^{ref}} \cdot \overline{N_{ED}^{age}} \cdot P_{rate}^{year} \quad (3)$$

Notations	**Description**
$\overline{N_{ED}^{age}}$	The number of patients due to age interval in 2014 (5 years in this study).
N_{ref}	The total number of people in the catchment area of the hospital.
* D_{age}^{year}	The distribution of various age groups in the target catchment area in *year* (population pyramid).
P_{ED}^{age}	The probability of a person (due to *age*) who will go to ED.
P_{rate}^{year}	The ratio of population in *year* to the reference year (2014).

Model assumption: The probability of a person who will go to ED at least once per year depends on lots of factors, here we assume that **the probability is depends on age and do not change over different year**. That is to say, a fix probability will be used throughout the future to predict the number of patient attend to ED and, the age distribution of the patients.

* Got from the **Instituto Nacional de Estadística (INE)** http://www.ine.es/

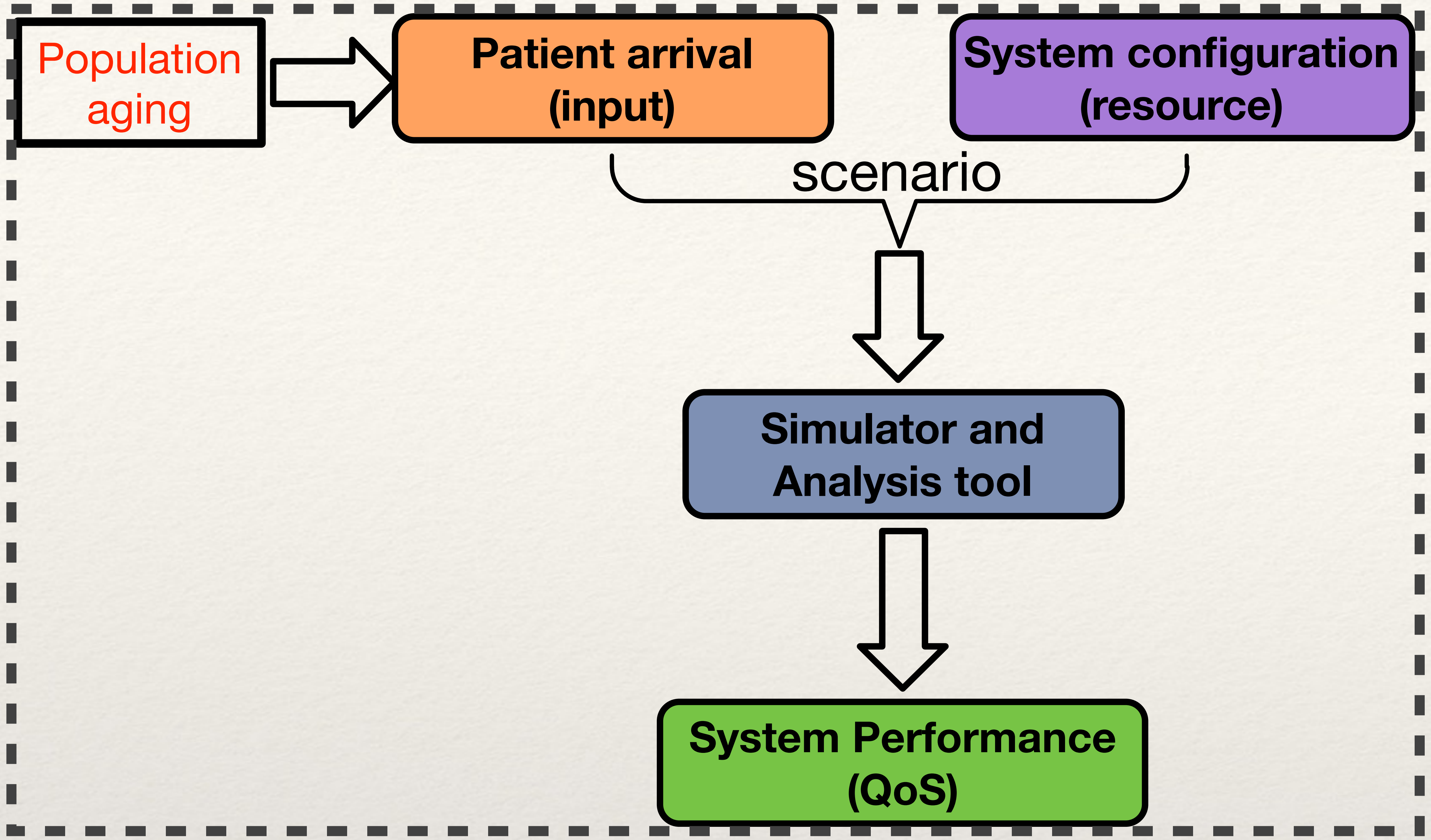
Patients' age distribution prediction in the future

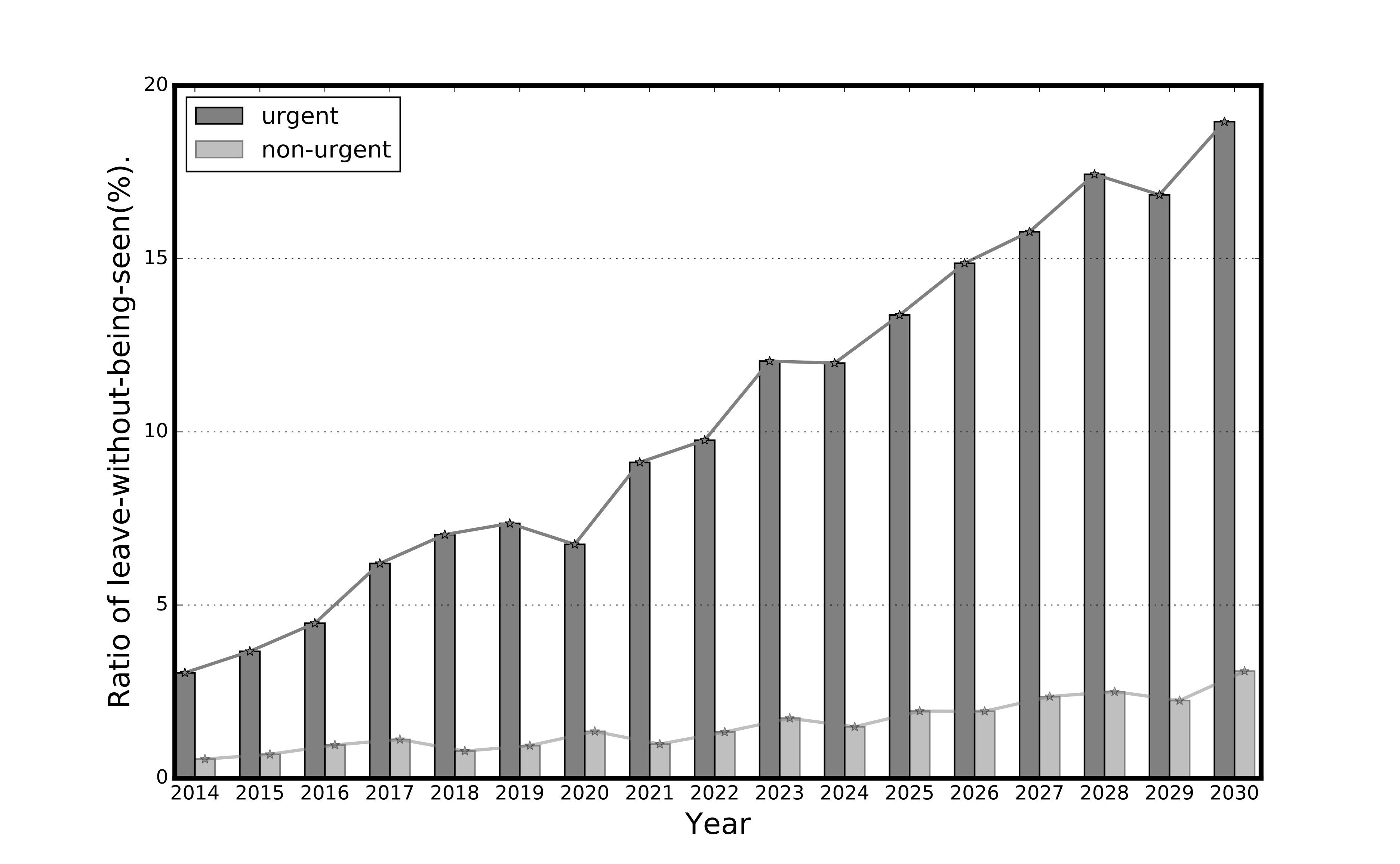


As **input**
to
the simulator
to
see **QoS**
in the future

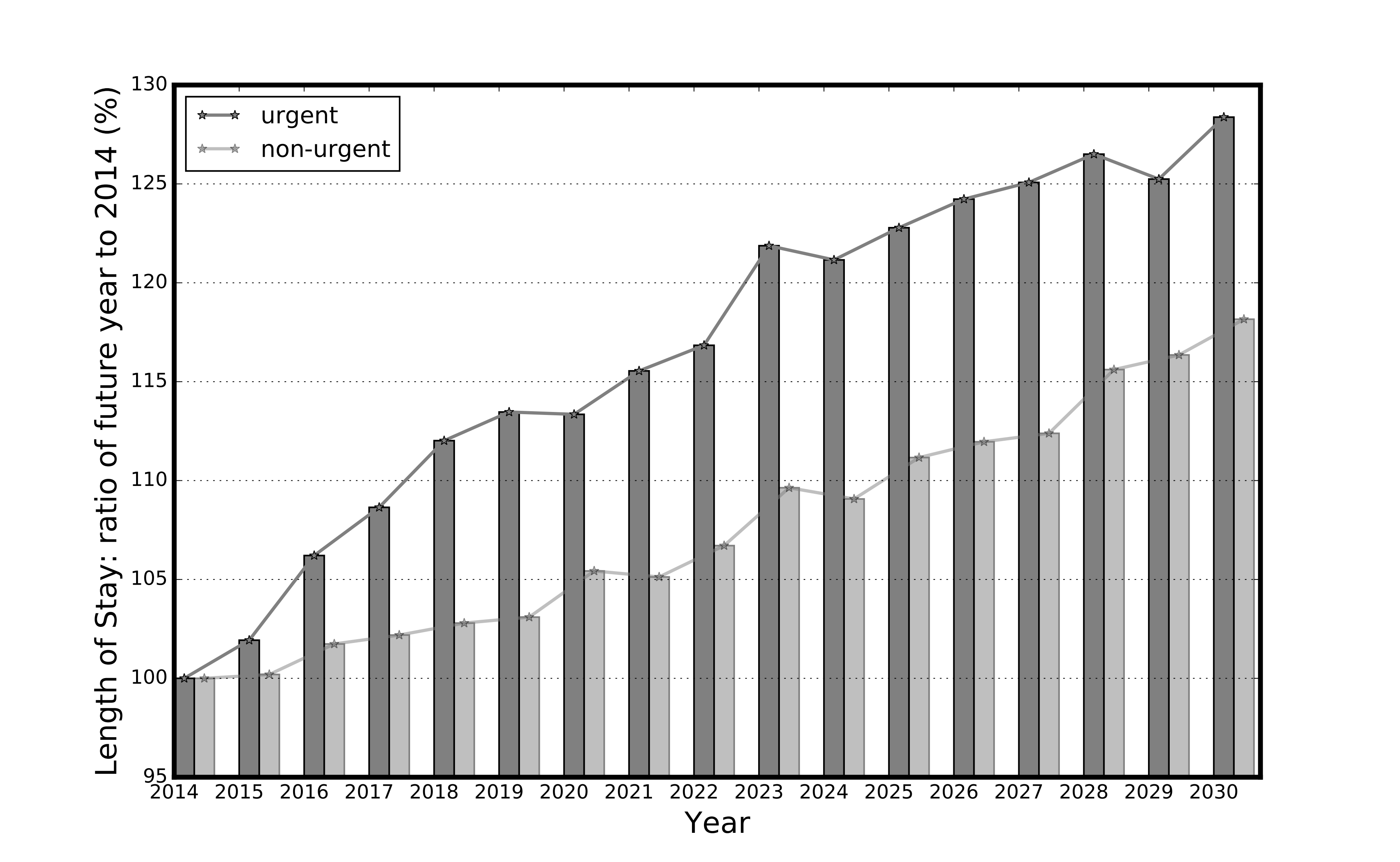
Knowledge from prediction: there will be more elder patients and less young patients attend ED

ED performance **predicted** by **simulation**

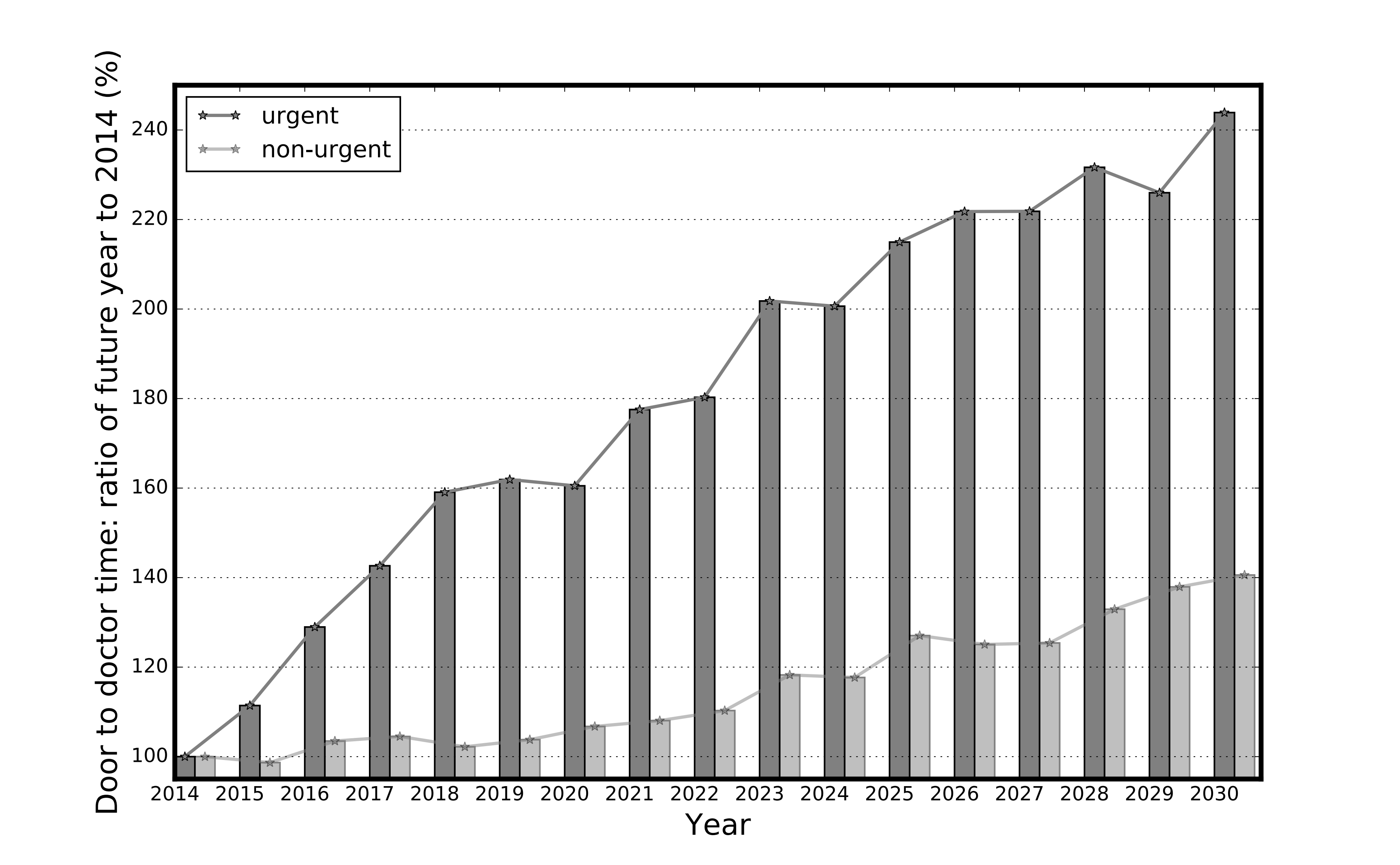




Leave-without-being-seen



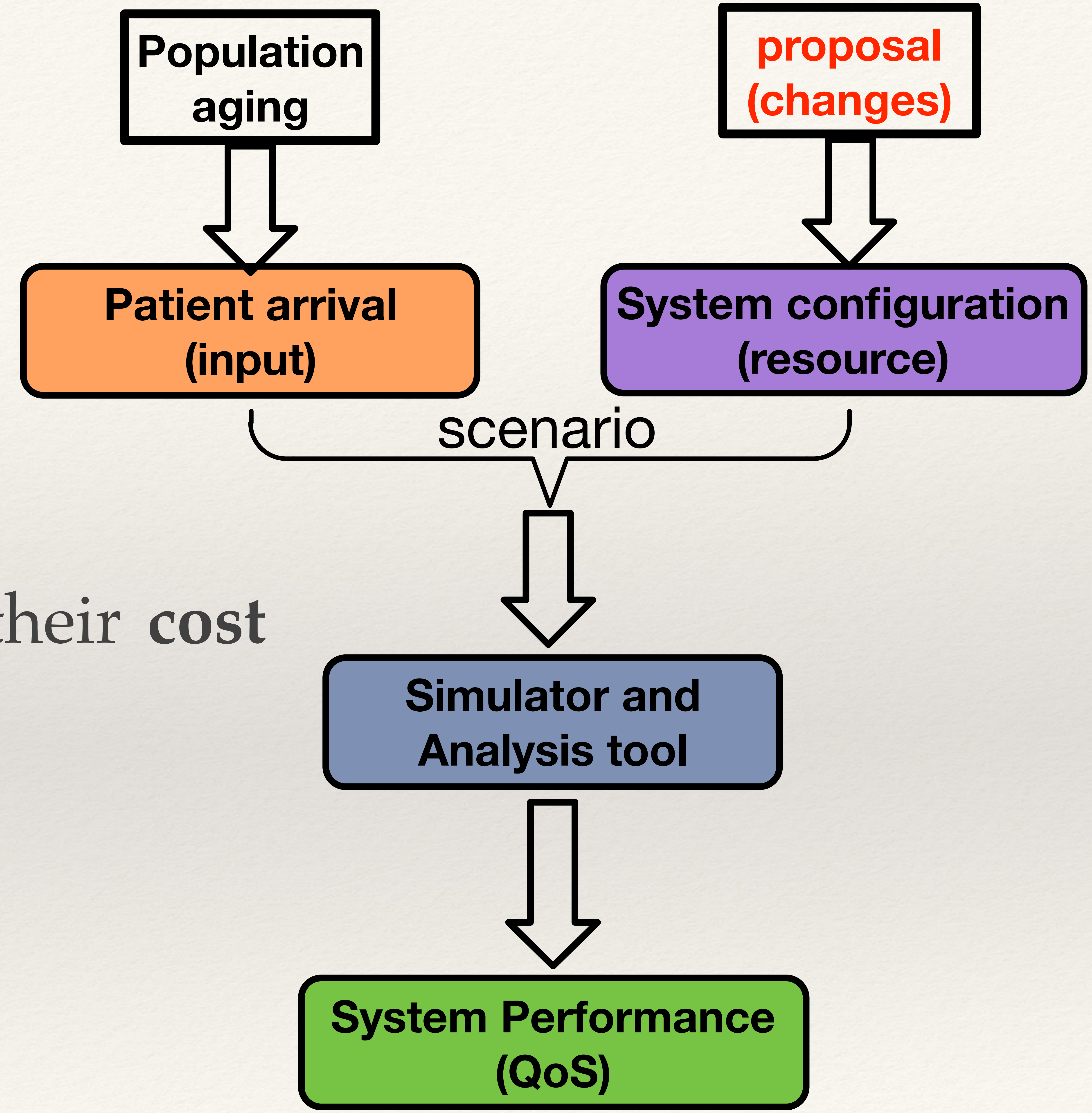
Length-of-Stay



Door-to-Doctor Time

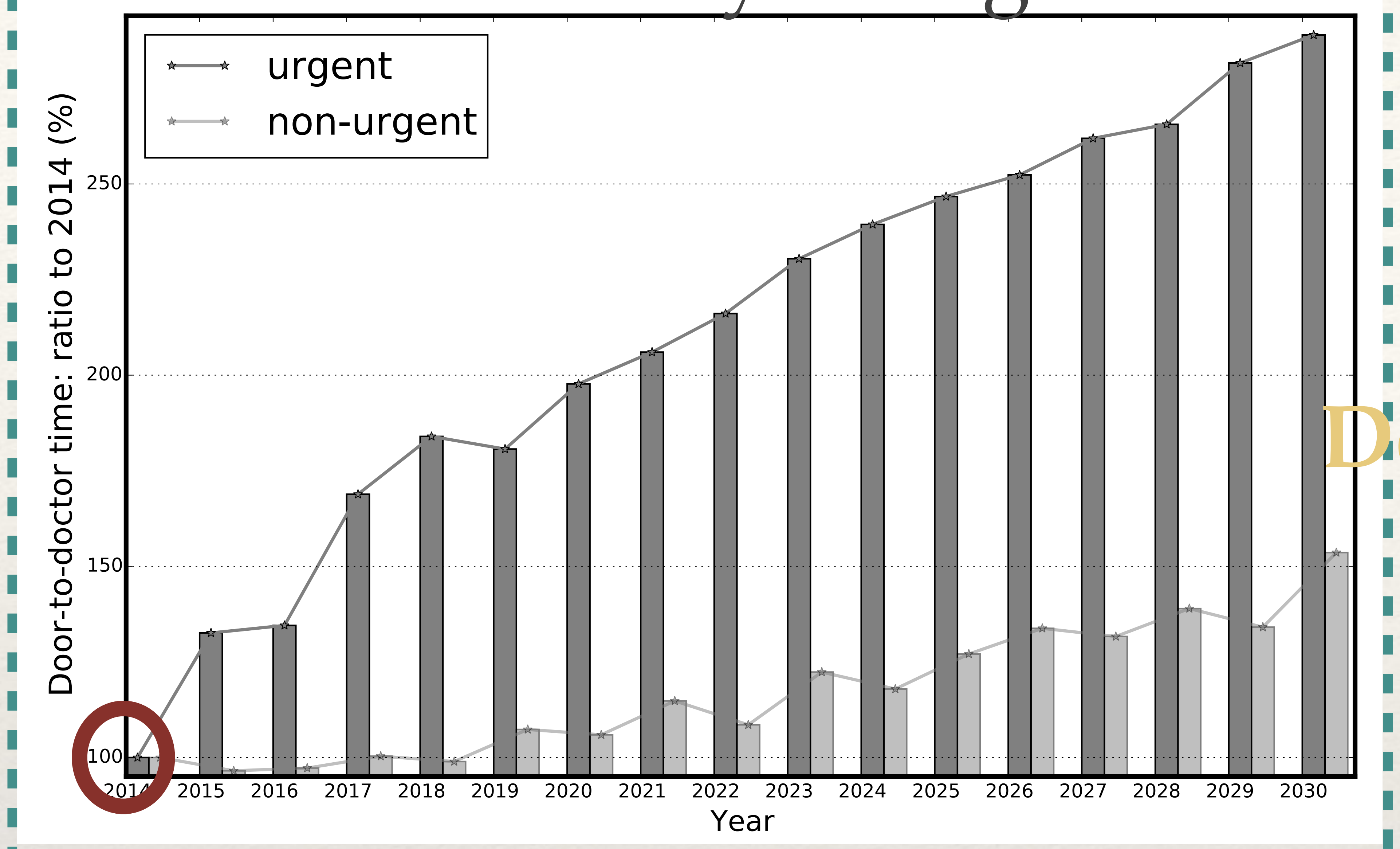
Make plans in advance.

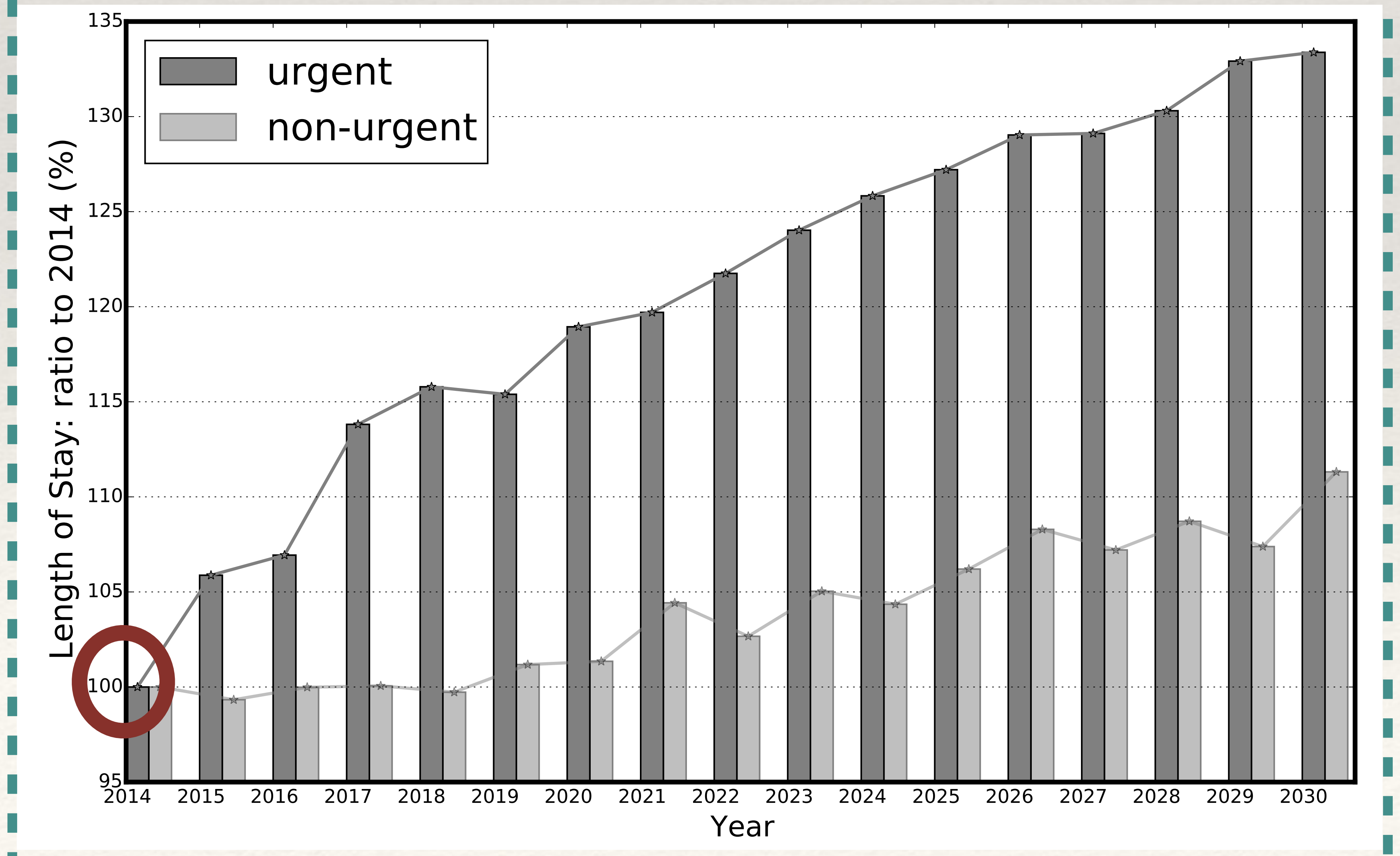
Propose longterm plans and **quantify** their **cost** and **benefit** with the ED simulator.



Effect of Changes?

future performance without any changes

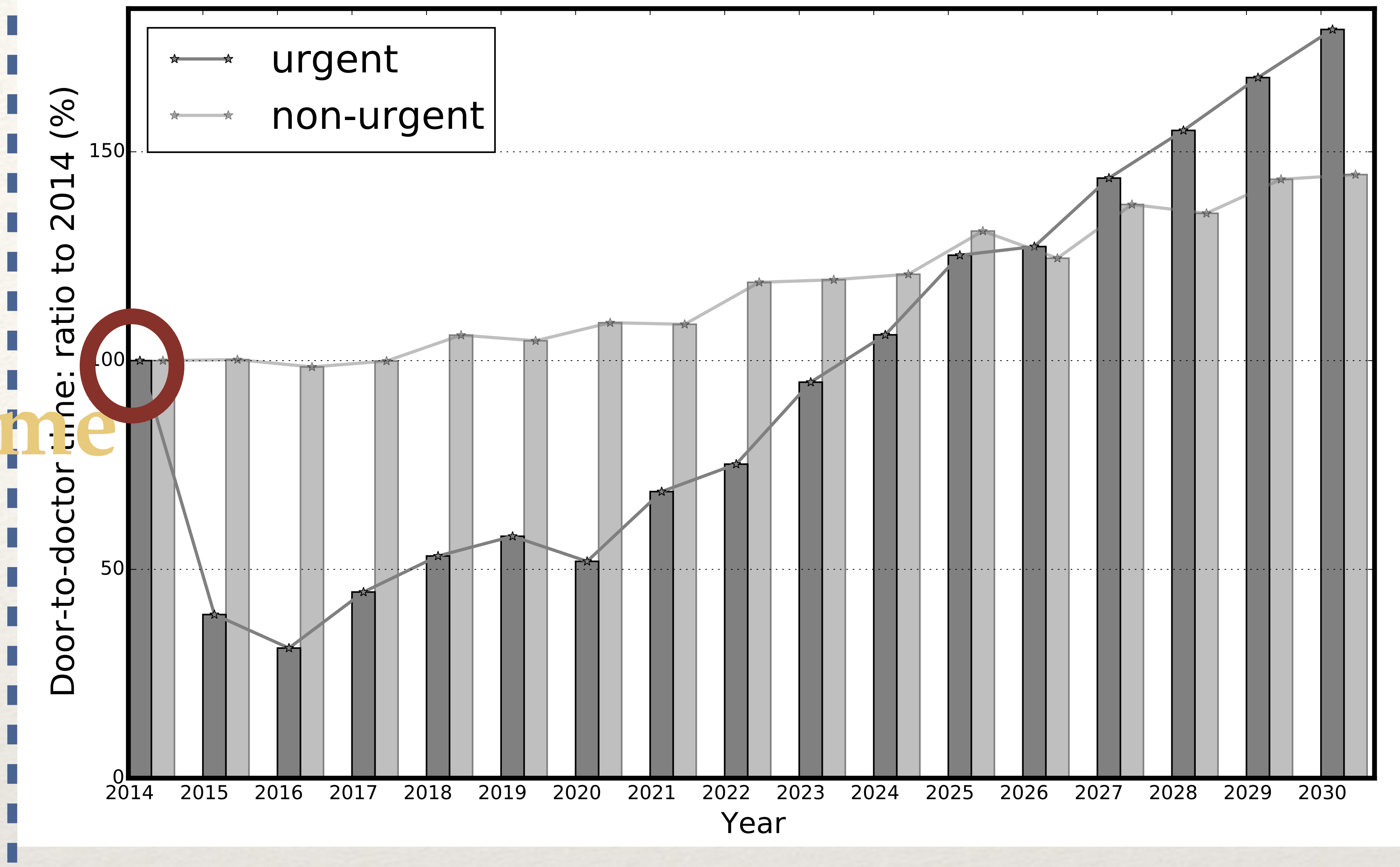


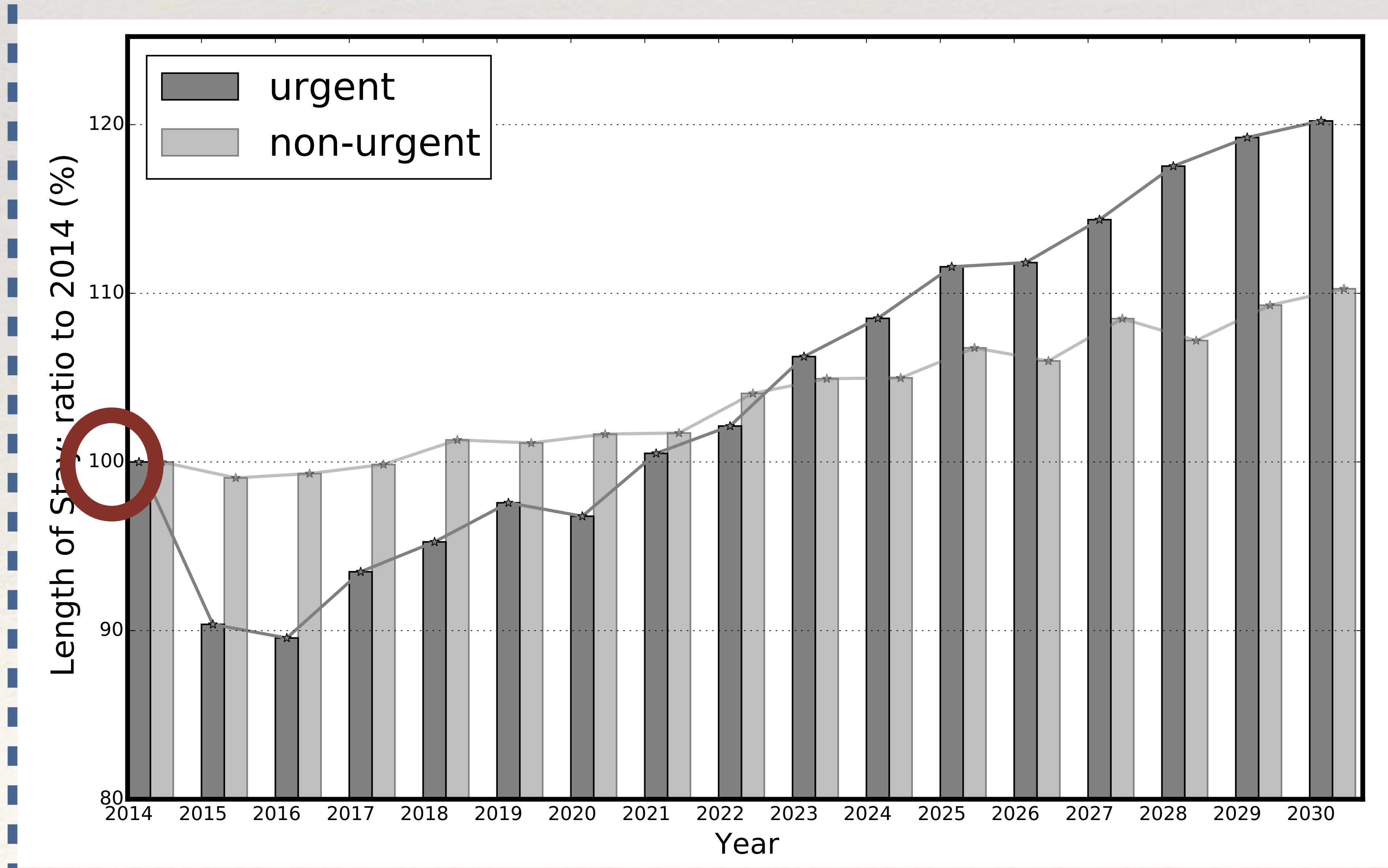


Door-to-Doctor Time

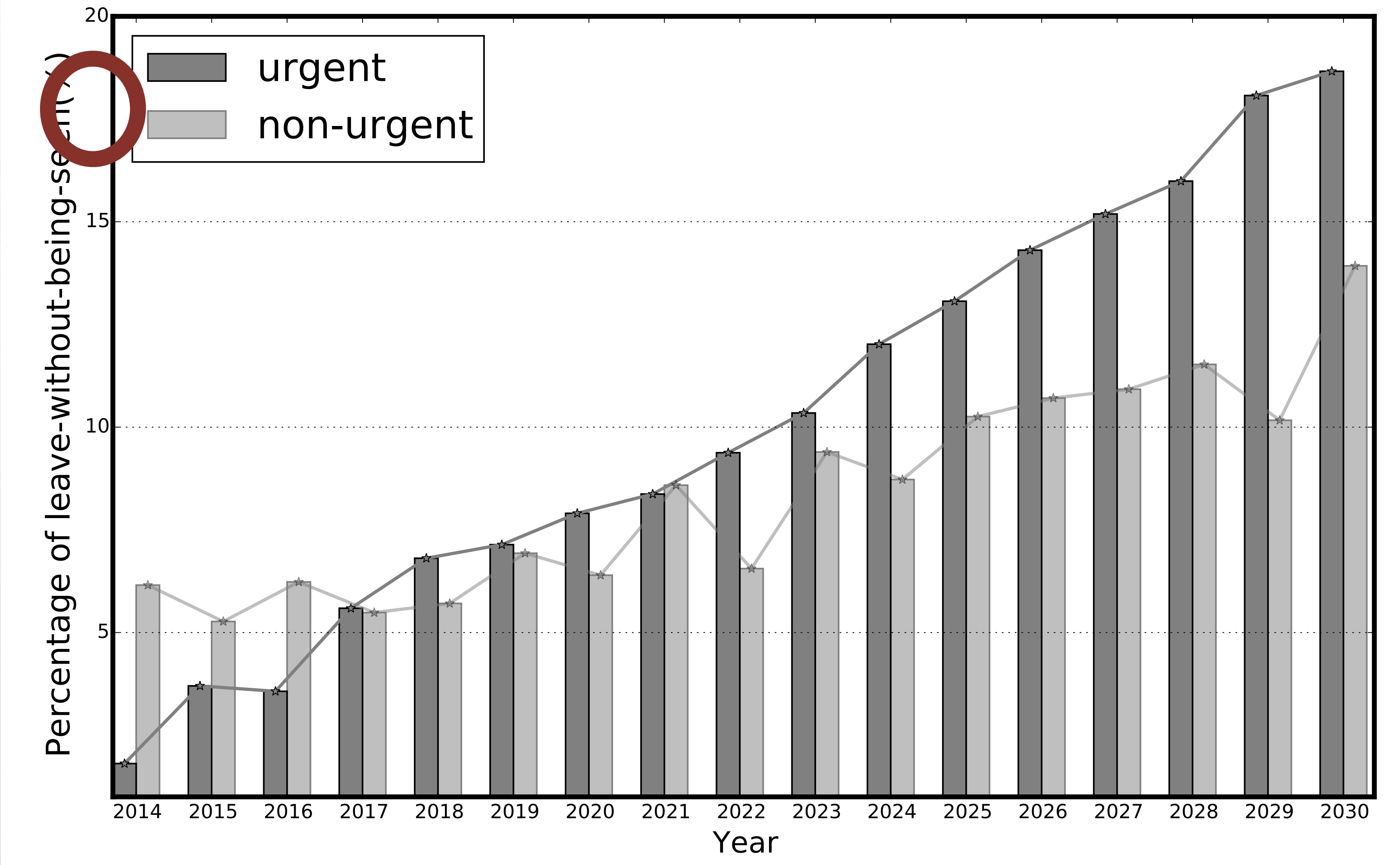
Length-of-Stay

future performance with: **3+** nurse in area A, **11+** careboxes



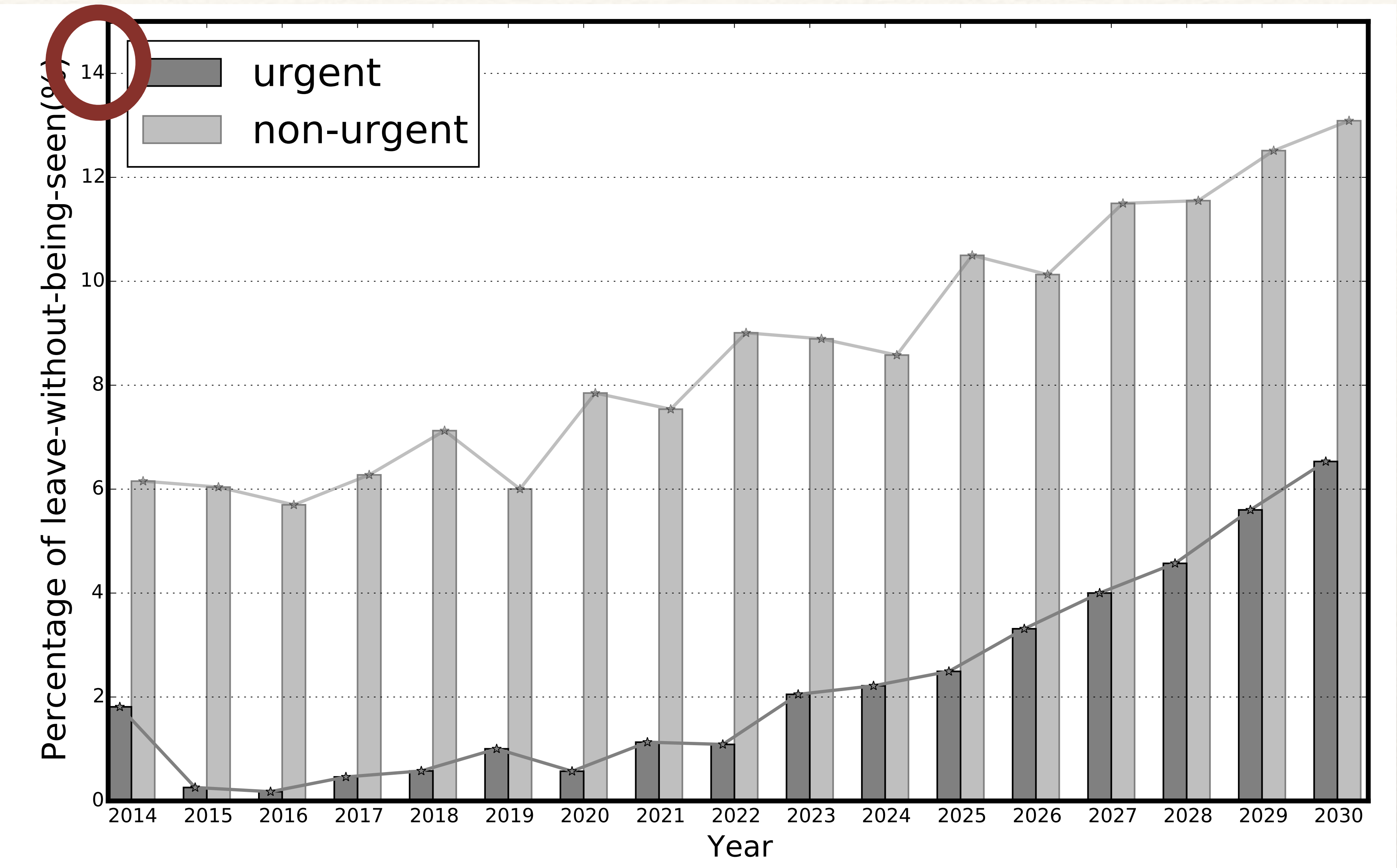


future performance without any changes



Leave without being seen

future performance with:
3+ nurse in area A, carebox: 49 => 60



Optimize alternatives with constraint (e.g., budget, space) — work in process.

Conclusions & Future Work

Conclusions:

(1) A General Agent-Based Model for EDs (Spanish type);

(2) Designed and Implemented an auto-calibration tool;

(3) with this tool, we can have: Every decision we make is based on information, stop guess.

In summary, start from simulating the emergency departments, our efforts proved the feasibility and ideality of using agent-based model & simulation techniques to study healthcare system.

Future Work:

(1) Population aging; How can emergency departments respond to population aging: a simulation study.

(2) A step towards building a full model of integrated care system.

Thank you for Your Attention!

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