

# IE 324 SIMULATION

## **2021 – 2022 SPRING**

## **INTRODUCTION**

# IE 324 SIMULATION

- Instructor:

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Office Hours: By appointment

- Teaching Assistants:

- Atahan Bayır

- Seyit Ulutaş

# COURSE DESCRIPTION

- Use of simulation as a decision tool.
- The design and analysis of simulation models.
- The use of simulation for estimation, comparison of policies, and optimization.
- Topics include principle of simulation modeling, software, general-purpose computer simulation languages, and statistical analysis of simulation input and output data.

# COURSE OUTLINE

- Introduction to Simulation
- Event Scheduling/Time Advance Algorithm
- Simulation by Hand
- Input Modeling
- Random Number Generation
- Random Variate Generation
- Arena Modeling Basic Operations
- Arena Modeling Detailed Operations
- Output Analysis of Terminating Simulations
- Output Analysis of Output from Steady-State Simulations
- Validation and Verification
- Comparing Alternative Scenarios
- Optimization via Simulation
- Variance Reduction Techniques (if time permits)

# TEXTBOOKS

- ***Required Text Books:***

- Banks, J., Carson, J. S., Nelson, B. L., and Nicol, D. M., Discrete-Event System Simulation, 2013, Pearson
- Kelton, W. D., Sadowski, R. P., and Zupick, N. B., Simulation with Arena, 6th Ed., McGraw Hill, 2015

- ***Recommended Text Books:***

- Seila, A., Ceric, V., Tadikamalla, P., Applied Simulation Modeling, Duxbury, 2003
- Law, A. M., Simulation Modeling and Analysis, 4th Ed., McGraw Hill, 2006
- Fishman, G. S., Discrete-Event Simulation: Modeling, Programming, and Analysis, Springer, 2001
- Rosetti, M. D., Simulation Modeling and Arena, Wiley, 2009

# GRADING

- Midterm: 35%
- Final Exam: 35%
- Arena Quiz: 10%
- Arena Project: 15%
- Homework Assignments: 5%

THIS ASSESSMENT CRITERIA AND THE PERCENTAGES ARE SUBJECT TO CHANGE AS THE PANDEMIC PROGRESSES!

# POLICIES

- ***Open-Book Policy:*** The midterm and final exam will be **CLOSED BOOKS** and **CLOSED NOTES**. A formula sheet and necessary statistical tables will be provided. Arena Quiz will be **OPEN BOOK** (Kelton et. al. only) and **OPEN NOTES**.
- ***Group Policy:*** Your project will be done in groups of maximum 3 students.
- ***Homework Assignments:*** Individual homework assignments will be given and graded based on effort.

# POLICIES

- ***Makeup Policy:*** A make-up examination for the midterm or final will only be given under highly unusual circumstances (such as serious health or family problems). The student should contact the instructor as early as possible and provide the instructor with proper documentation (such as a medical note certified by Bilkent University's Health Center). **There is no make-up for quizzes.**
- ***Software Policy:*** The simulation software **ARENA** can only be installed to Windows computers. This means Mac users should either have their computers a Dual-Boot, or they will need an emulator software (like parallels). You are welcome to use the BCC Computer Labs but this might change during the semester.
- You must install ARENA version 14.5. No other version should be used! We will supply the installation files.

# POLICIES

## ***Web Site/Email:***

- <https://courses.ie.bilkent.edu.tr/ie324>
- Students are responsible for all the announcements made in class, on the web page or via e-mail.
- It is the students' responsibility to be aware of what has been covered in lectures, and to check the web page and e-mail accounts regularly and not miss any activity or information

# POLICIES

- COVID-19 Rules:

- As per the senate decision, you **MUST** have your **masks covering your face and mouth on at all times!** This means **NO EATING** and **NO DRINKING** except for water.
  - A window will be kept open, so dress appropriately.
  - You **MUST** keep your social distance as much as possible.
  - You should sit at the same seat at each lecture.
- Any change in the university policies about conducting classes and examinations will result an update on the topics covered and grading assessments including their percentages. **All effort will be made to make these changes as smooth as possible.**

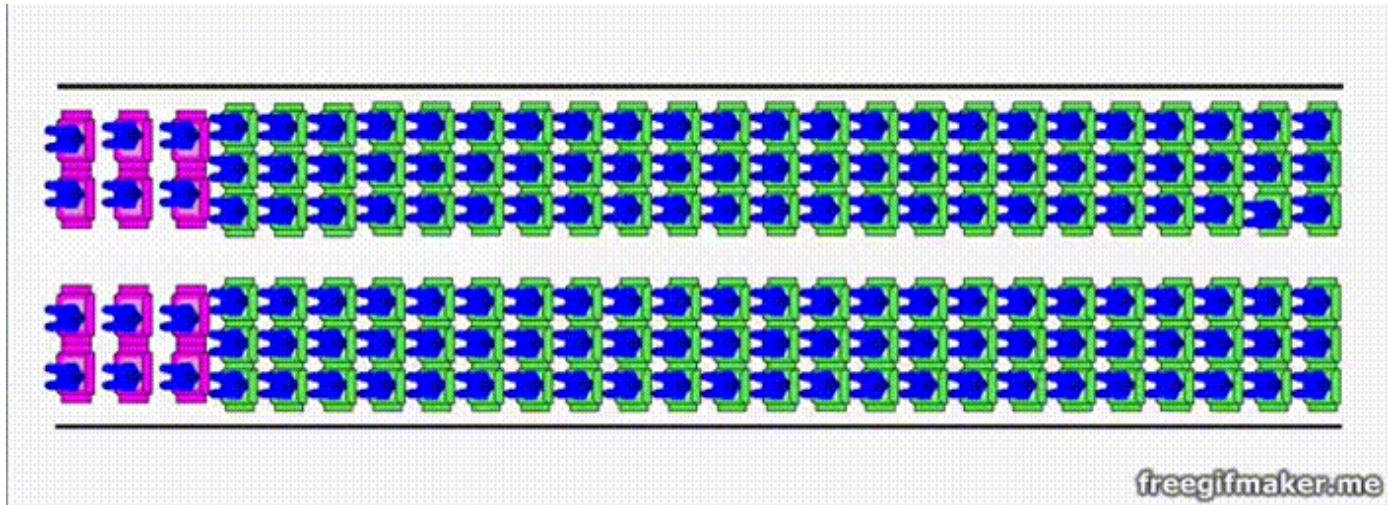
# QUESTIONS?

# AIRPLANE BOARDING

- How to board an airplane?
- The order of boarding is usually determined by the carrier and denoted with your boarding group.

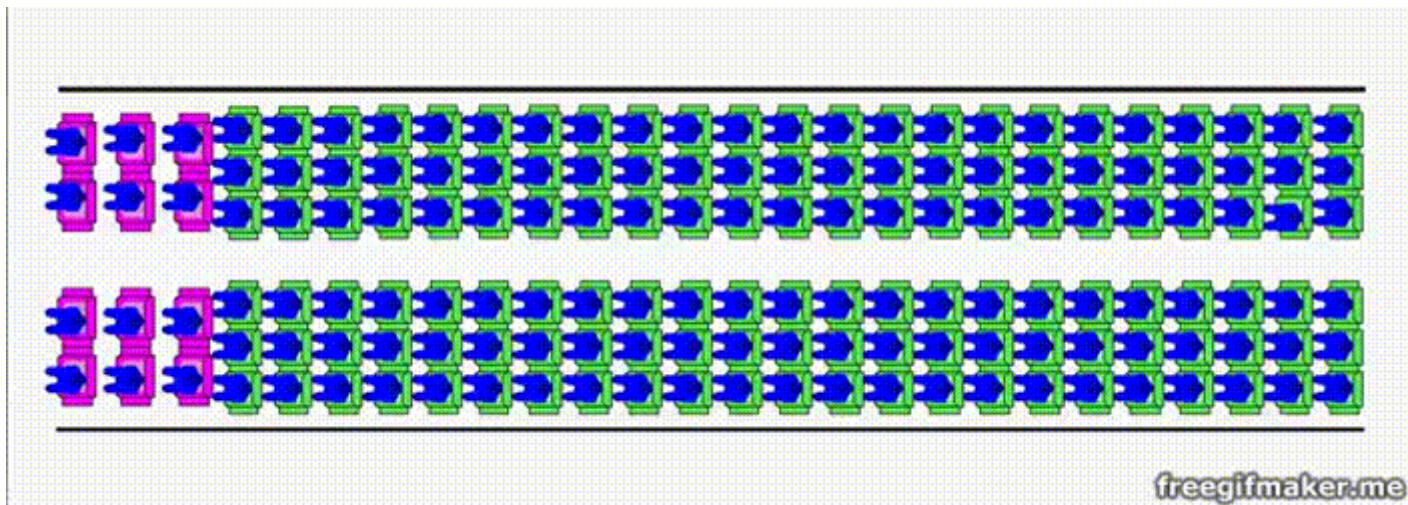


# AIRPLANE BOARDING (BACK TO FRONT)



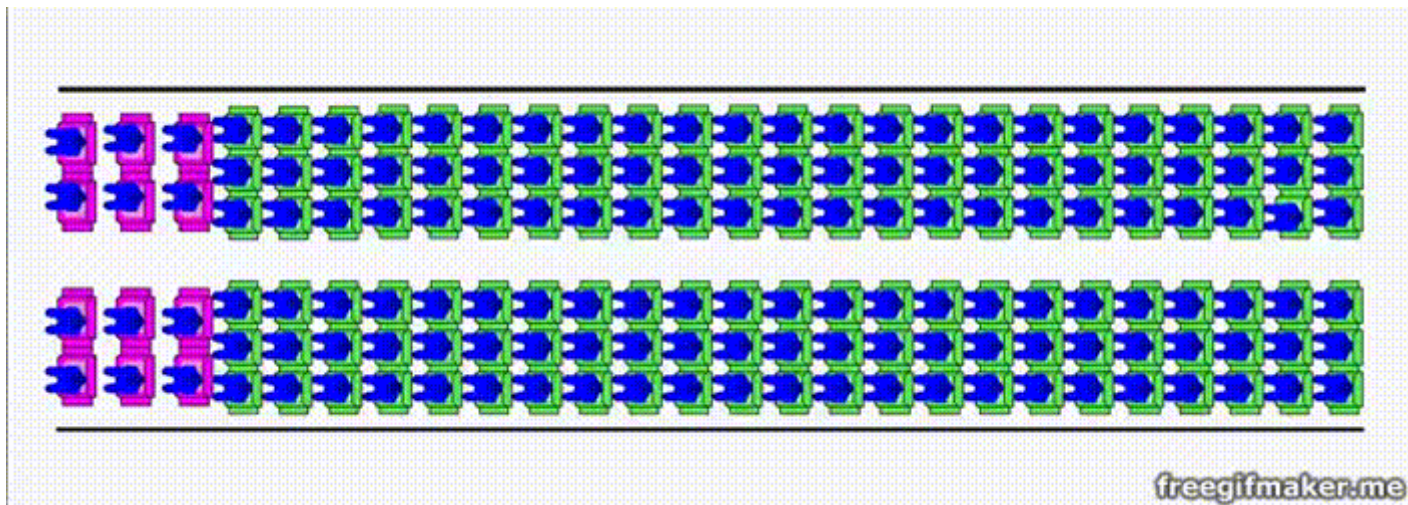
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# AIRPLANE BOARDING (RANDOM)



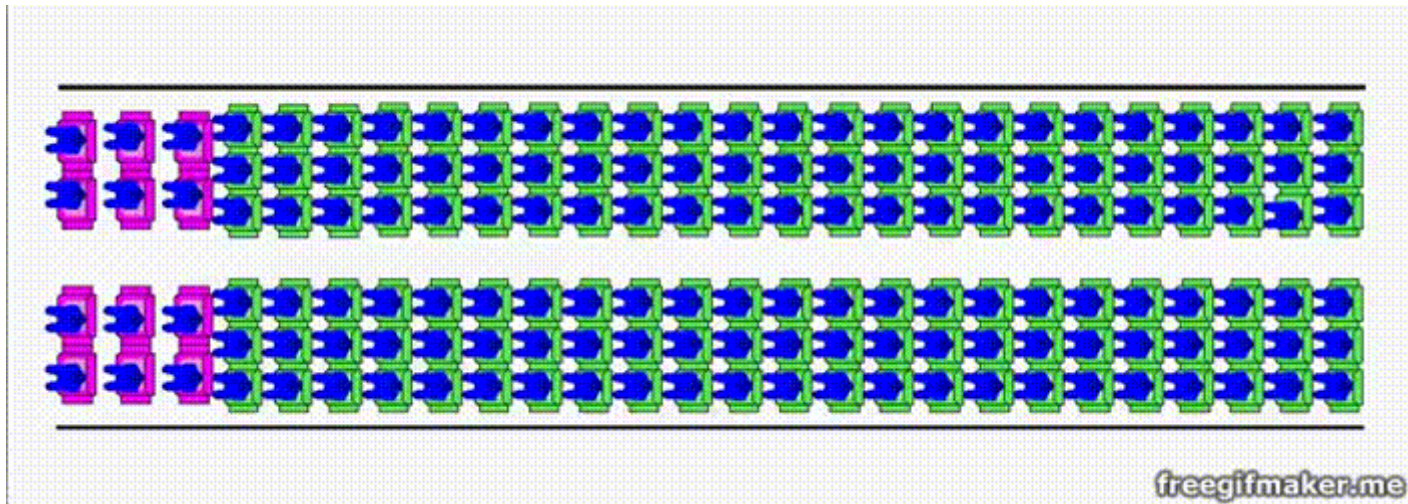
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# AIRPLANE BOARDING (OUTSIDE IN)



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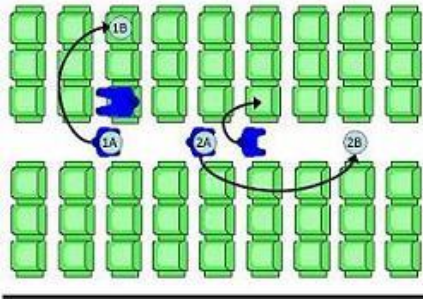
# AIRPLANE BOARDING (BY SEAT)



Source: Menkes van den Briel <http://www.menkes76.com/projects/boarding/boarding.htm>

# AIRPLANE BOARDING

- How to determine the best method?
  - What performance metrics to decide?
- Things to think about:
  - Passenger movements / lineup order



- Single, double door usage?
  - Different type of passengers (young, old, with babies/kids, disabled...)
  - Passengers with/without carry-on
- How to make the analysis?

# SYSTEM

A set of interacting components or entities operating together to achieve a common goal or objective.

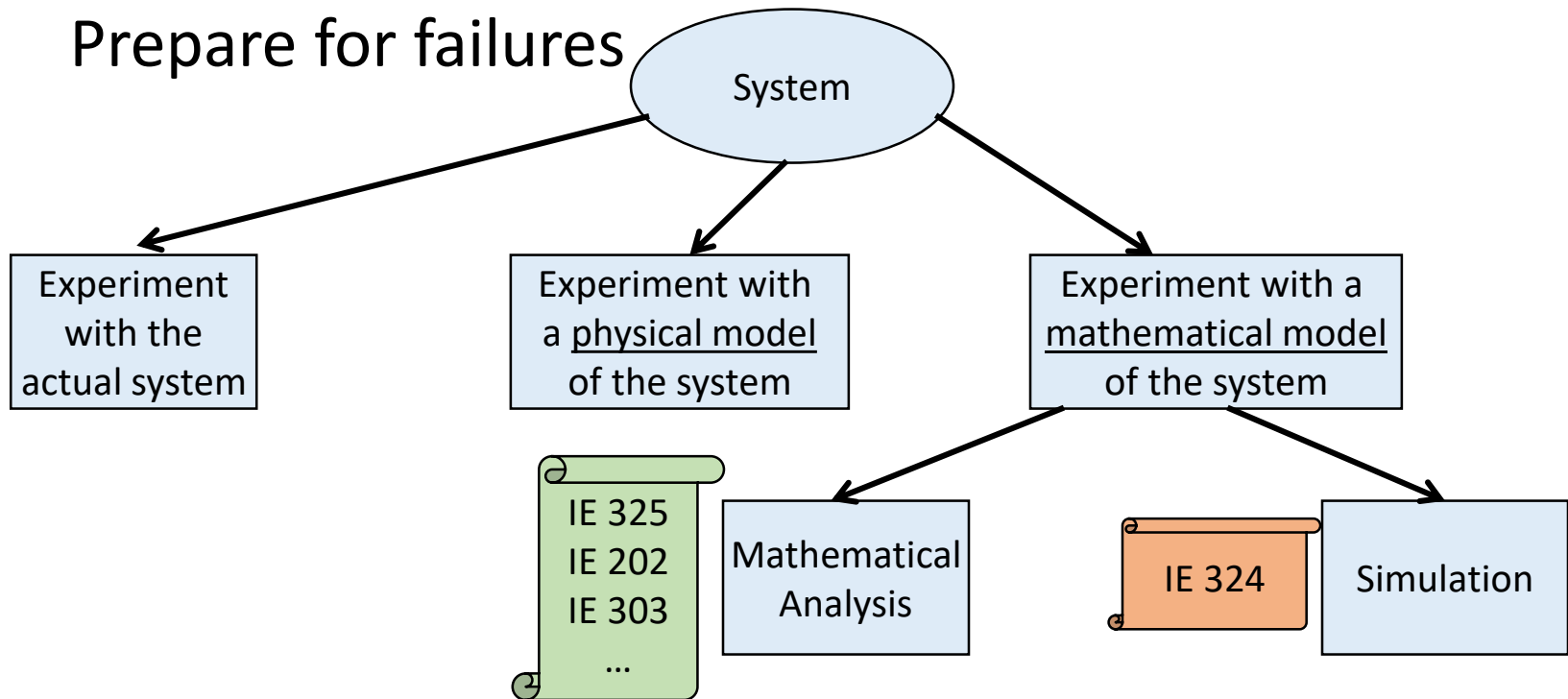
## Examples

- Manufacturing facility
- Bank operation
- Airport operations (passengers, security, planes, crews, baggage)
- Transportation/logistics/distribution operation
- Hospital facilities (emergency room, operating room, admissions)
- Computer network
- Freeway system
- Business process (insurance office)
- Fast-food restaurant
- Supermarket
- Theme park
- Emergency-response system

REAL WORLD SYSTEMS OF INTEREST ARE HIGHLY COMPLEX!!!

# WHY AND HOW TO STUDY A SYSTEM?

- Measure/estimate performance
- Improve operation
- Prepare for failures



# MODEL

- An abstract and simplified representation of a system
  - Not an exact re-creation of the original system!
  - Specifies assumptions/approximations about how the system works
  - Translates them into a set of logical and mathematical relations
- If model is simple, you may use:
  - Queueing Theory
  - Linear Programming
  - Differential Equations
- If model is complex, **simulation** is usually the only way!

# WHAT IS SIMULATION?

- The imitation of the operation of a real-world process or system *over time*...
  - Most widely used tool (along with LP) for decision making
- Applied to complex systems that are impossible to solve mathematically
- This course focuses on one form of simulation modeling
  - Discrete-event simulation modeling

# WHAT IS SIMULATION?

Simulation models seek to:

- Describe the behaviour of the system
- Construct theories or hypotheses based on the observed behaviour
- Use these theories to predict the future behaviour, that is, the effects that will be produced by changes in the system or its method of operation

# ORIGIN OF SIMULATION

- Lie in statistical sampling theory, e.g., random numbers, random sampling  
(Before the 2<sup>nd</sup> world war)
- Monte Carlo simulation  
(During the 2<sup>nd</sup> world war)
- Modern Applications  
(After the 2<sup>nd</sup> world war)

# SIMULATION AS A TOOL

- 1945-70 A technique of last resort
- Rasmussen & George (1978) - Ranked 5th
- Thomas & Decosta (1979) - Ranked 2nd
- Shannon et al. (1980) - Ranked 2nd
- Harpel et al. (1989) -Ranked 2nd
- (Getting more popular...)

# CLASSIFICATION OF SIMULATION MODELS

## Static (Monte Carlo)

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Represents the system at a particular point in time

- Estimation of  $\pi$
- Risk Analysis in Business

## Dynamic Systems

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Represents the system behaviour over time

### Continuous Simulation:

- (Stochastic) Differential Equations

- Water Level in a Dam

### Discrete Event Simulation:

- System quantities (state variables) change with events

- Queueing Systems
- Inventory Systems

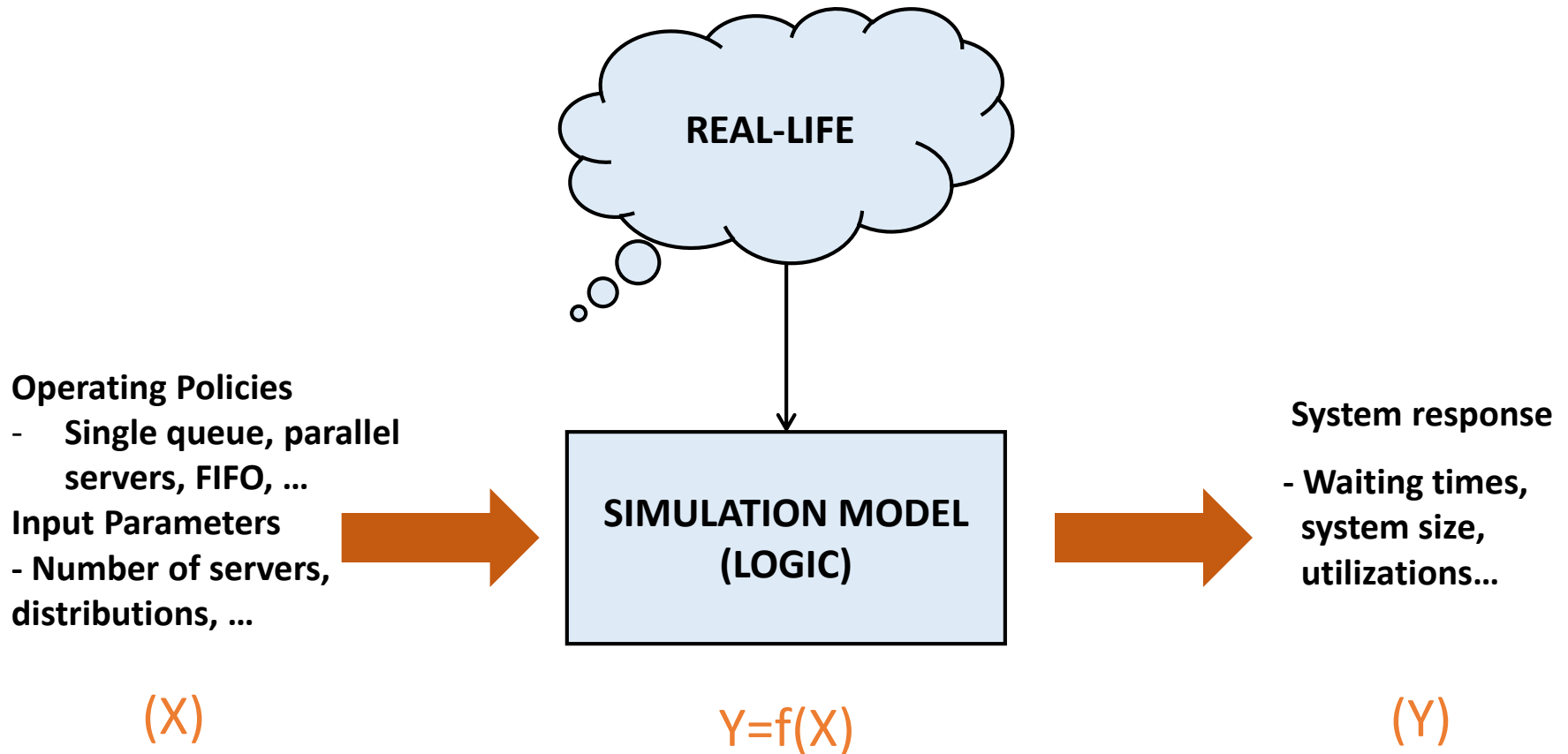
# CAPABILITIES / ADVANTAGES

- Display dynamic behaviour
- Handles randomness and uncertainty
- Diagnose problems (Understand “why?”)
- Explore possibilities (“What if?”)
- Time compression and expansion (controlling time)
- Requires fewer assumptions (than analytical models)
- Flexible and easy to change
- Credible\* and results are easier to explain

# LIMITATIONS

- “Run” rather than “solved”.
- Cannot generate optimal solution on their own
- Requires specialized training (probability, statistics, computer programming, modelling, system analysis, simulation methodology)
- Costly (software and hardware)

# INPUT/OUTPUT PROCESS



# EXAMPLE: Health Center

- Number of Doctors
- Capacity of equipment
- Arrival rate
- Queue Discipline

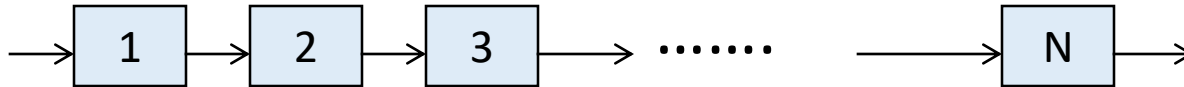


SIMULATION  
MODEL OF A  
HEALTH CENTER

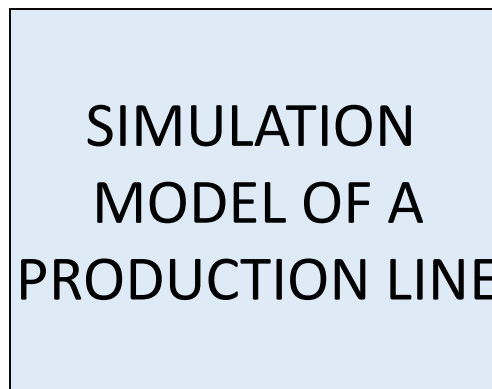


- Time in system
- Utilization of doctors
- Number served

# EXAMPLE: Serial production line



- Size of the line
- Size of buffer
- Buffer allocation
- Location of bottleneck
- Processing times

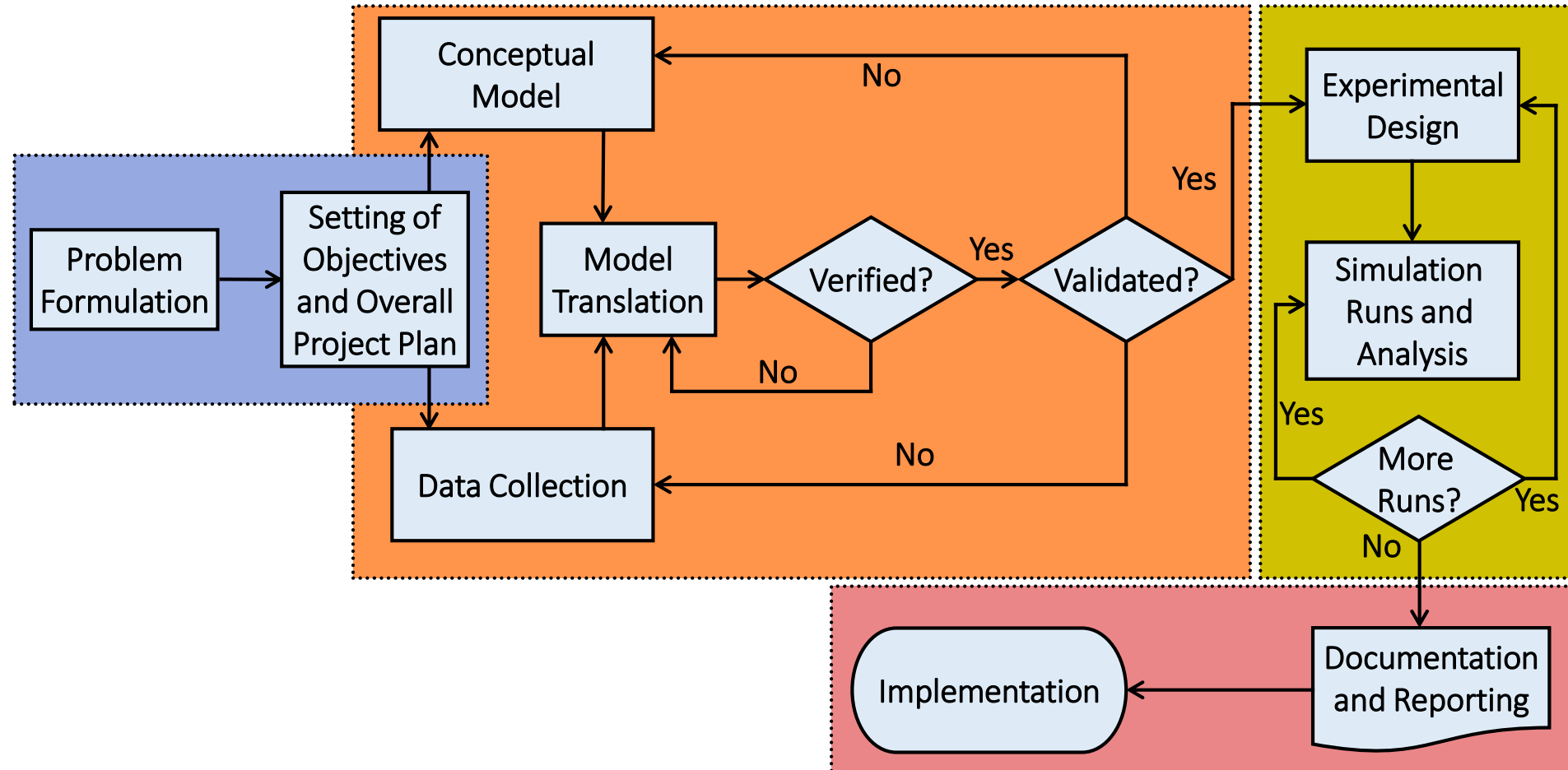


- Throughput
- Interdeparture time variability
- Utilization

# ANALYTICAL VS SIMULATION

- Use analytical models whenever possible
- Use simulation models when:
  1. Complete mathematical formulation does not exist or an analytical solution cannot be developed
  2. Analytical methods are available, but the mathematical procedures are so complex that simulation provides a simpler solution
  3. It is desired to observe a simulated history of the process over a period of time in addition to estimating certain system performances

# STEPS IN A SIMULATION STUDY



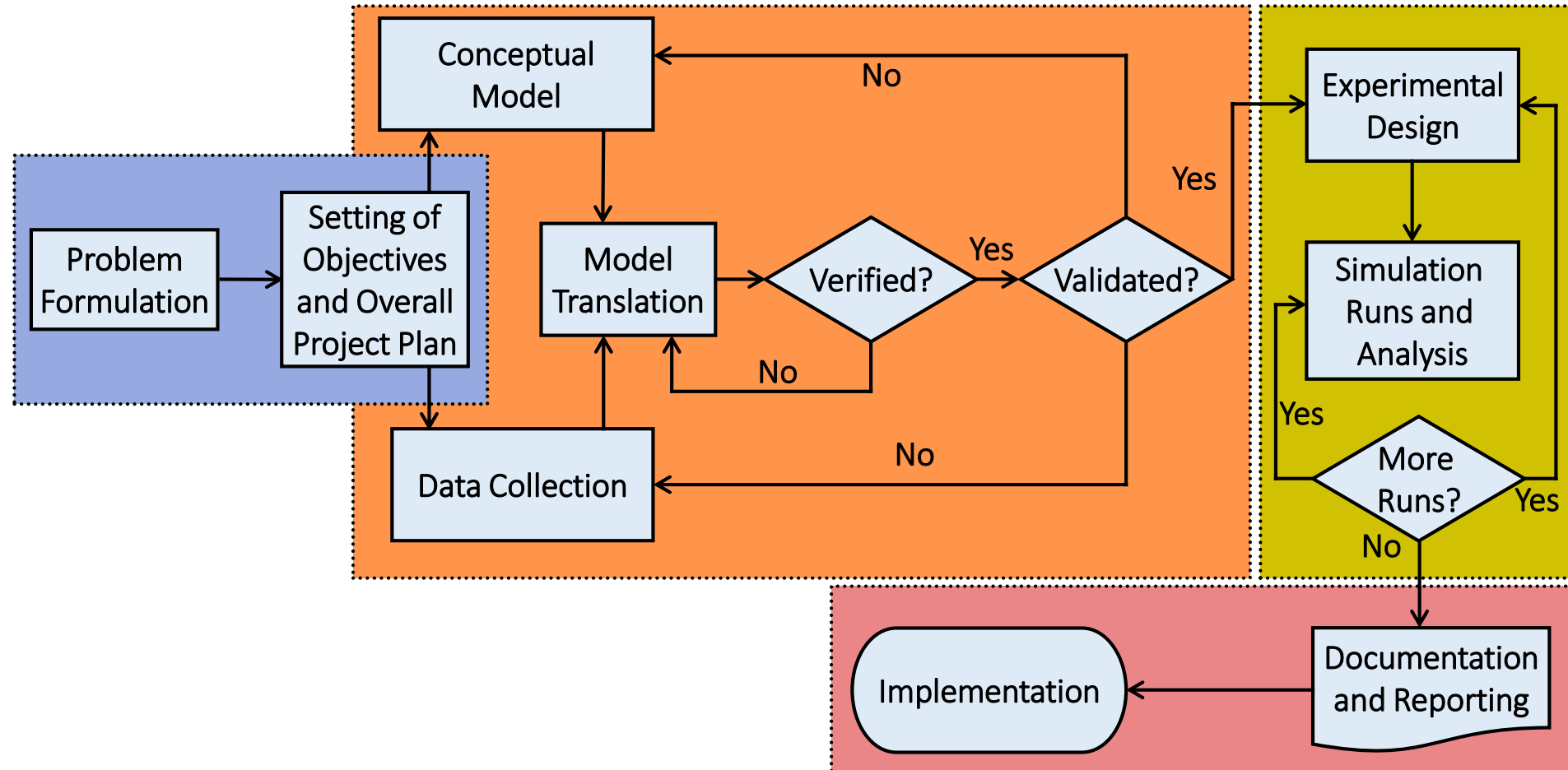
# PROBLEM FORMULATION (NOT MODEL)

- A statement of the problem
  - the problem is clearly understood by the simulation modeler
  - the formulation is clearly understood by the client
- Criteria for selecting a problem
  - Technical and economical feasibility
  - Perceived urgency for a solution

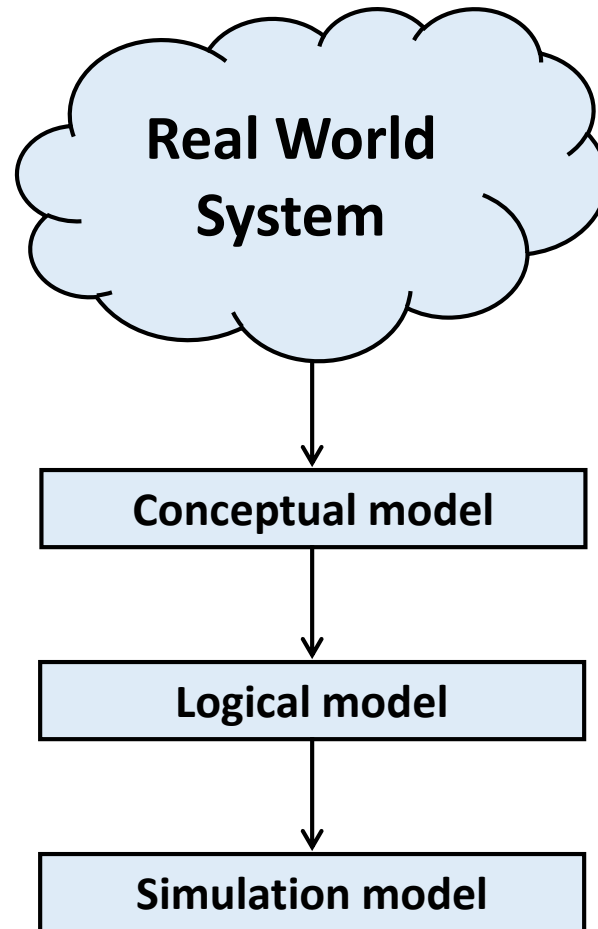
# SETTING OBJECTIVES AND PROJECT PLAN

- Determine the questions that are to be answered
  - Objective to be achieved
  - Identify scenarios to be investigated
  - Level of details (assumptions)
  - Determine the end-user, data, hardware, software, personnel, and time requirements
- Is simulation appropriate?

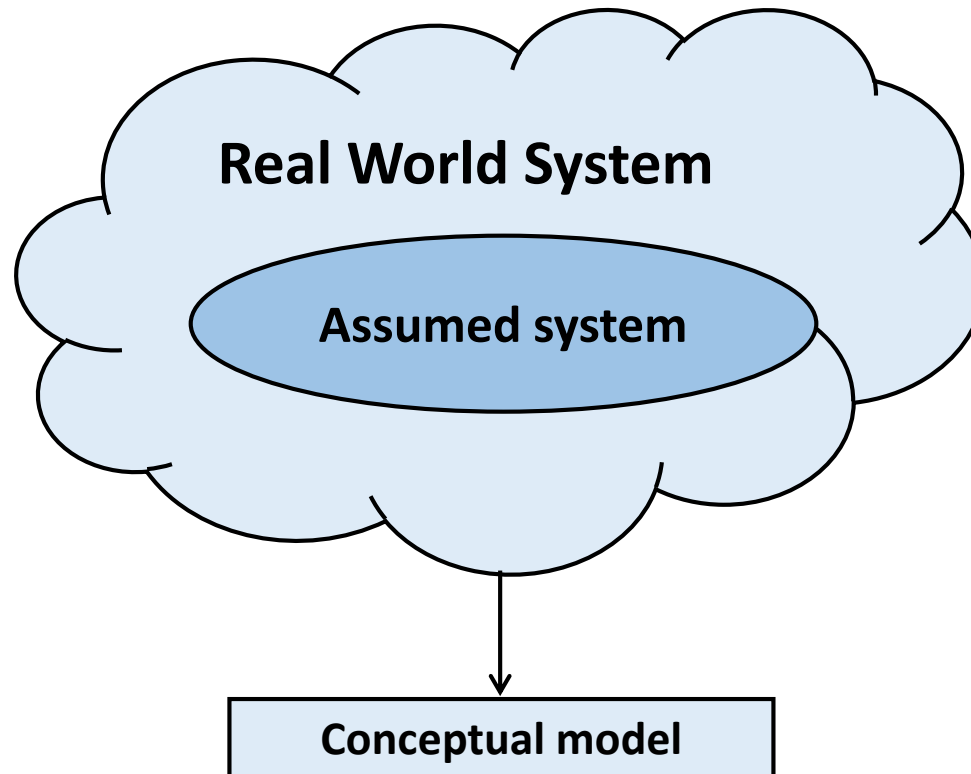
# STEPS IN A SIMULATION STUDY



# MODEL DEVELOPMENT



# CONCEPTUAL MODEL

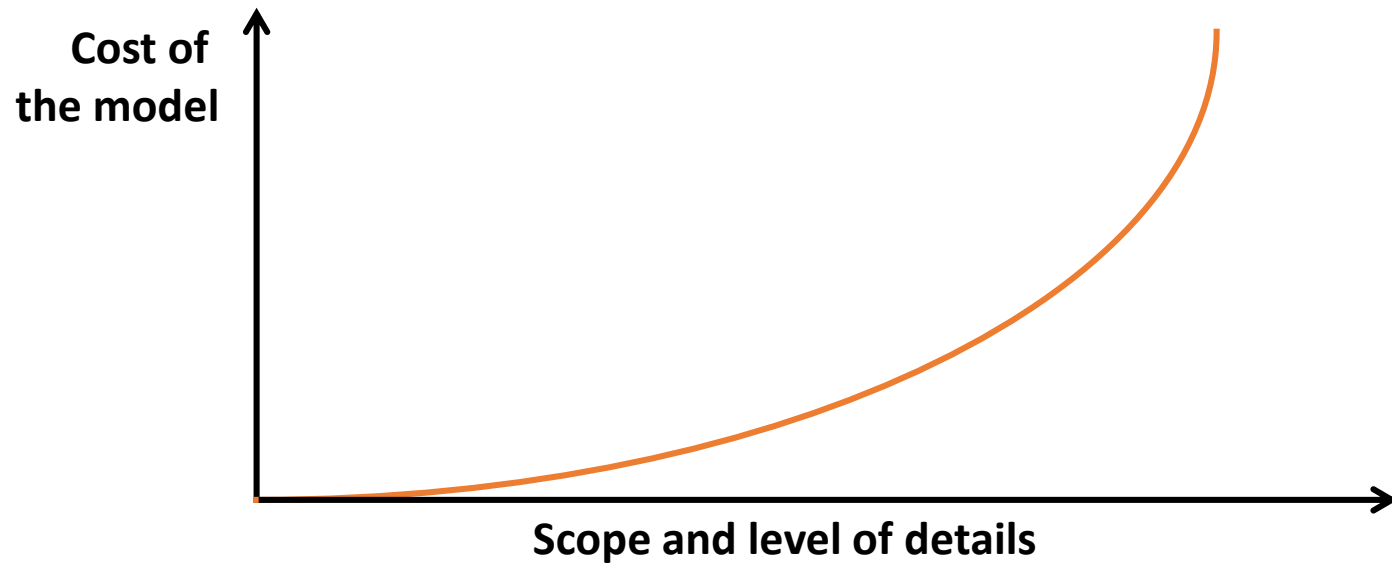
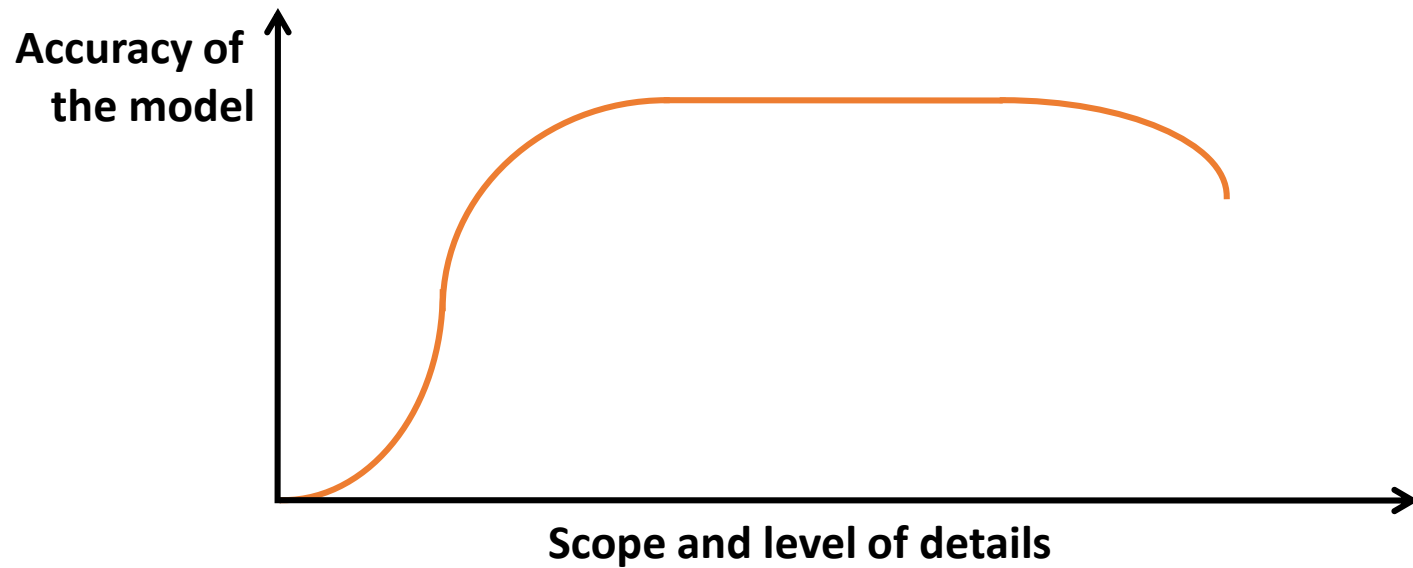


# CONCEPTUAL MODEL

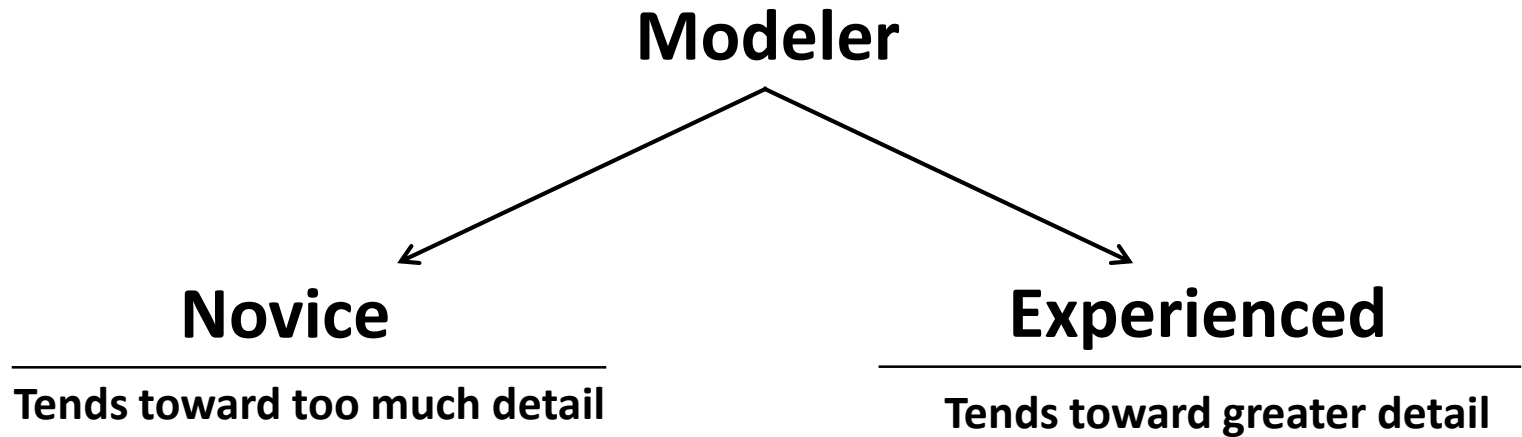
- Level of details - assumptions
- Model components
  - Events, entities, attribute, exogenous variables, endogenous variables, and their relationships
- Data requirements

# LEVEL OF DETAIL

- Too little detail result in lost of information and goals cannot be accomplished
- Too much detail requires:
  - more time and effort
  - longer simulation runs
  - more likely to contain errors

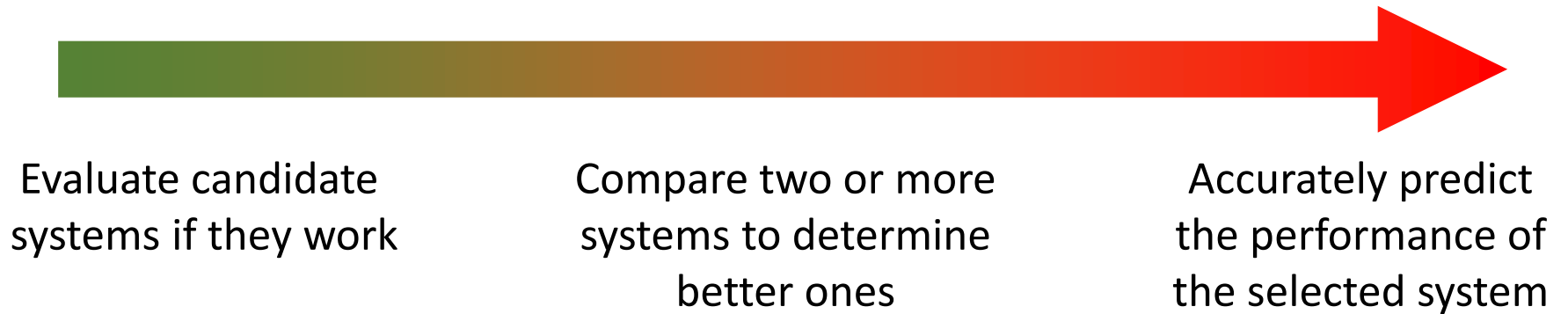


# LEVEL OF DETAIL



**KISS**

# LEVEL OF DETAIL



# COMPONENTS OF A SYSTEM

***Entity***: is an object of interest in the system

- *Dynamic objects* — get created, move around, change status, affect and are affected by other entities, leave (maybe)
- Usually have multiple *realizations* floating around
- Can have different types of entities concurrently

Example: Health Center

Patients

Visitors



# COMPONENTS OF A SYSTEM

***Attribute***: is a characteristic of all entities, but with a specific value “local” to the entity that can differ from one entity to another.

Example: Patient

Type of illness,

Age,

Sex,

Temperature,

Blood Pressure



# COMPONENTS OF A SYSTEM

**Resources:** what entities compete for

- Entity *seizes* a resource, uses it, *releases* it
- Think of a *resource being assigned to an entity*, rather than an entity “belonging to” a resource
- “A” resource can have several *units* of capacity which can be changed during the simulation

Example: Health Center

Doctors, Nurses

X-Ray Equipment



# COMPONENTS OF A SYSTEM

***Variable:*** A piece of information that reflects some characteristic of the whole system, not of specific entities

- Entities can access, change some variables

Example: Health Center

Number of patients in the system,

Number of idle doctors,

Current time



# COMPONENTS OF A SYSTEM

- ***State***: A collection of variables that contains all the information necessary to describe the system at any time

Example: Health Center

{Number of patients in the system,  
Status of doctors (busy or idle),  
Number of idle doctors,  
Status of Lab equipment, etc.}



# COMPONENTS OF A SYSTEM

- **Event:** An instantaneous occurrence that changes the state of the system

## Example: Health Center

Arrival of a new patient,

Completion of service  
(i.e., examination)

Failure of medical  
equipment, etc.



# COMPONENTS OF A SYSTEM

**Activity:** represents a time period of specified length.

Example: Health Center

Surgery,

Checking temperature,

X-Ray.

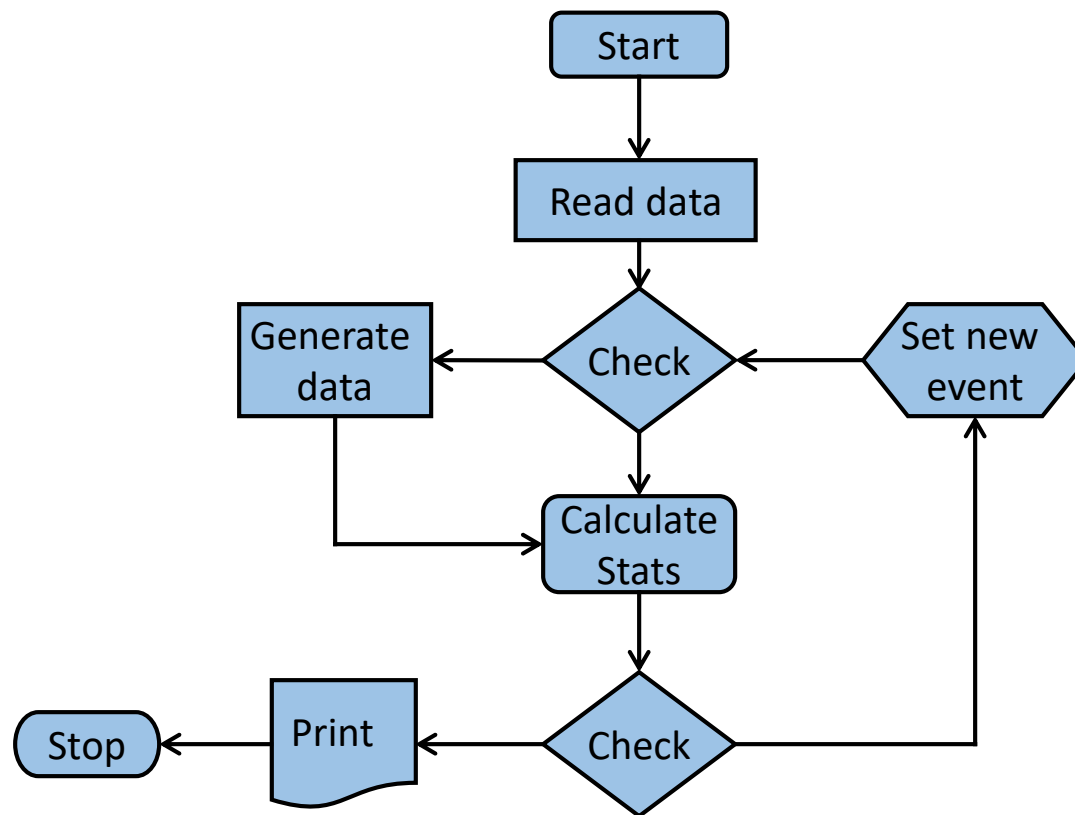


# DATA COLLECTION AND ANALYSIS

- Data collection is an expensive process!
- The client often collects the data & submit it in electronic format
- Simulation analyst analyse the data
  - Determine the random variables
  - Determine the data requirements
  - Analyse the data
  - Fit distribution functions

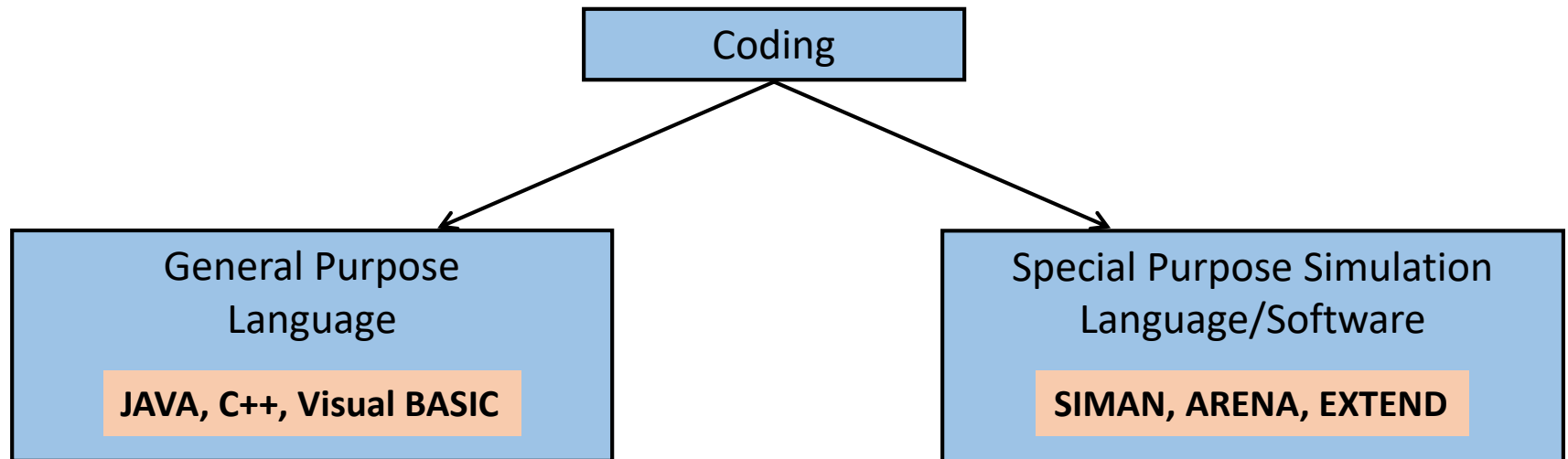
# LOGICAL (or Flowchart model)

Shows the logical relationships among the elements of the model

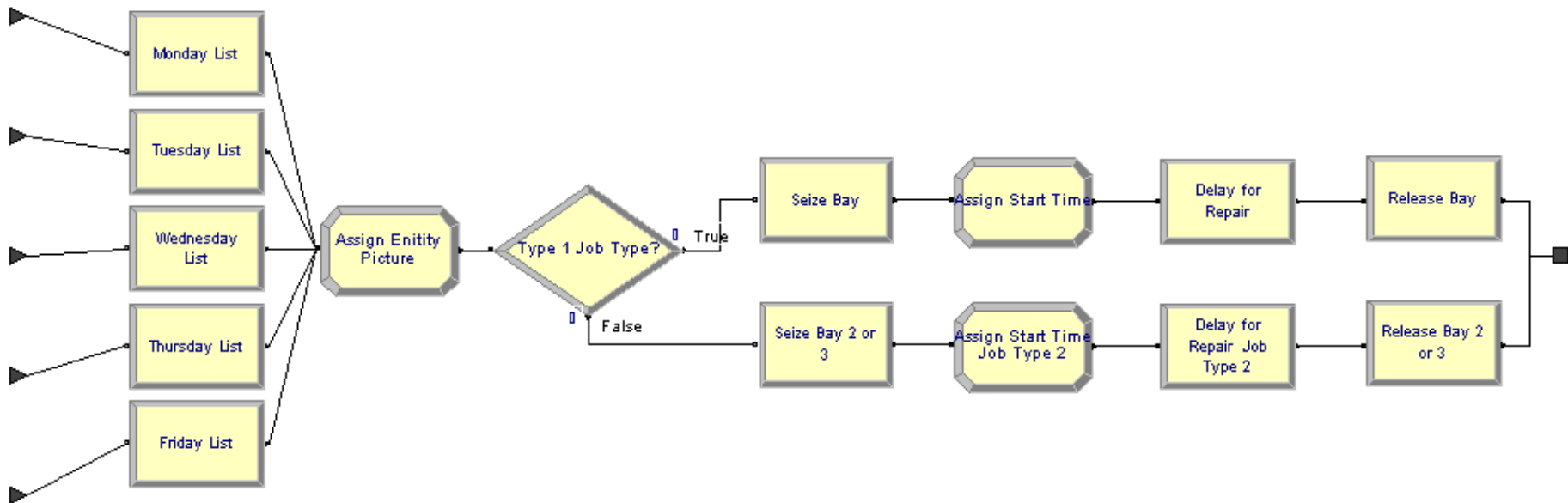


# MODEL TRANSLATION

- Simulation model executes the logic contained in the flow-chart model



# ARENA EXAMPLE



# SIMAN EXAMPLE

```
--- MODEL FILE ---  
  
BEGIN;  
CREATE,1:,EXPO(40):EX(40):MARK(1);  
QUEUE,1;  
SEIZE:DOCTOR;  
DELAY:EXPO(30);  
TALLY:1,INT(1);  
RELEASE:DOCTOR;  
COUNT:1:DISPOSE;  
END:  
  
----EXPERIMENTAL FILE ----  
  
BEGIN;  
PROJECT,HEALTH_CENTRE, IHSA SABUNCUOGLU,24/1/2000;  
DISCRETE,100,1,1;  
RESOURCES:1,  
DOCTORS;  
DSTATS:1,NQ(!),NUMBER_IN_QUEUE:  
2,NR(1),DOCTOR UTILIZATION;  
TALLIES:1, TIME IN HEALTH_CENTRE;  
COUNTERS:1,No. OF PATIENTS SERVED;  
END;
```

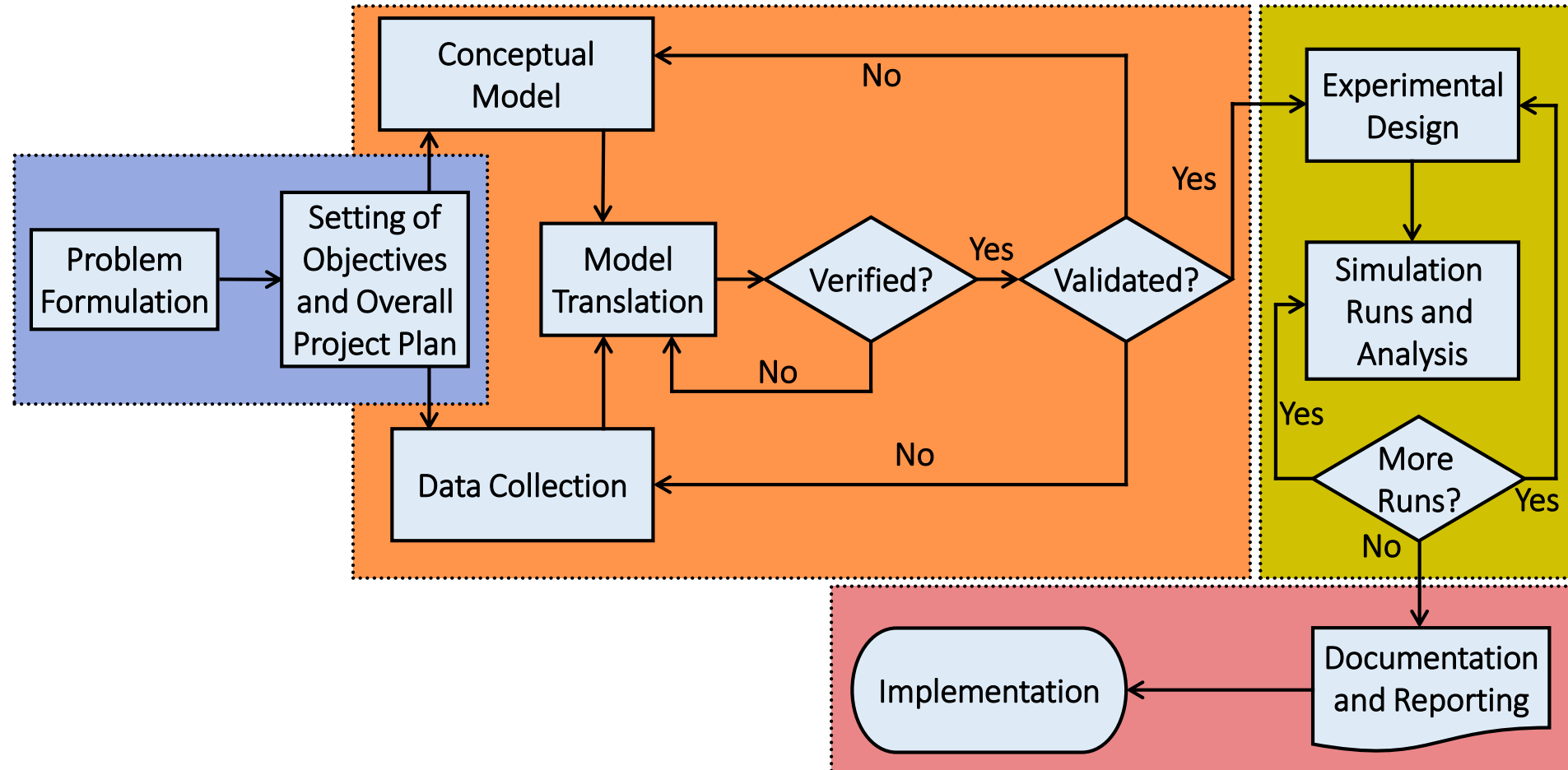
# JAVA EXAMPLE

```
public static void main(String argv[])
{
    Initialization();

    //Loop until first "TotalCustomers" have departed
    while (NumberofDepartures < TotalCustomers)
    {
        Event evt = FutureEventList[0]; //get imminent event
        removefromFEL(); //be rid of it
        Clock = evt.get_time(); //advance in time
        if (evt.get_type() == arrival) ProcessArrival();
        else ProcessDeparture();
    }

    ReportGeneration();
}
```

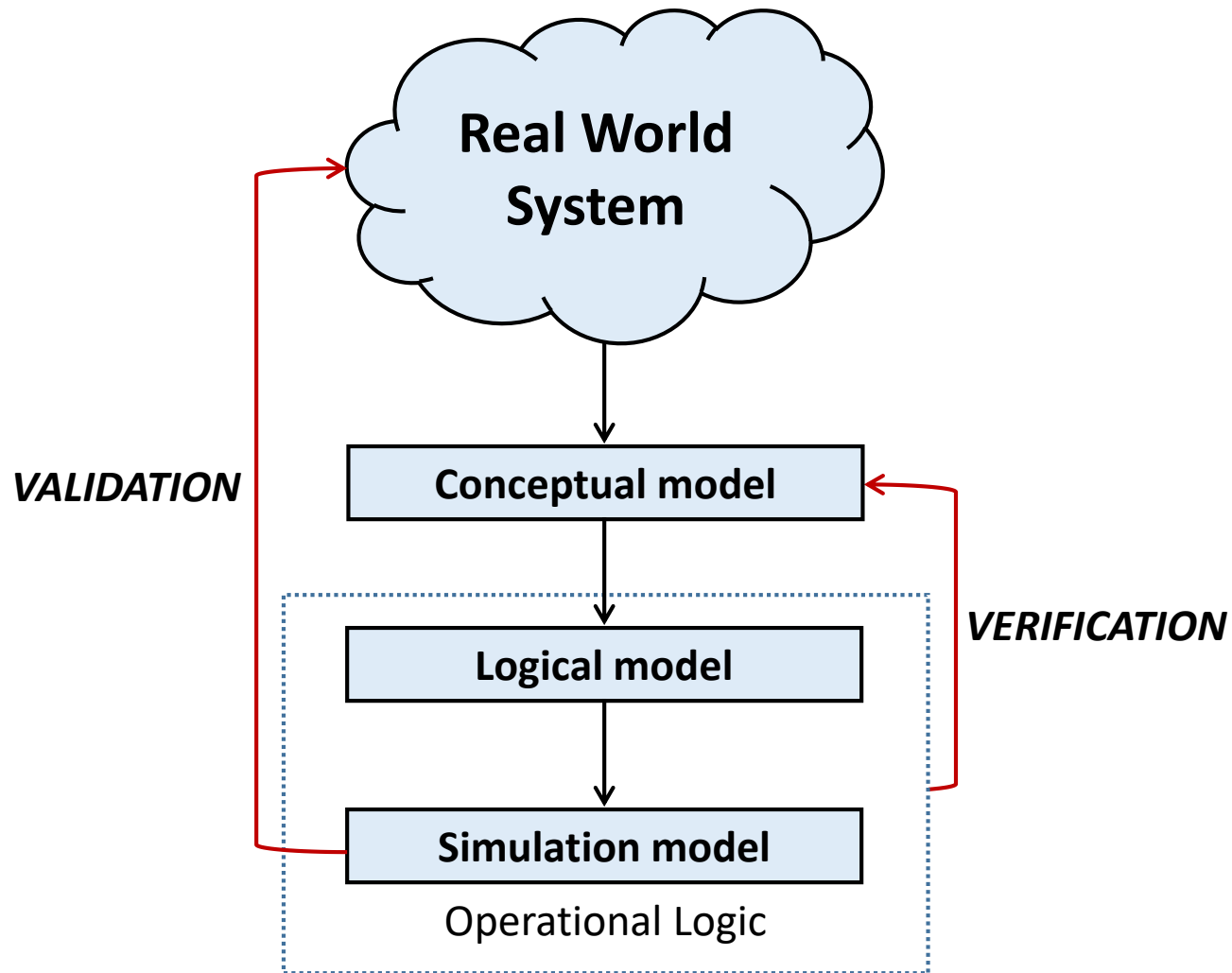
# STEPS IN A SIMULATION STUDY



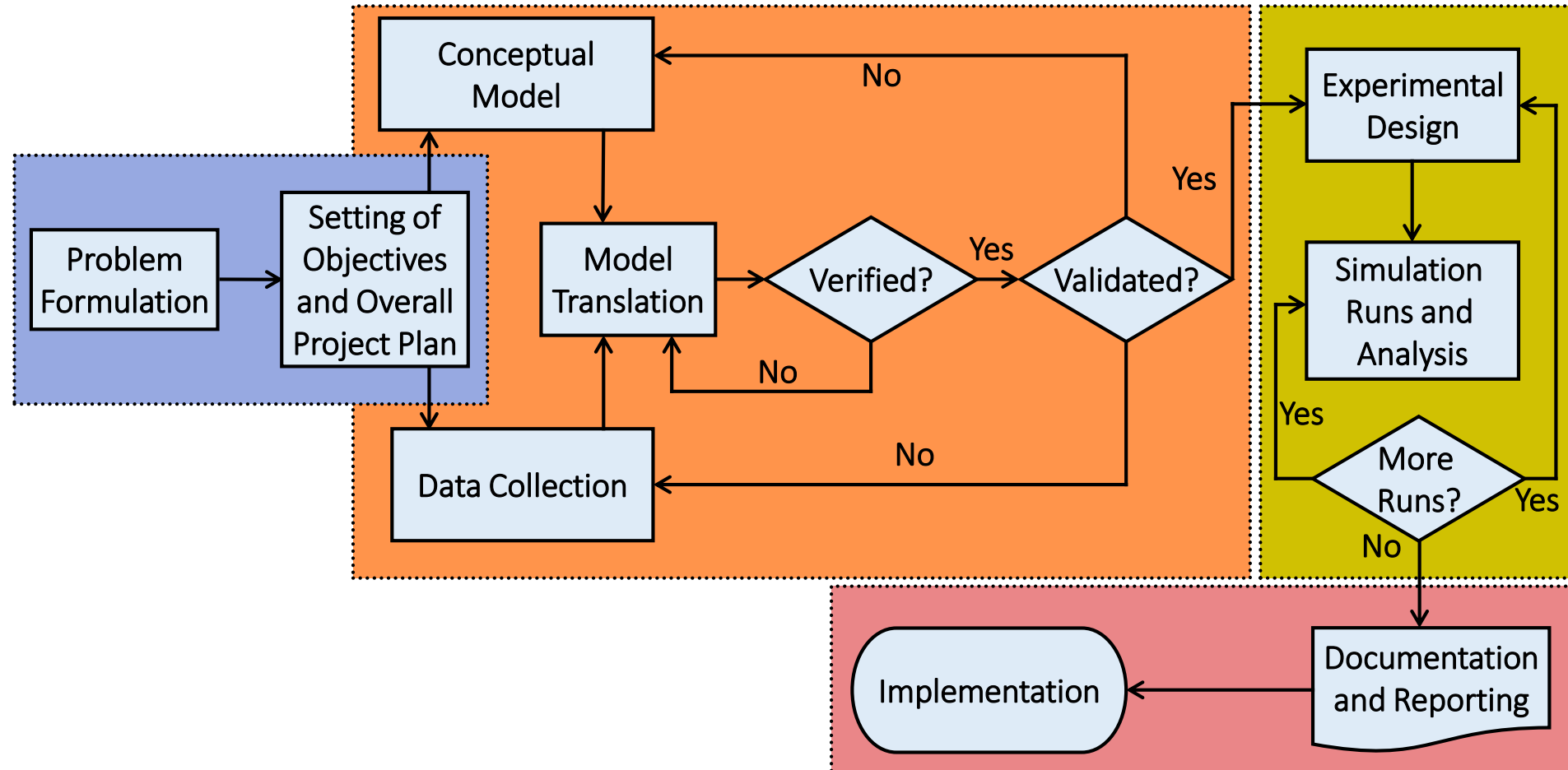
# VERIFICATION AND VALIDATION

- ***Verification***: the process of determining if the operational logic is correct.
  - Debugging the simulation software
- ***Validation***: the process of determining if the model accurately represents the system.
  - Comparison of model results with collected data from the real system

# VERIFICATION AND VALIDATION



# STEPS IN A SIMULATION STUDY



# ANALYSIS OF RESULTS

- Statistical tests for significance
  - Point Estimation
  - Confidence-Interval Estimation
- Interpretation of results
- More runs?

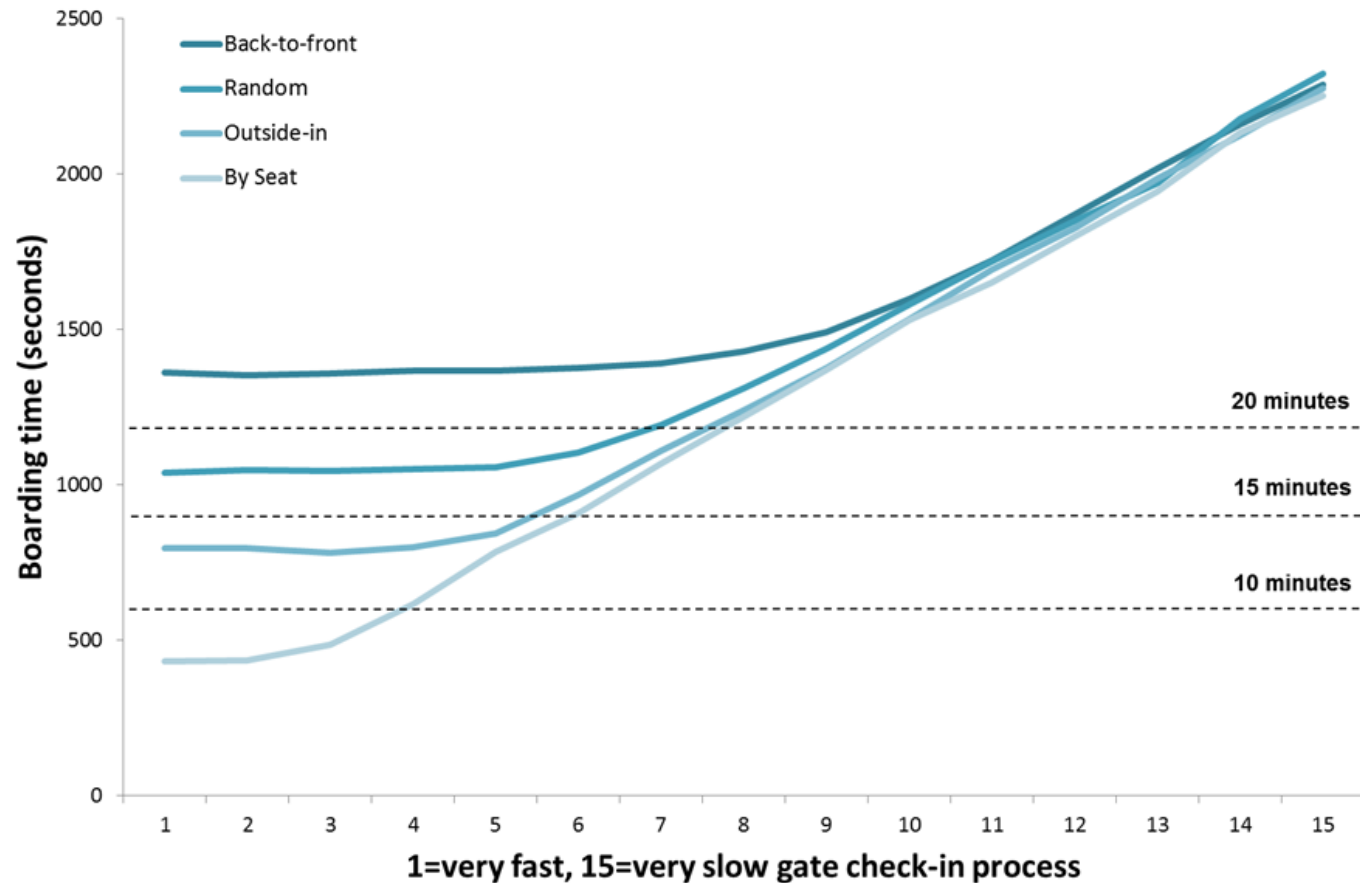
# EXPERIMENTAL DESIGN

- Alternative scenarios to be simulated
- Type of output data analysis (steady state vs transient state analysis)
- Number of simulation runs
- Length of each run
- The manner of initialization
- Variance reduction

# DOCUMENTATION & REPORTING

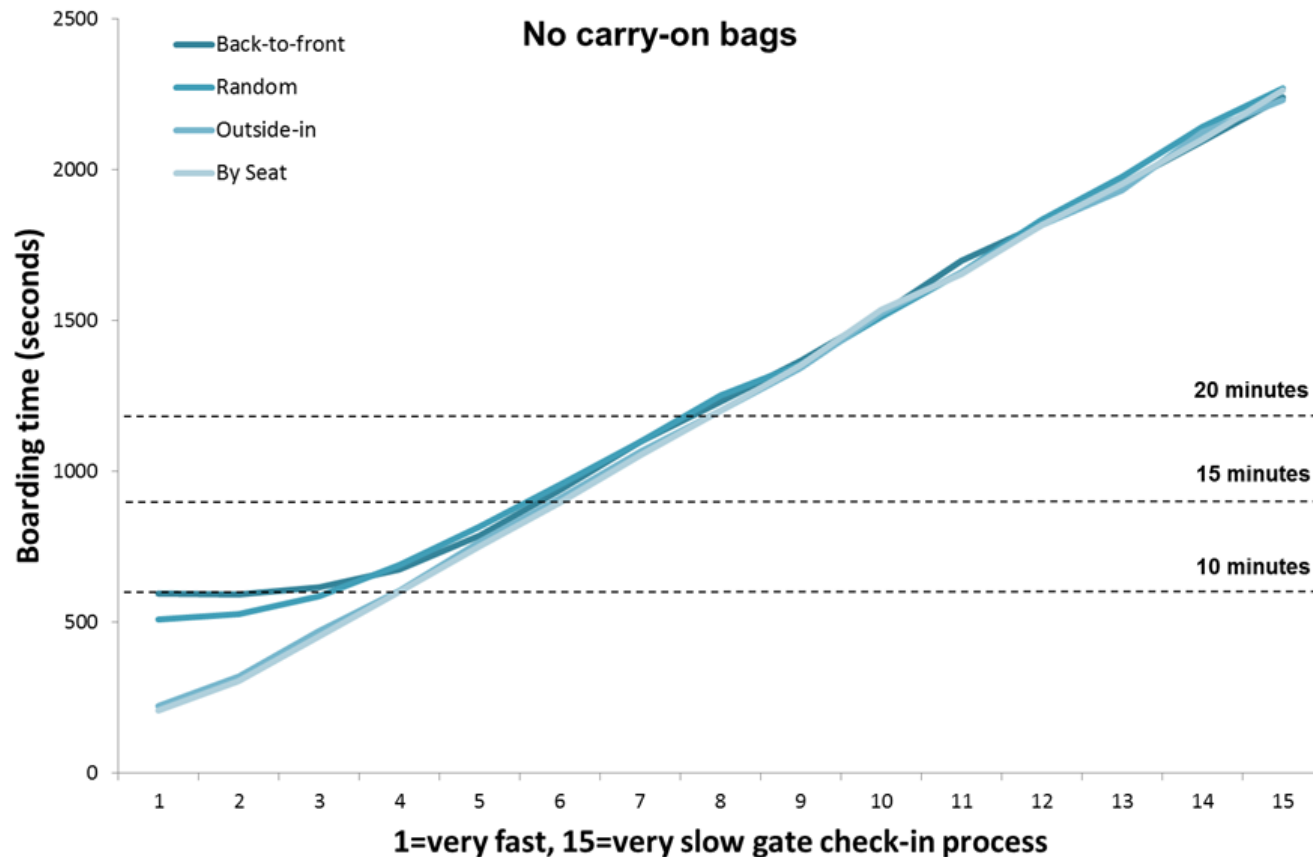
- Program Documentation
  - Allows future modifications
  - Creates confidence
- Progress Reports
  - Frequent reports (e.g. monthly) are suggested
  - Alternative scenarios
  - Performance measures or criteria used
  - Results of experiments
  - Recommendations

# AIRPLANE BOARDING (COMPARISON)



Source: Menkes van den Briel <http://www.menkes76.com/projects/boarding/boarding.htm>

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