IE 324 SIMULATION

2024 SPRING

INTRODUCTION

IE 324 SIMULATION

- Instructor:
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  - Office Hours: By appointment
- Teaching Assistants:
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  - Sena Aslı Bozkurt

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.
- Emphasis is primarily on applications in the areas of production management.
- 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 %
- ARENA Quiz: 13%
- Final Exam: 35 %
- Course Project: 12 %
- Homework Assignments: 5%

THIS ASSESSMENT CRITERIA AND THE PERCENTAGES ARE SUBJECT TO CHANGE!

POLICIES

- ***Open-Book Policy:*** You may use the **Simulation with Arena** during the Arena Quizzes. However, the midterm and final exam will be **CLOSED BOOKS** and **CLOSED NOTES**. A formula sheet and necessary statistical tables will be provided.

- ***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

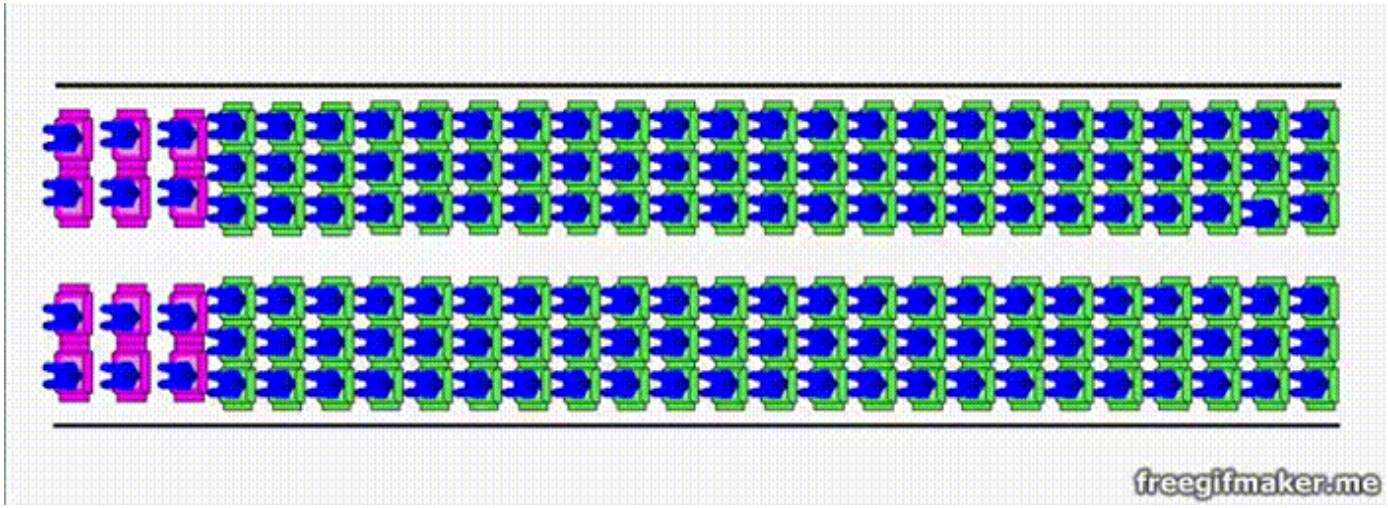
QUESTIONS?

AIRPLANE BOARDING

- How to board an airplane?

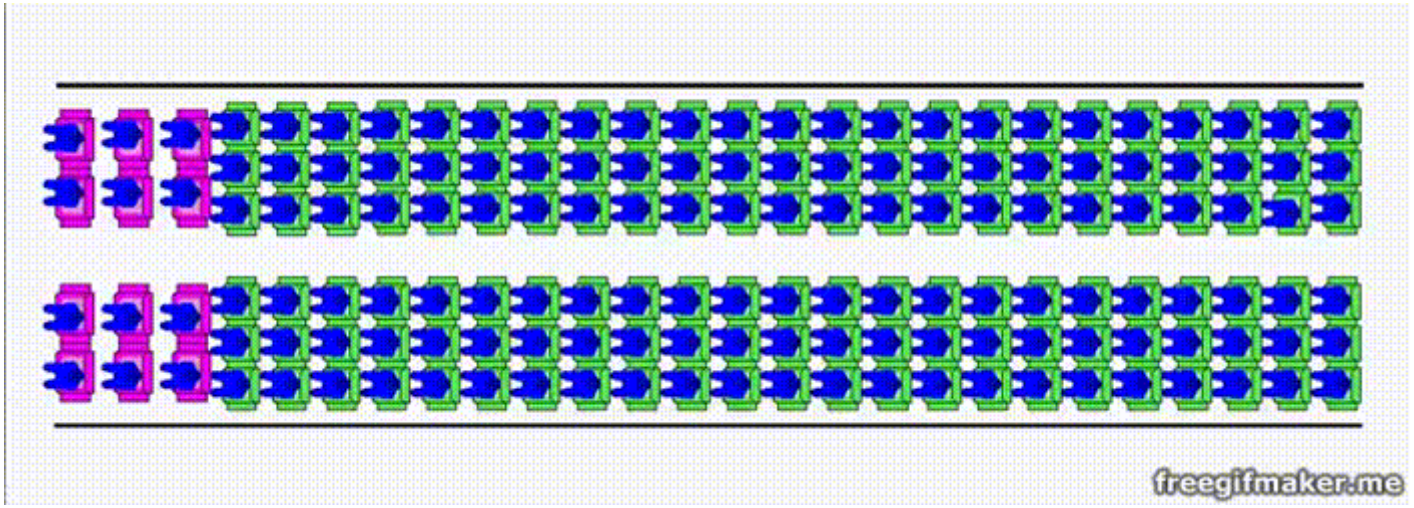
- The order of boarding is usually determined by the carrier and denoted with your boarding group.

AIRPLANE BOARDING (BACK TO FRONT)



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

AIRPLANE BOARDING (RANDOM)



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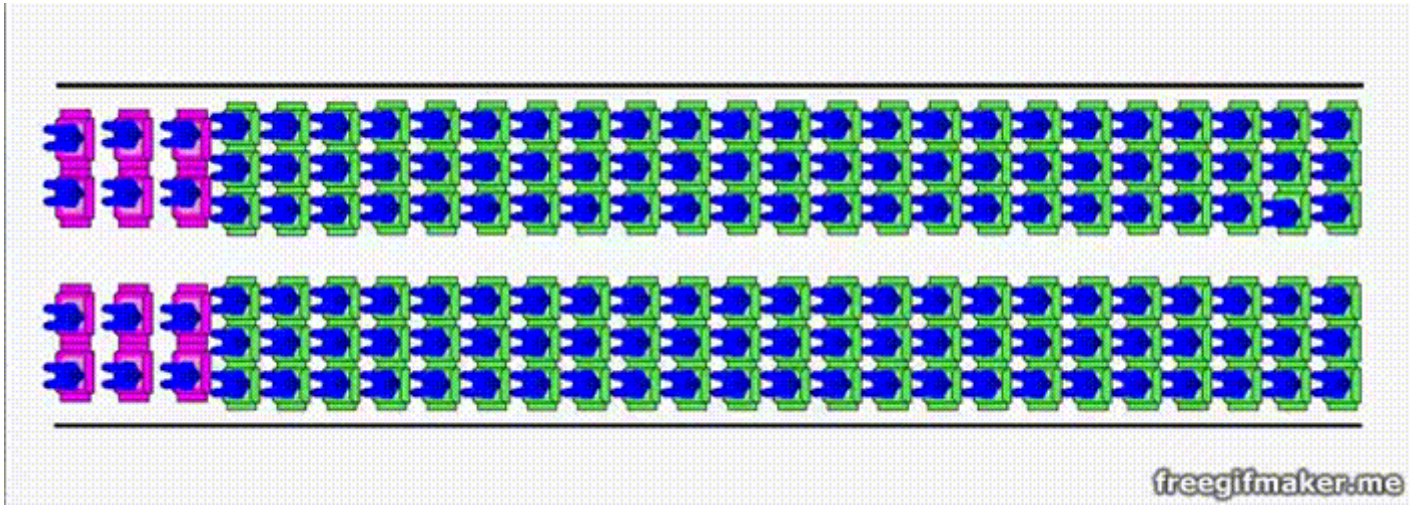
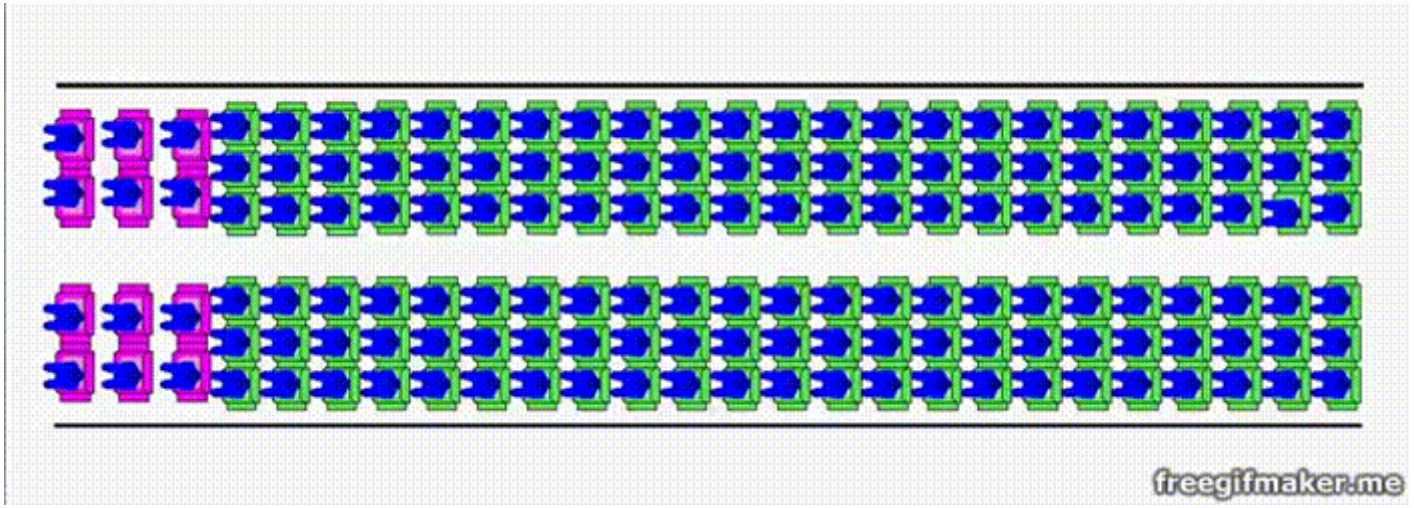
AIRPLANE BOARDING (OUTSIDE IN)



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

AIRPLANE BOARDING (BY SEAT)



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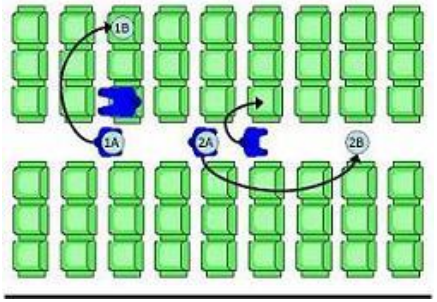
AIRPLANE BOARDING

- 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.

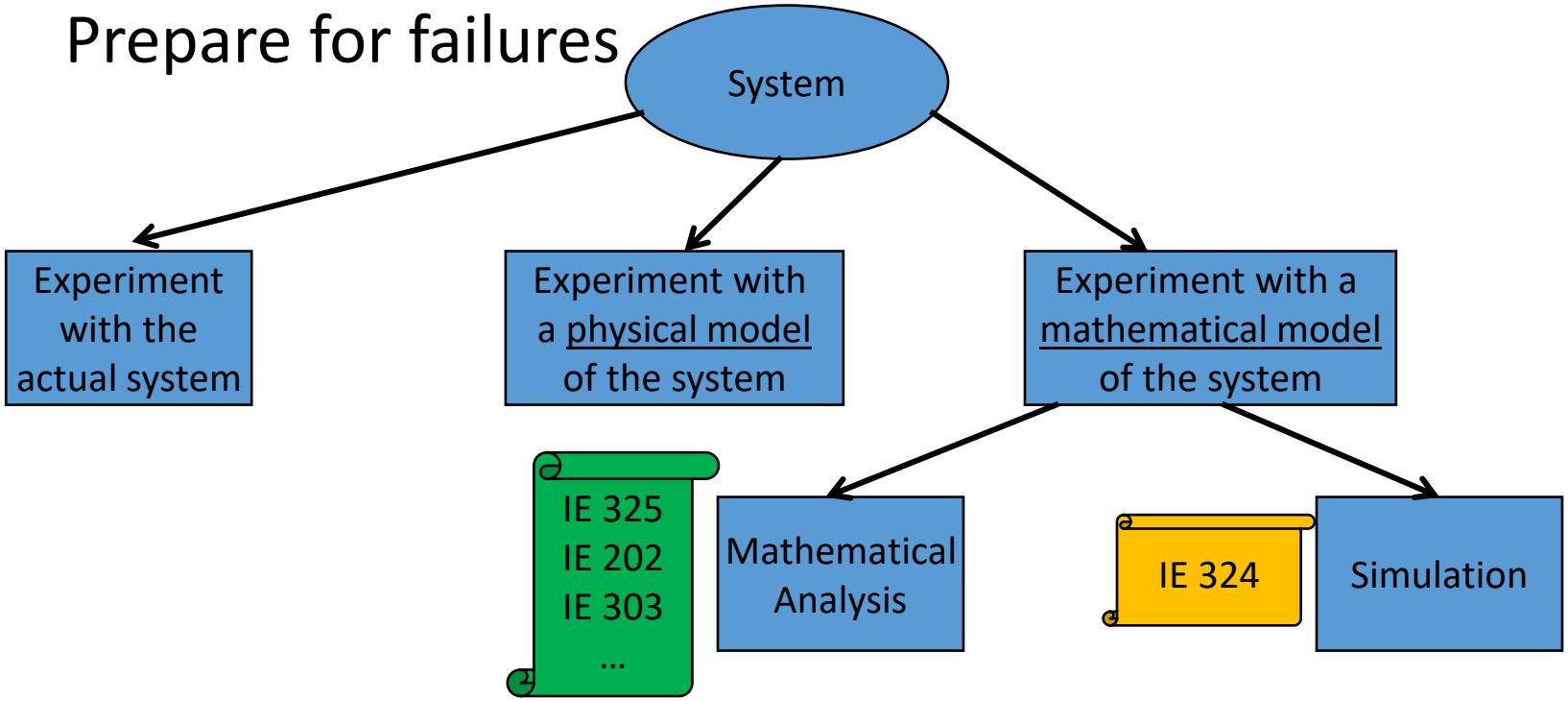
Examples

- 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 enough, study it with 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 LP) for decision making
  - Usually on a computer with appropriate software
  - An analysis (descriptive) tool – can answer what if questions
- Applied to complex systems that are impossible to solve mathematically
- This course focuses on one form of simulation modelling
  - 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 2nd world war)

- Monte Carlo simulation
  (During the 2nd world war)

- Modern Applications
  (After the 2nd 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…)

CHARACTERISTICS

- Mathematical
- Numeric
- Descriptive
- Deterministic/Stochastic
- Static/Dynamic
- Discrete/Continuous

CLASSIFICATION OF SIMULATION MODELS

Static (Monte Carlo)

Represents the system at a particular point in time

- Estimation of π
- Risk Analysis in Business

Dynamic Systems

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

ANALYTICAL VS SIMULATION

- Use analytical model whenever possible
- Use simulation 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

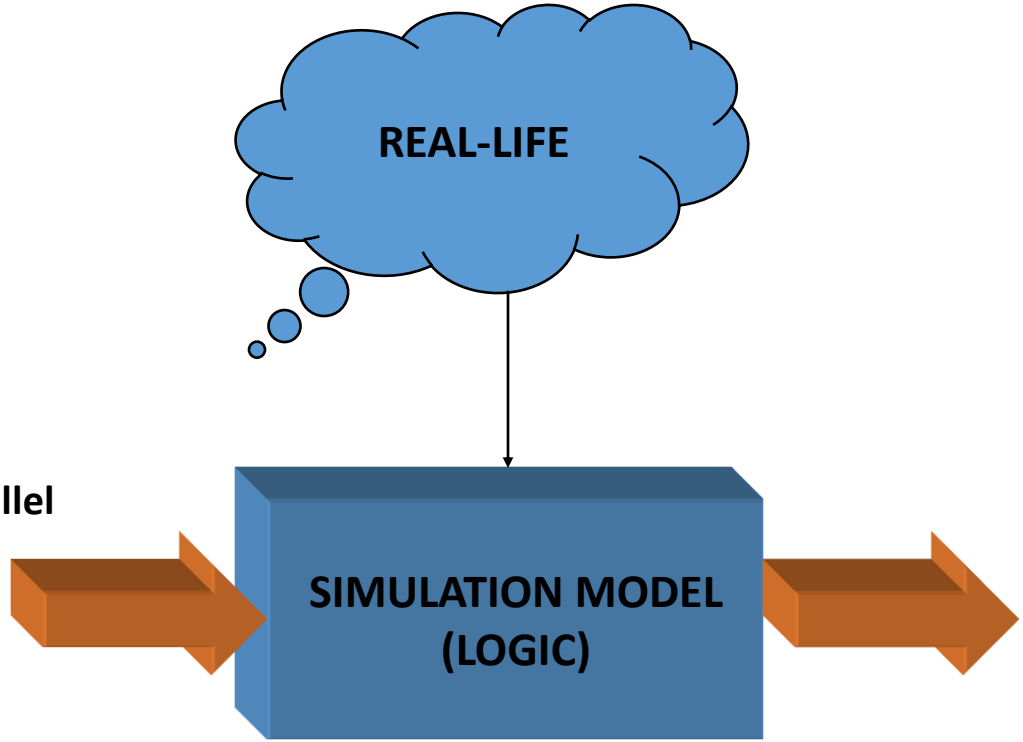
CAPABILITIES / ADVANTAGES

- Display dynamic behaviour
- Handles randomness and uncertainty
- Diagnose problems (Understand “why?”)
- Explore possibilities (“What if?”)
- Time compression and expansion
- 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, modeling, system analysis, simulation methodology)
- Costly (software and hardware)

INPUT/OUTPUT PROCESS



Operating Policies
- **Single queue, parallel servers, FIFO, …**

Input Parameters
- **Number of servers, distributions, …**

(X)

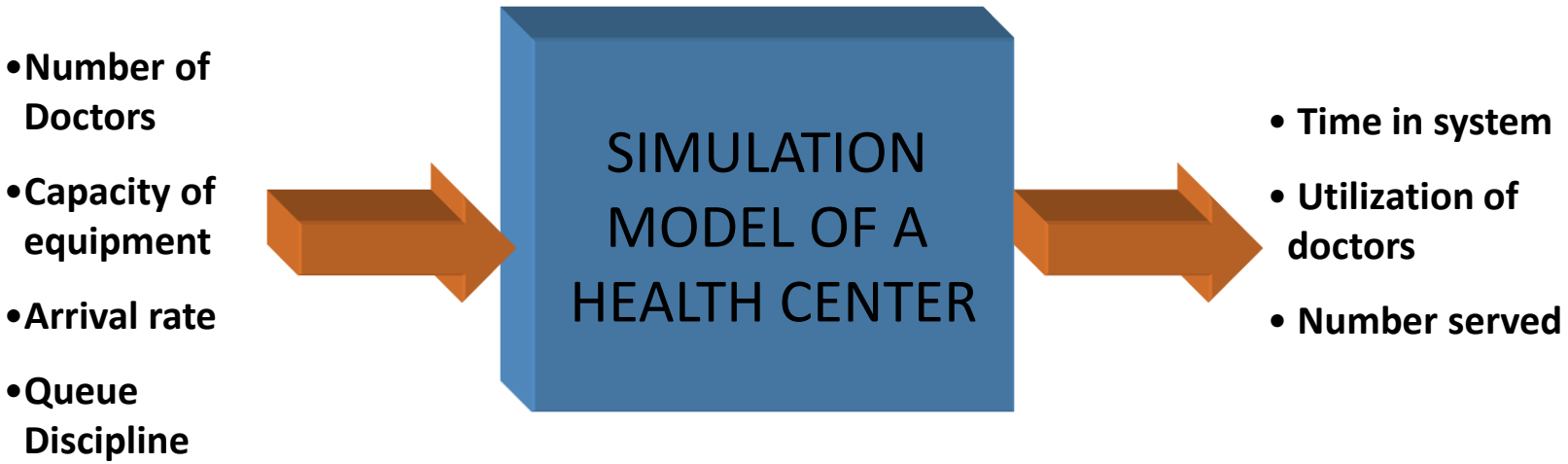
System response

- **Waiting times, system size, utilizations…**

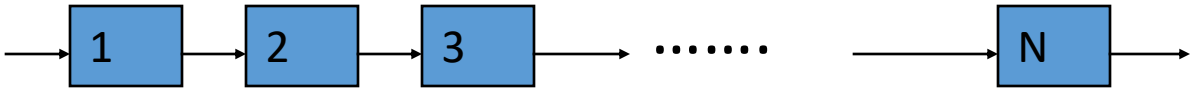
(Y)

Y=f(X)

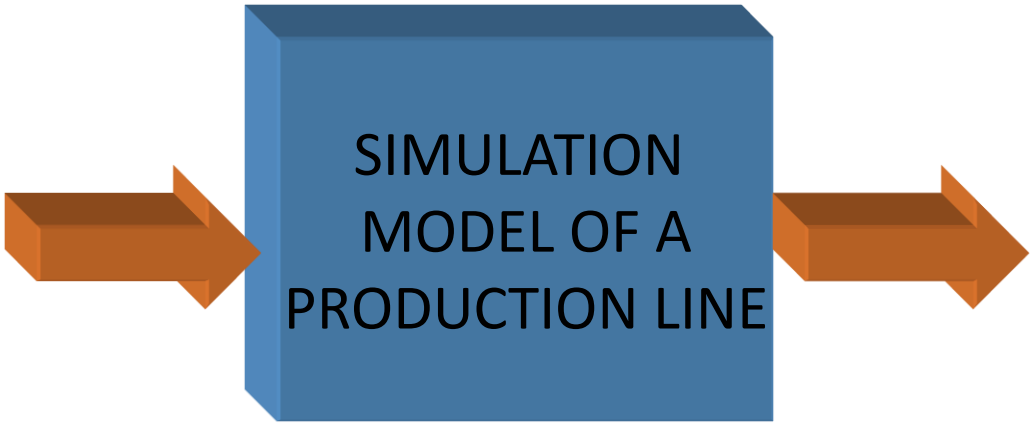
EXAMPLE: Health Center



EXAMPLE: Serial production line

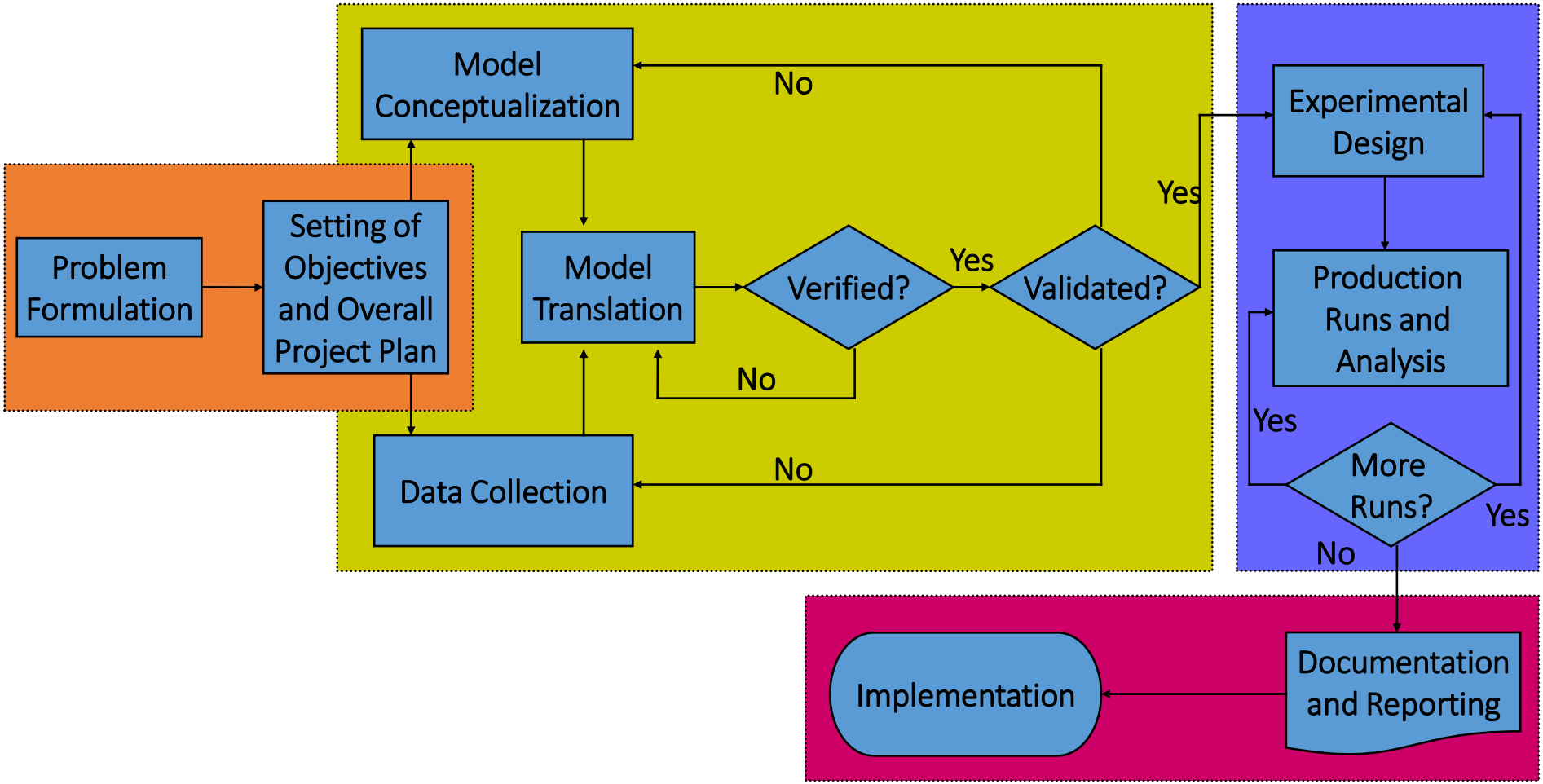


- **Size of the line**
- **Size of buffer**
- **Buffer allocation**
- **Location of bottleneck**
- **Processing times**



- **Throughput**
- **Interdeparture time variability**
- **Utilization**

STEPS IN A SIMULATION STUDY



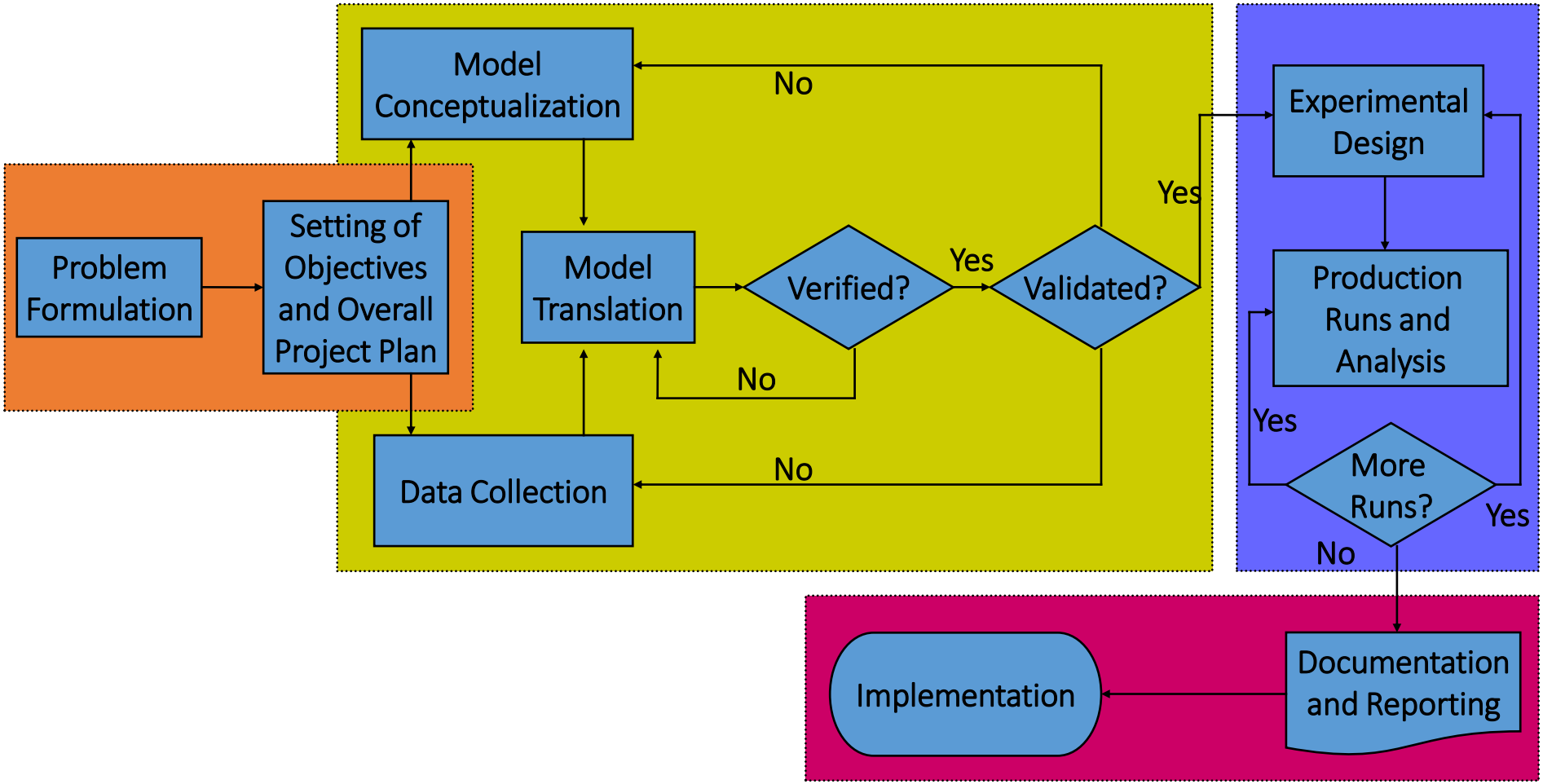
PROBLEM FORMULATION (NOT MODEL)

- A statement of the problem
  - the problem is clearly understood by the simulation analyst
  - the formulation is clearly understood by the client
- Criteria for selecting a problem
  - Technical and Economical Feasibility
  - Perceived Urgency for a Solution

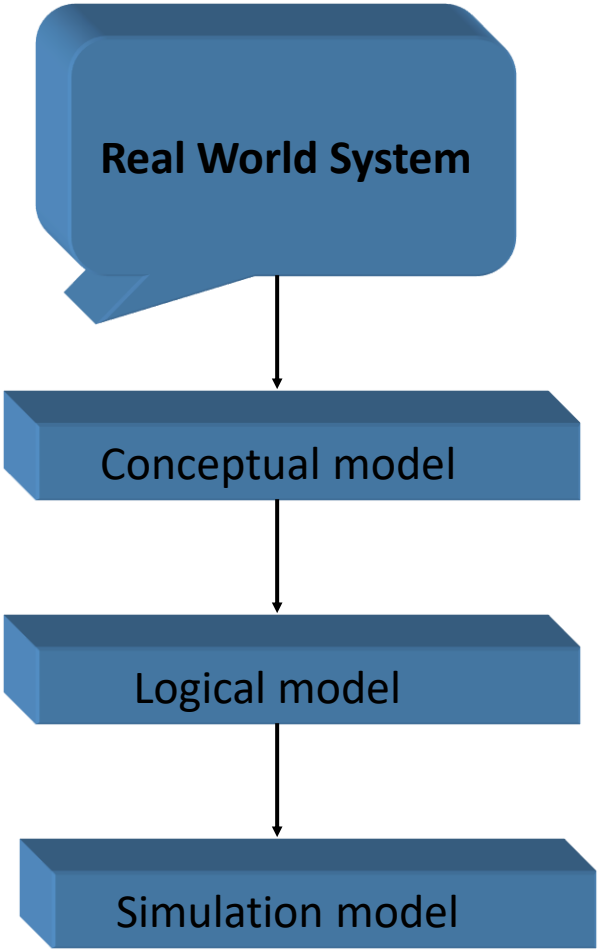
SETTING OBJECTIVES AND PROJECT PLAN

- Determine the questions that are to be answered
- (Is simulation appropriate?)
- Identify scenarios to be investigated
- Level of details (assumptions)
- Determine the end-user
- Determine data requirements
- Determine hardware, software, & personnel requirements
- Prepare a time plan
- Cost plan and billing procedure

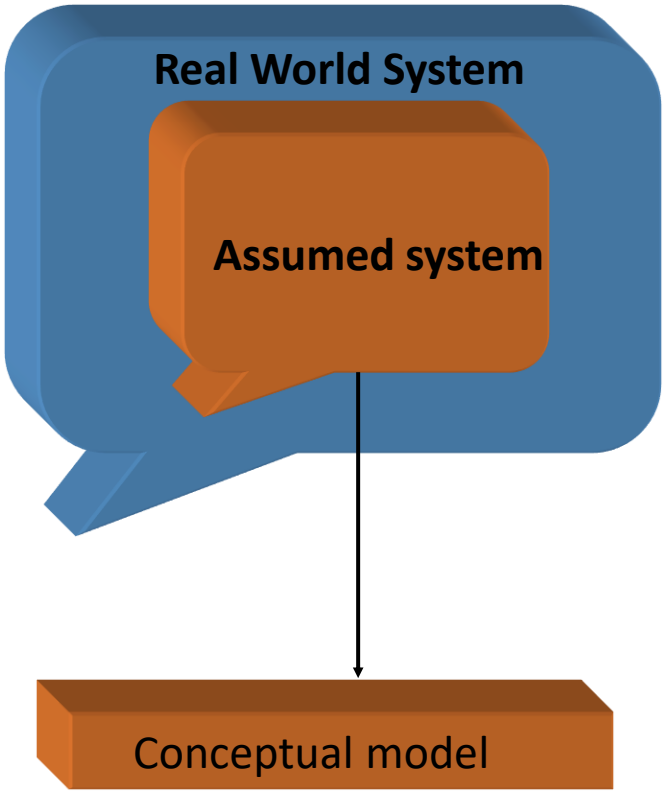
STEPS IN A SIMULATION STUDY



MODEL DEVELOPMENT



CONCEPTUAL MODEL

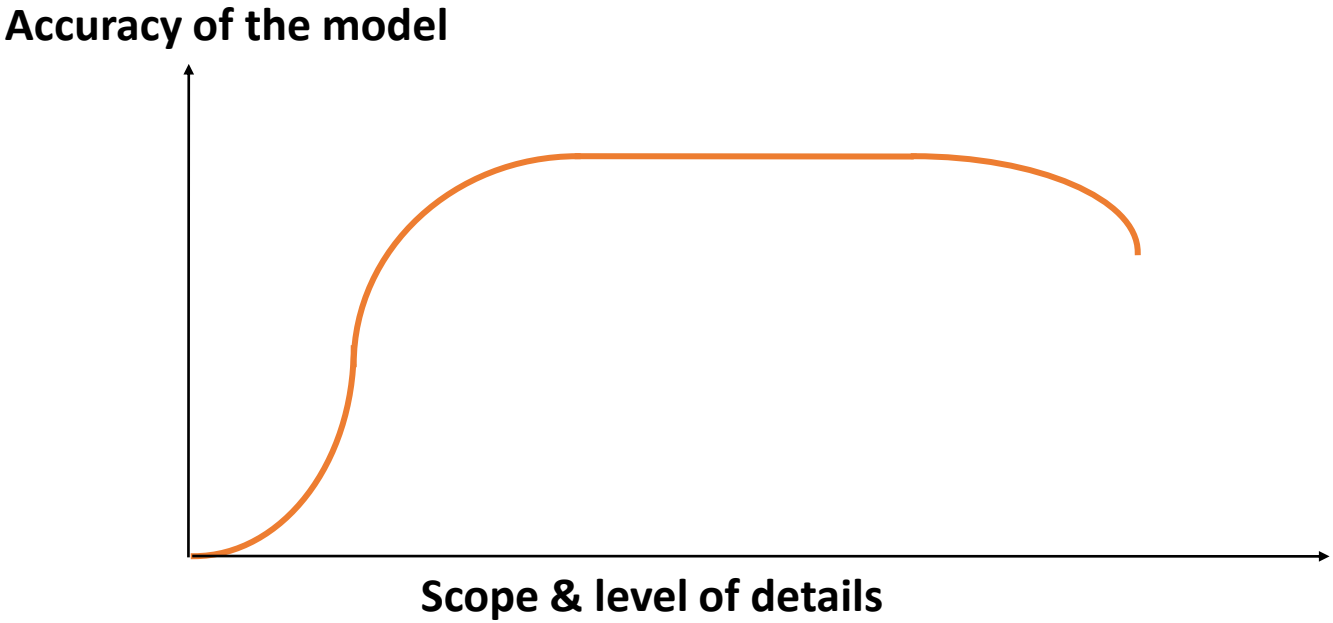


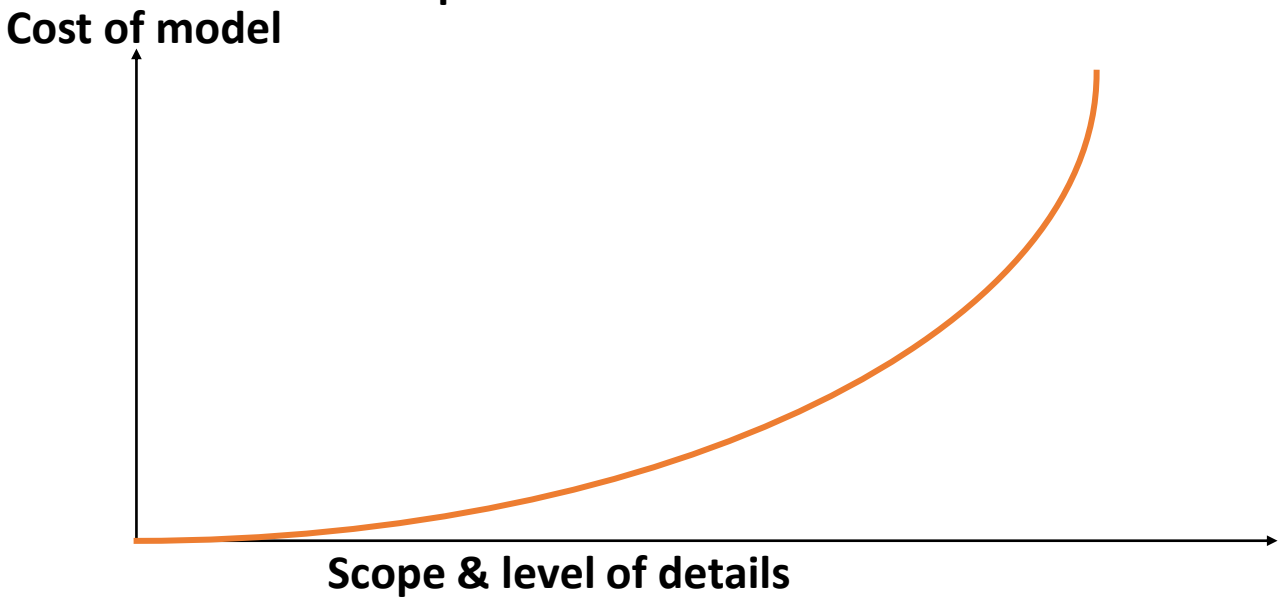
CONCEPTUAL MODEL

- Questions to be answered
  - Why this analysis is performed
- Level of details (assumptions)
- Performance measures
- Events, entities, attribute, exogenous variables, endogenous variables, and their relationships
- Data requirements

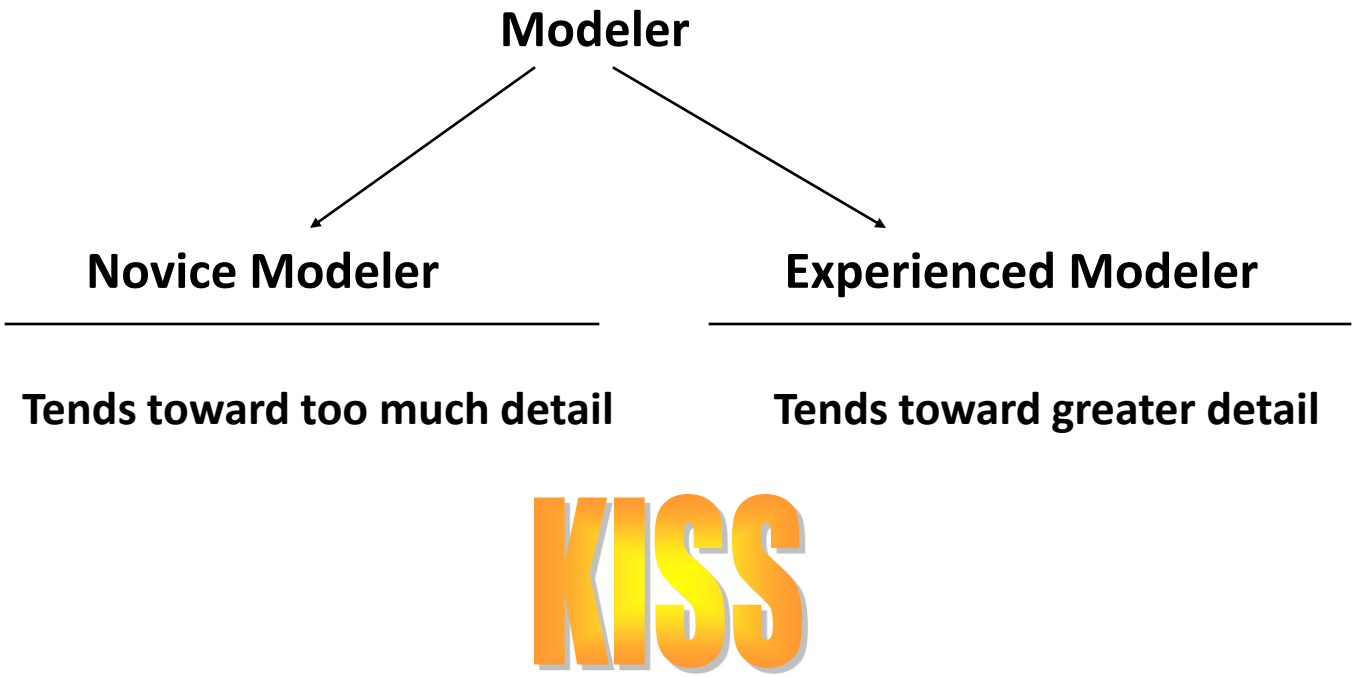
LEVEL OF DETAIL

- 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


Accuracy of the model
Scope & level of details


Cost of model
Scope & level of details

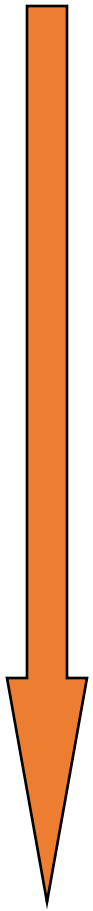
LEVEL OF DETAIL



LEVEL OF DETAIL

Level of details

(increase)



- Evaluate candidate systems if they work
- Compare two or more systems to determine better ones
- Accurately predict the performance of selected system

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 Centre

Arrival of a new patient,

Completion of service (i.e., examination)

Failure of medical equipment, etc.

COMPONENTS OF A SYSTEM

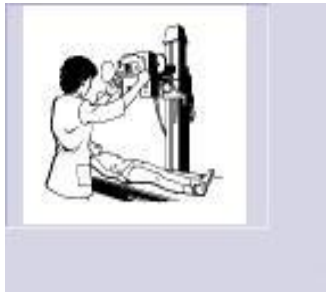
Activity: represents a time period of specified length.

Example: Health Center

Surgery,

Checking temperature,

X-Ray.

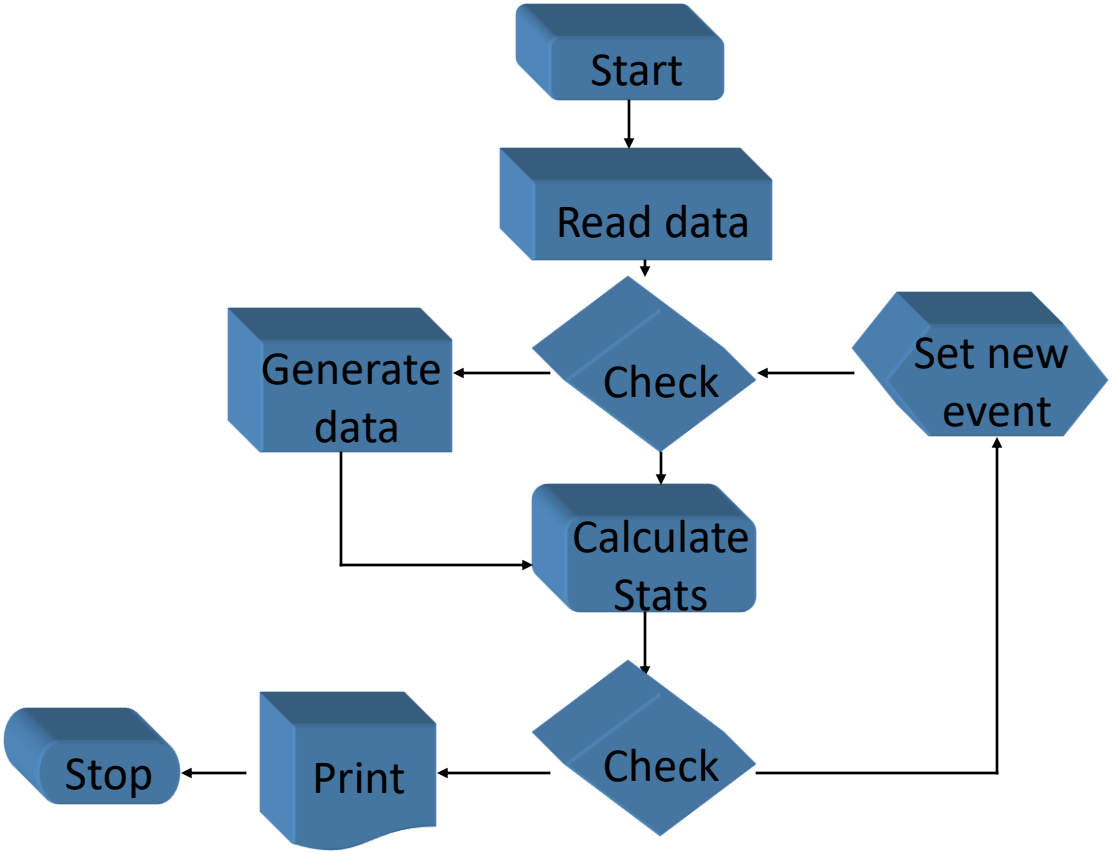


DATA COLLECTION AND ANALYIS

- 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

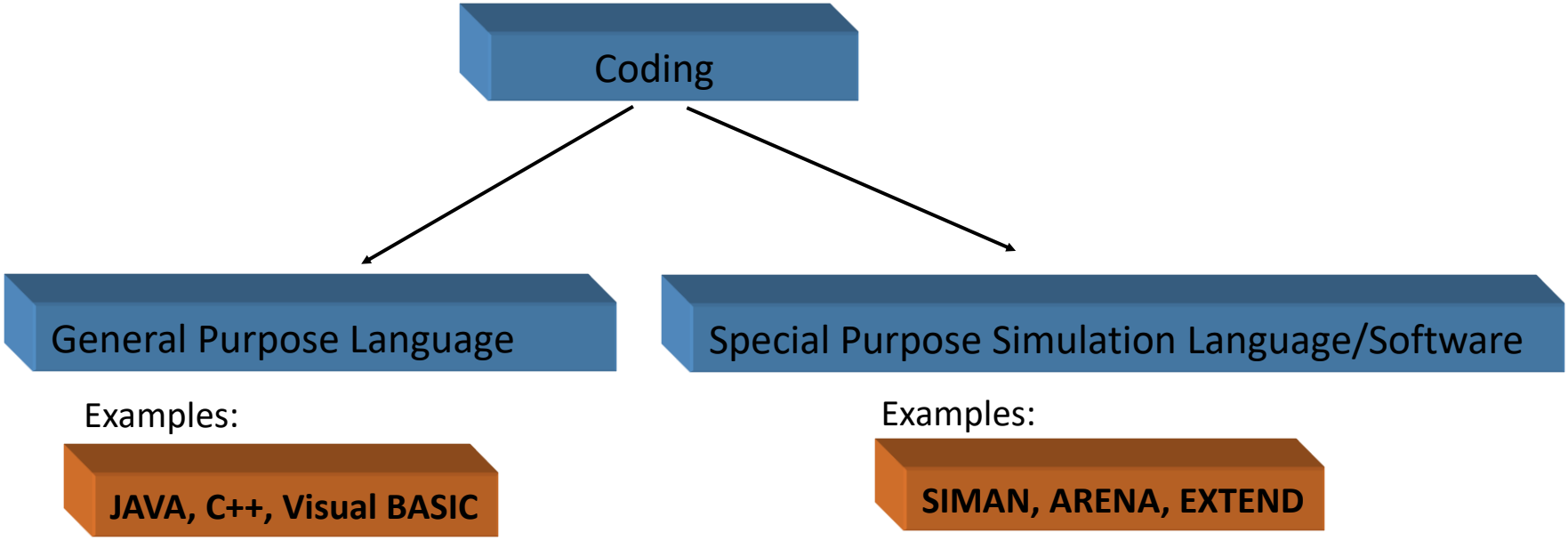
LOGICAL (or Flowchart model)

Shows the logical relationships among the elements of the model



MODEL TRANSLATION

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



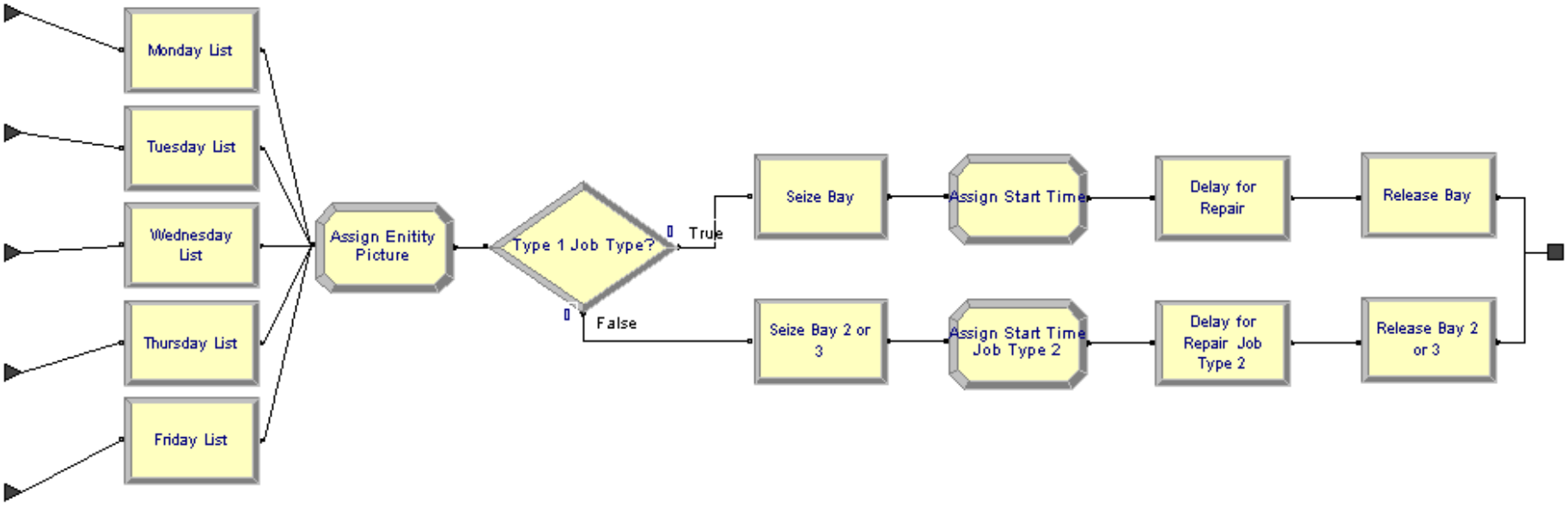
Simulation model

```
                        ---  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:
```

ARENA EXAMPLE



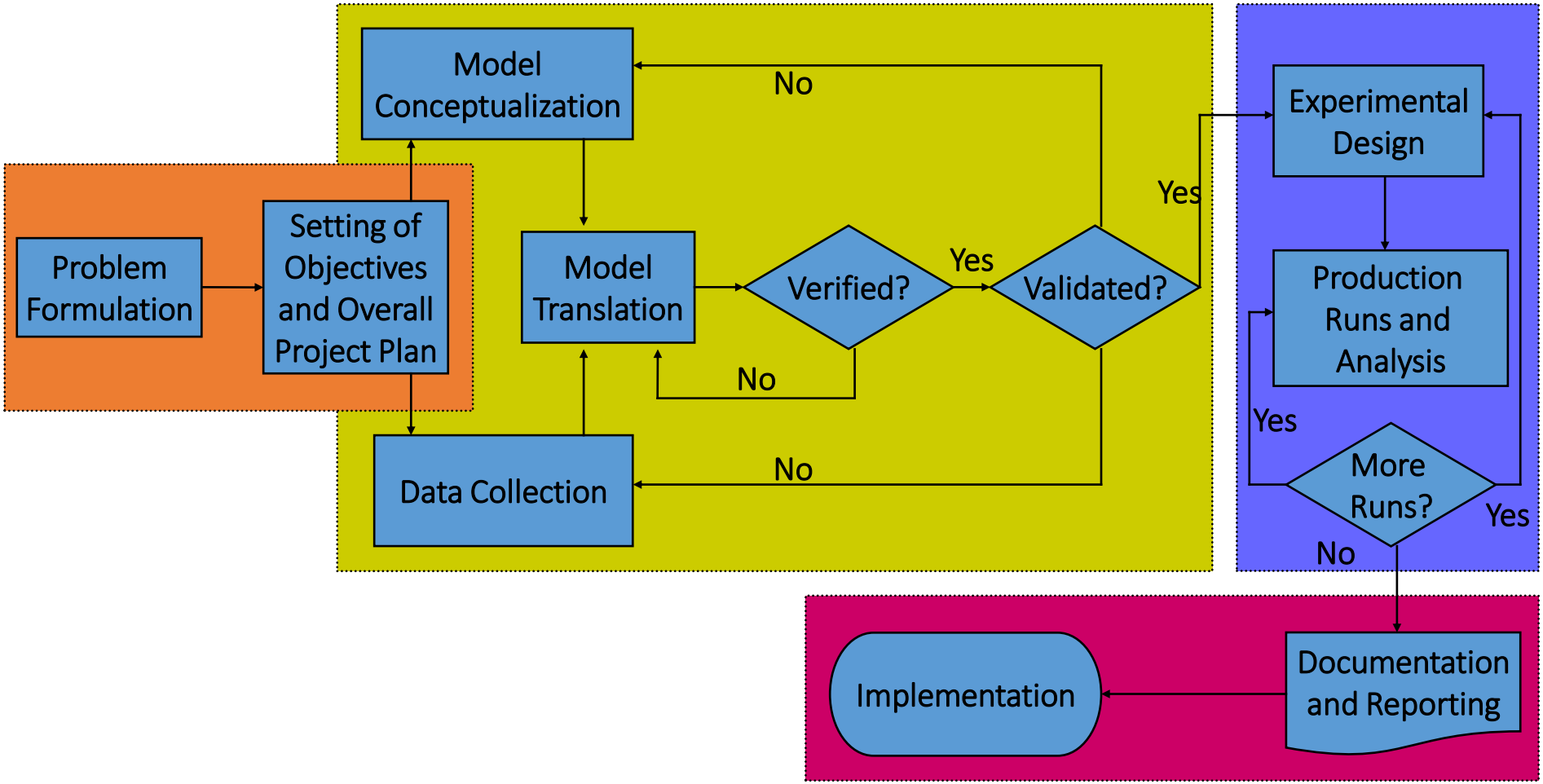
JAVA EXAMPLE

```
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

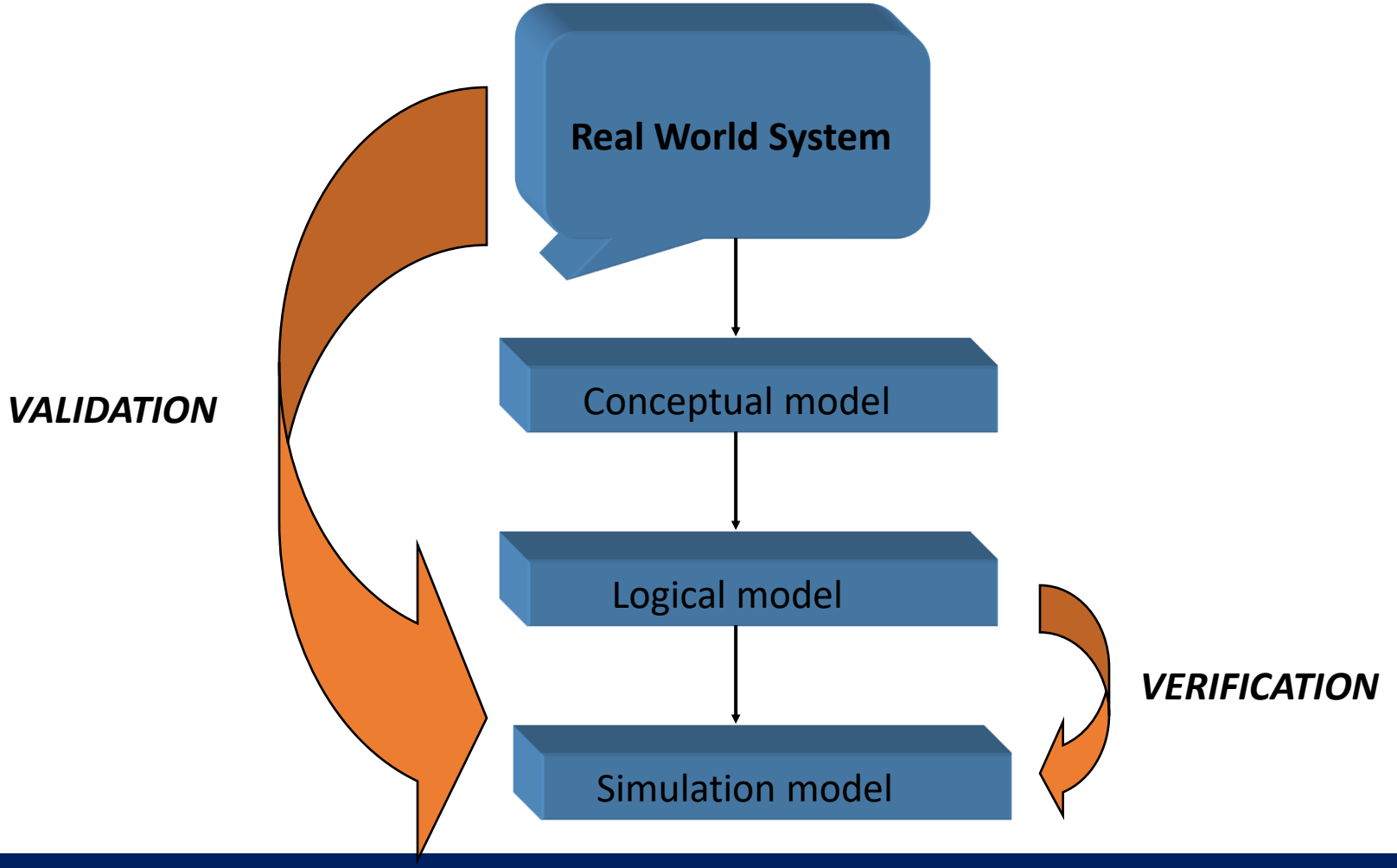


VERIFICATION AND VALIDATION

- ***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



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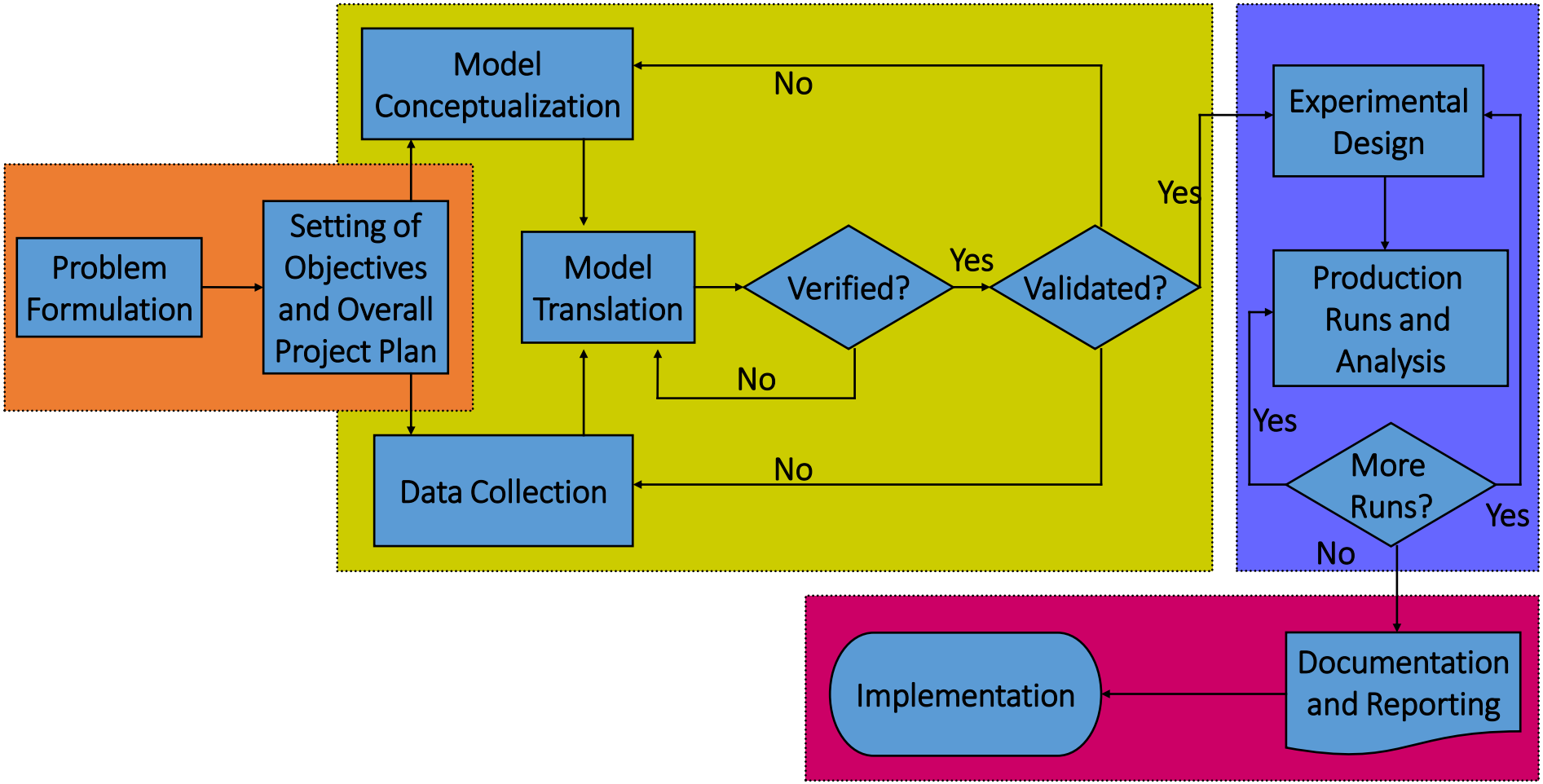


EXPERIMENTAL DESIGN

- 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

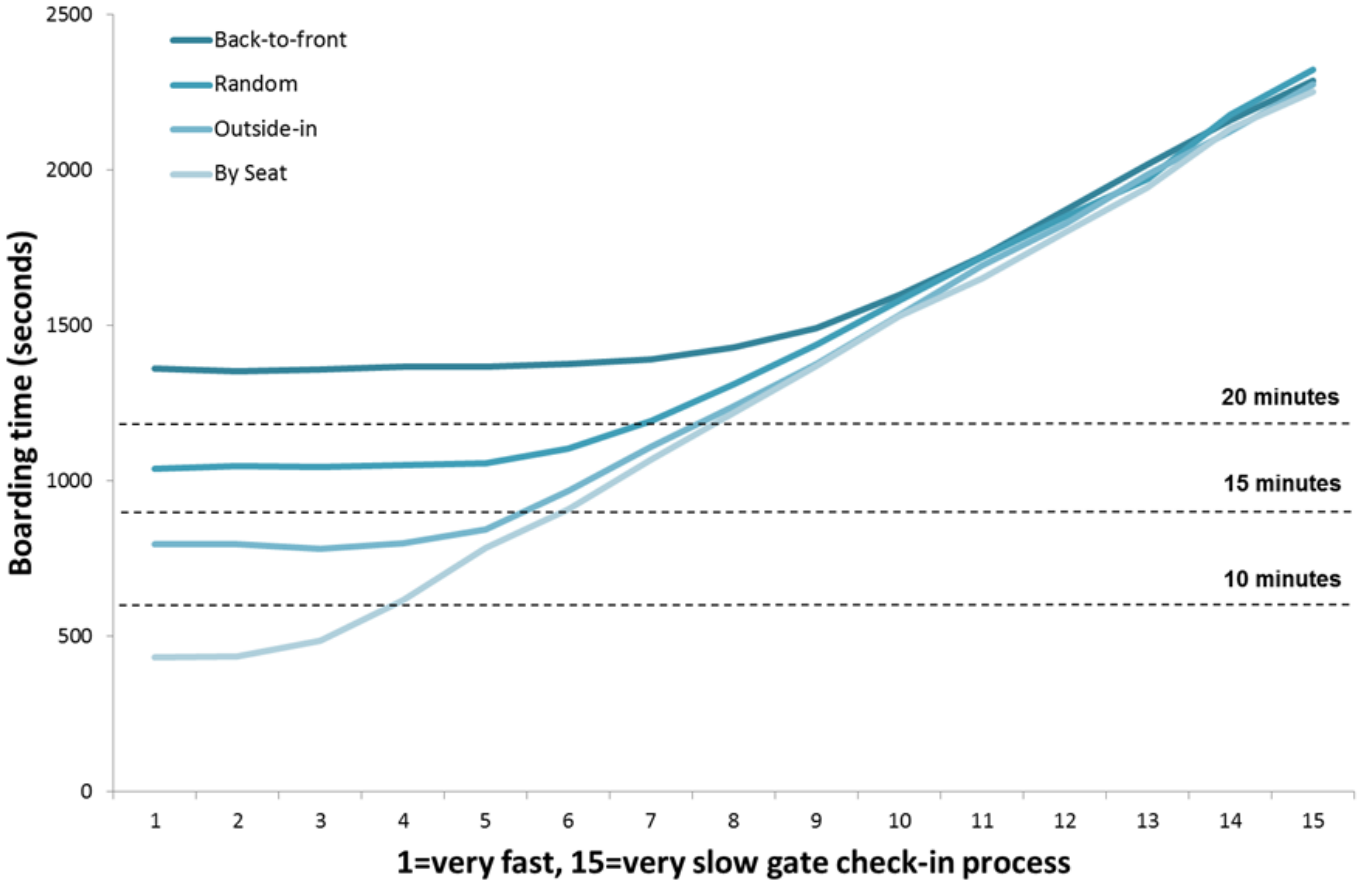
ANALYSIS OF RESULTS

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

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)



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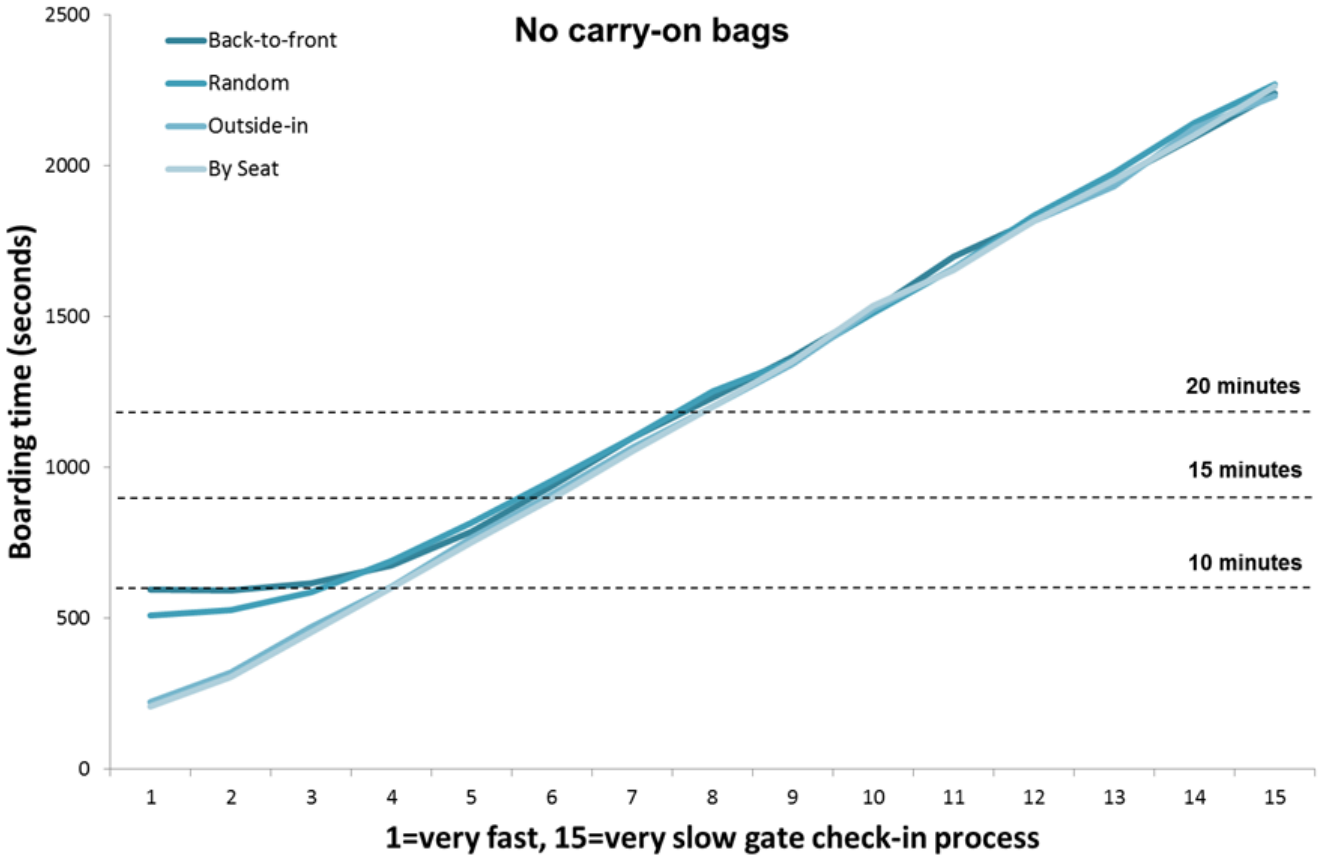

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