INTRODUCTION TO SIMULATION

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
  - A synthesis (prescriptive) tool – if complemented by other tools
- Applied to complex systems that are impossible to solve mathematically
- This course focuses on one form of simulation modelling – discrete-event simulation modelling.

APPLICATIONS

Systems – facility or process, actual or planned

<u>Examples</u>

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)
Criminal justice system
Chemical plant
Fast-food restaurant
Supermarket
Theme park
Emergency-response system

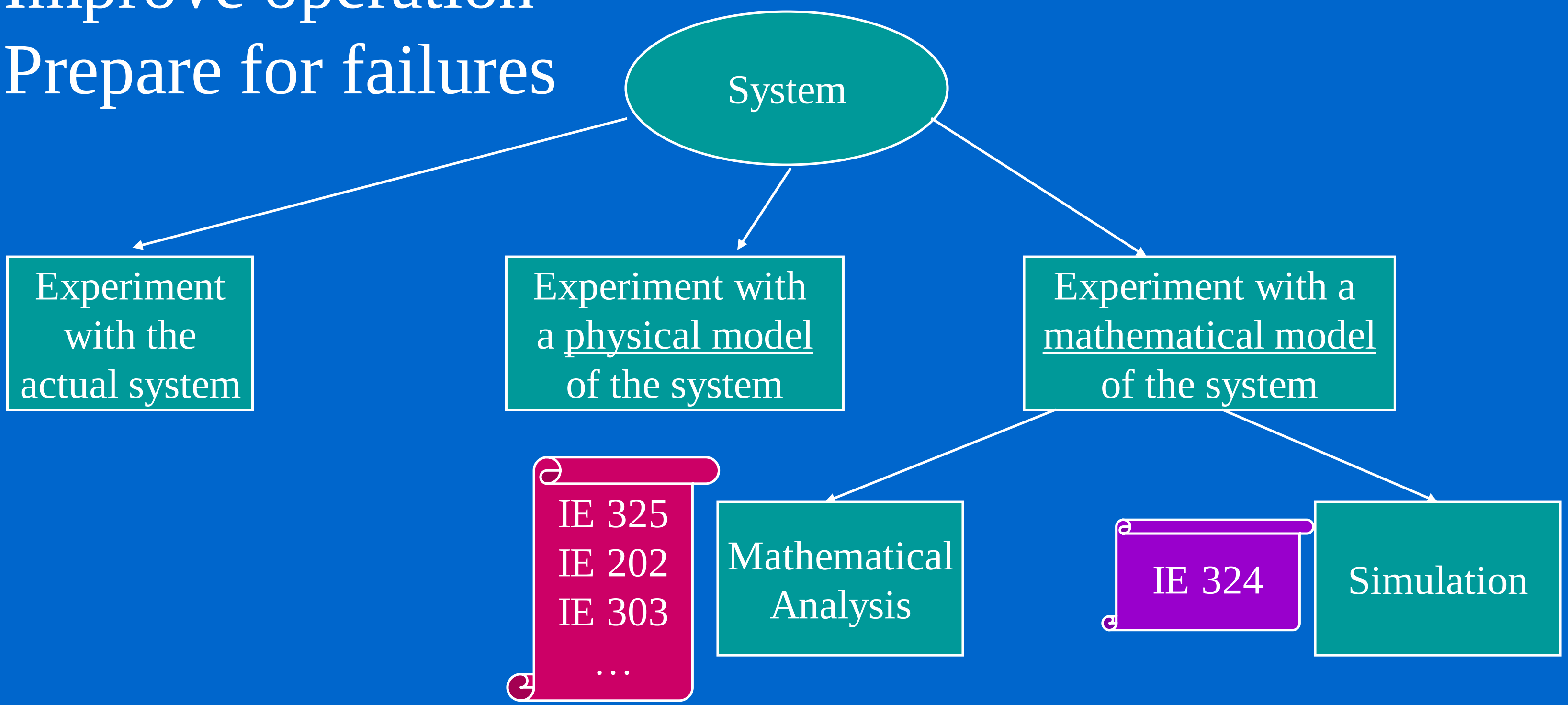
SYSTEM

- A set of interacting components or entities operating together to achieve a common goal or objective.
- Examples:
  - A manufacturing system with its machine centers, inventories, conveyor belts, production schedule, items produced.
  - A telecommunication system with its messages, communication network servers.
  - A theme park with rides, workers, …

REAL WORLD SYSTEMS OF INTEREST ARE HIGHLY COMPLEX!!!

WHY & HOW TO STUDY A SYSTEM

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



MATHEMATICAL MODEL

- An abstract and simplified representation of a system
- Specifies
  - Important components
  - Assumptions/approximations about how the system works
- Not an exact re-creation of the original system!
- If model is simple enough, study it with Queueing Theory, Linear Programming, Differential Equations…
- If model is complex, Simulation is the only way!!!

GETTING ANSWERS FROM MODELS

ACTUAL SYSTEM

Operating Policies

- **Single queue, parallel servers**
- **FIFO**

Input Parameters

- **No of servers**
- **Inter-arrival Time Distribution**
- **Service Time Distributions**

Output Parameters

- **Waiting Times**
- **System Size**
- **Utilizations**

Y = f (X)

STOCHASTIC MODELS

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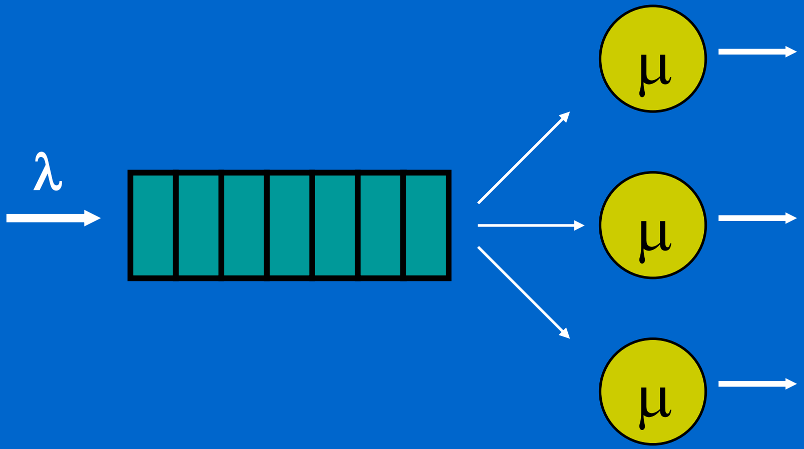
- Randomness or uncertainty is inherent
- Example: Bank with customers and tellers



ACTUAL SYSTEM

QUEUEING MODEL

CLASSIFICATION OF SIMULATION MODELS

Static (Monte Carlo)

Represents the system at a particular point in time

IID observations

- 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

HOW TO SIMULATE

- By hand
  - Buffon Needle and Cross Experiments (see Kelton et al.)
- Spreadsheets
- Programming in General Purpose Languages
  - Java
- Simulation Languages
  - SIMAN
- Simulation Packages
  - Arena

Issue: Modeling Flexibility vs. Ease of Use

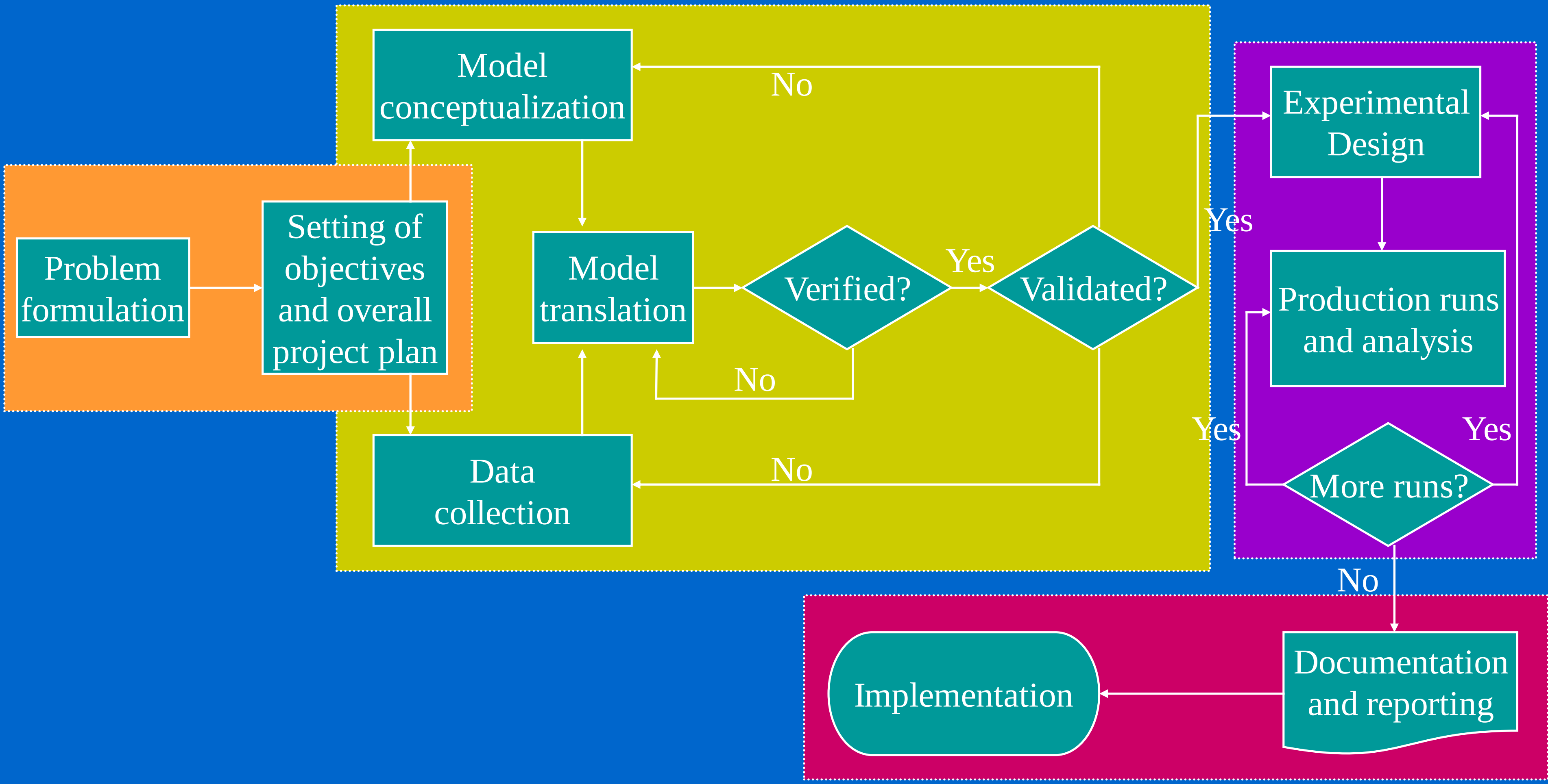
ADVANTAGES OF SIMULATION

- When mathematical analysis methods are not available, simulation may be the only investigation tool
- When mathematical analysis methods are available, but are so complex that simulation may provide a simpler solution
- Allows comparisons of alternative designs or alternative operating policies
- Allows time compression or expansion

DISADVANTAGES OF SIMULATION

- For a stochastic model, simulation estimates the output while an analytical solution, if available, produces the exact output
- Often expensive and time consuming to develop
- An invalid model may result with confidence in wrong results.

STEPS IN A SIMULATION STUDY



PROBLEM FORMULATION

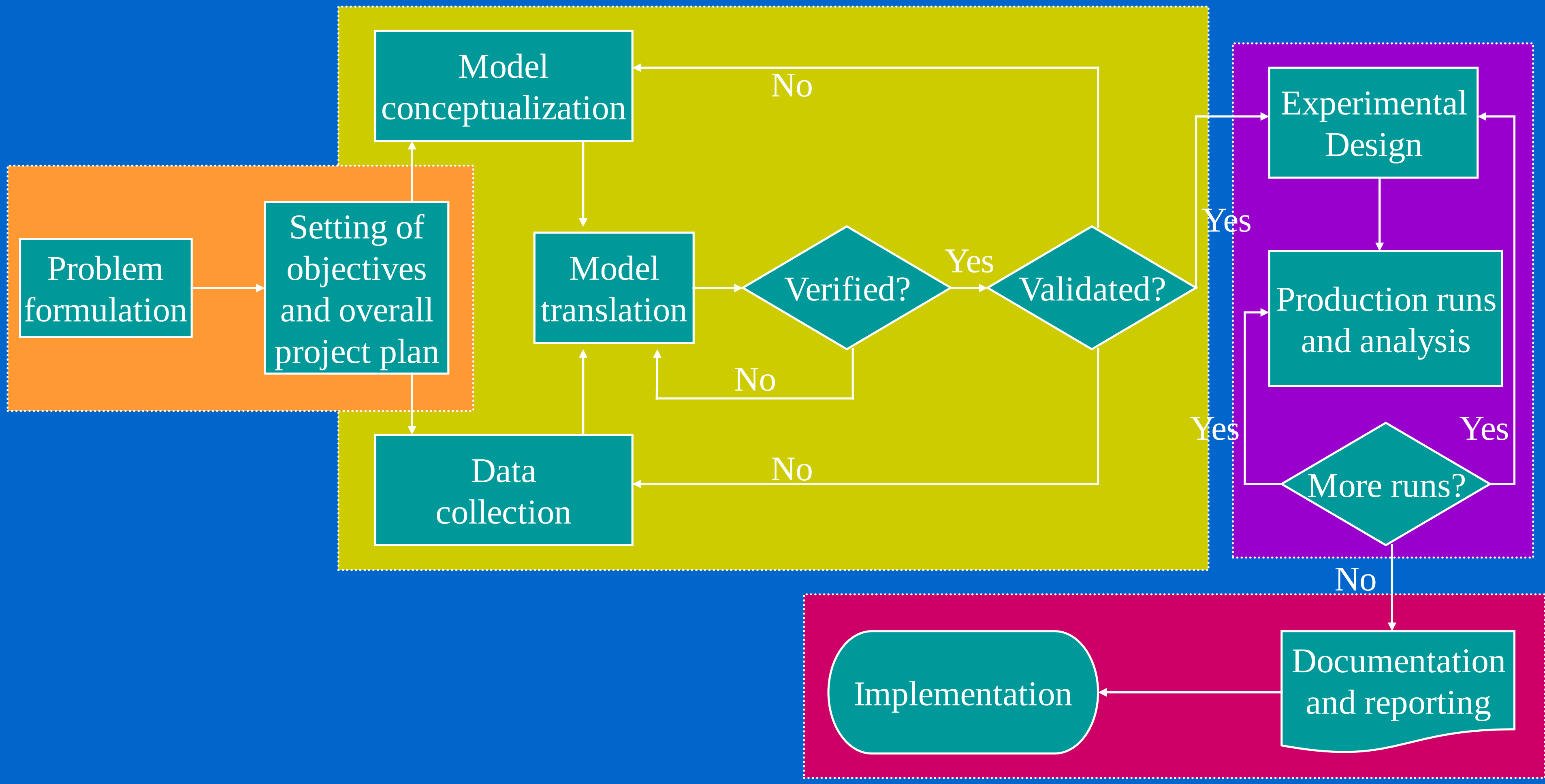
- A statement of the problem
  - the problem is clearly understood by the simulation analyst
  - the formulation is clearly understood by the client

SETTING OF OBJECTIVES & PROJECT PLAN

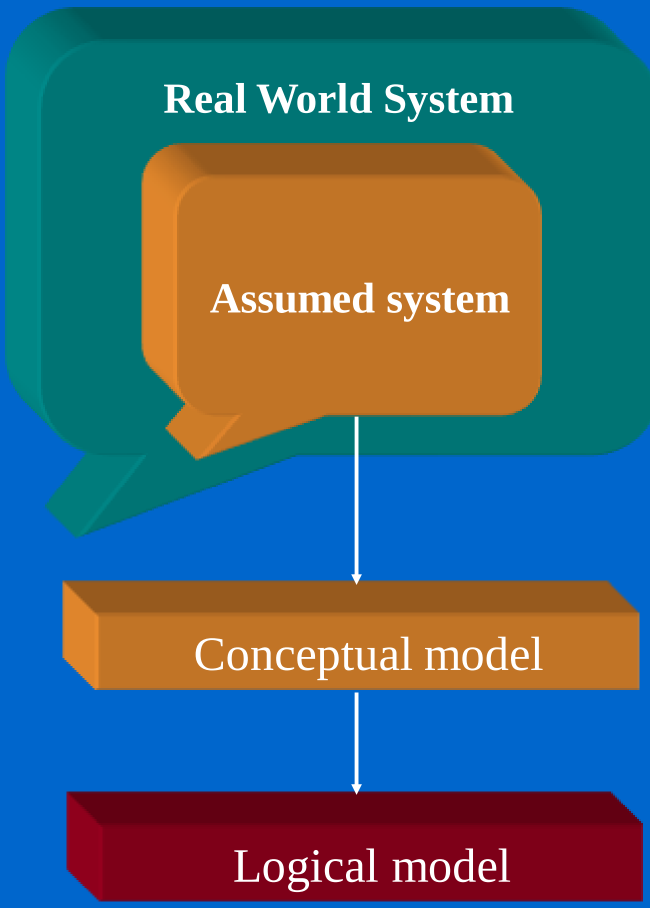
Project Proposal

- Determine the questions that are to be answered
- Identify scenarios to be investigated
- Decision criteria
- 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 CONCEPTUALIZATION

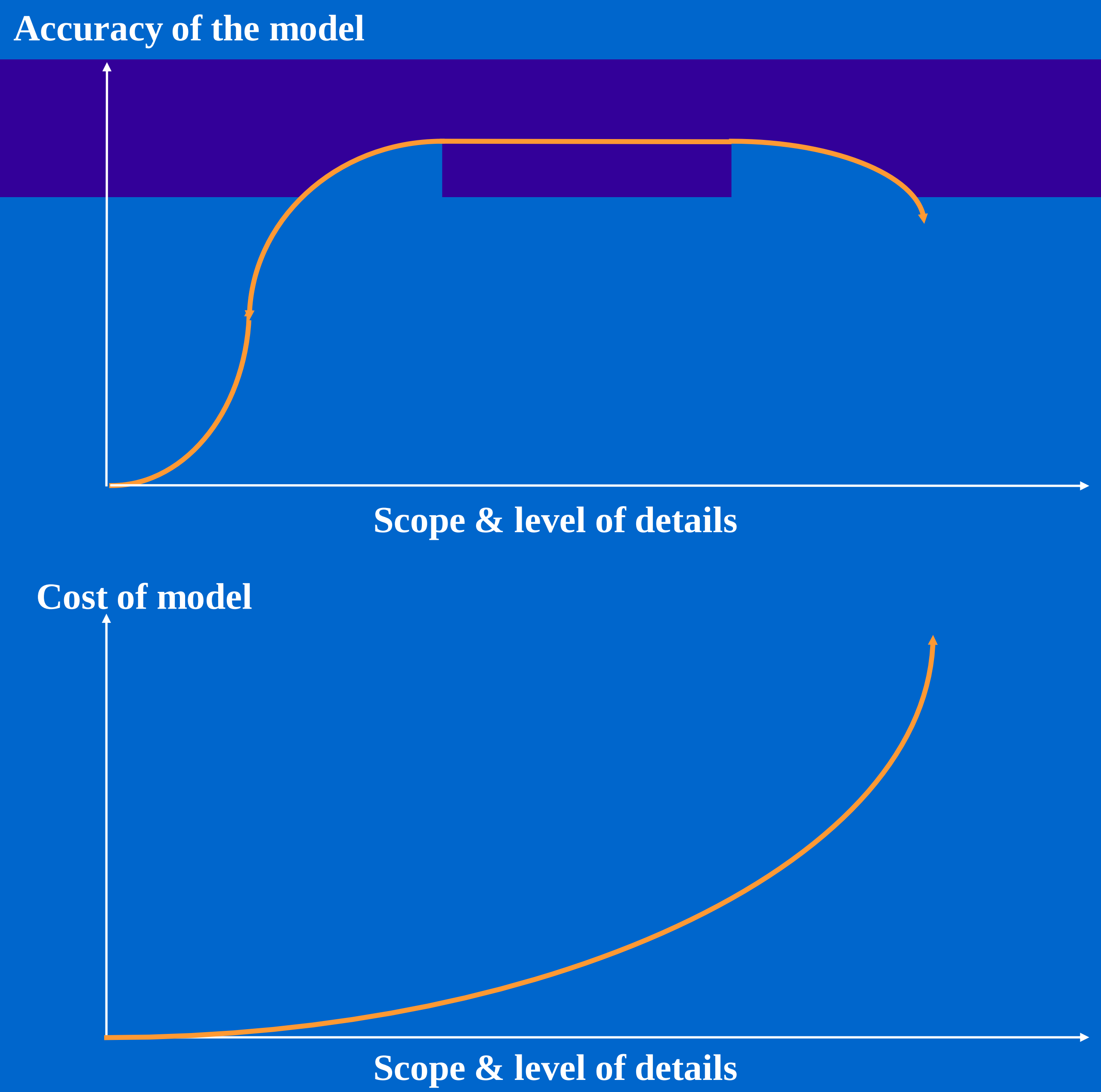


CONCEPTUAL MODEL

- Abstract essential features
  - Events, activities, entities, attributes, resources, variables, and their relationships
  - Performance measures
  - Data requirements
- Select correct level of details (assumptions)

LEVELS OF DETAIL

- Low levels of detail may result in lost of information and goals cannot be accomplished
- High levels of detail require:
  - 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

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

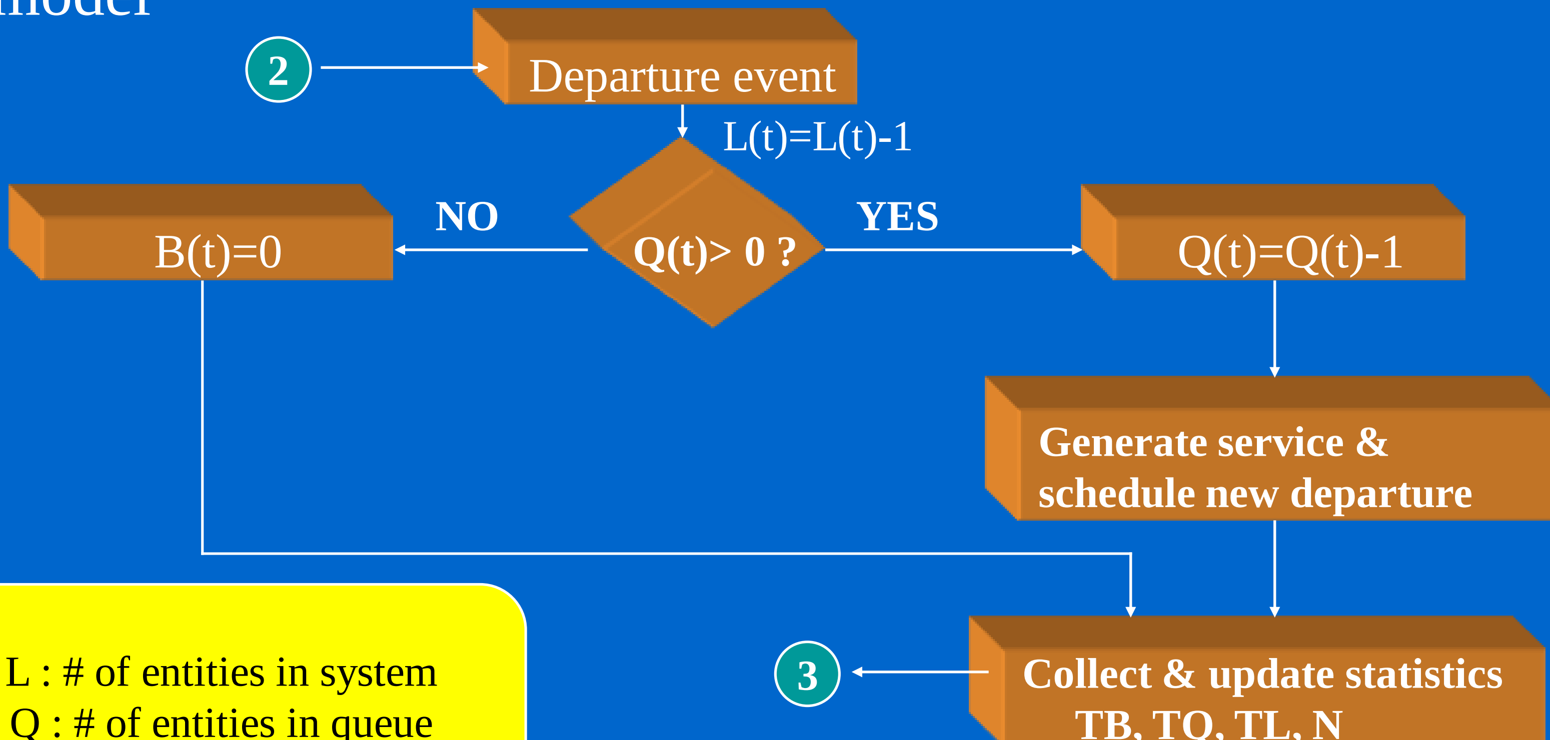
Surgery,

Checking temperature,

X-Ray.

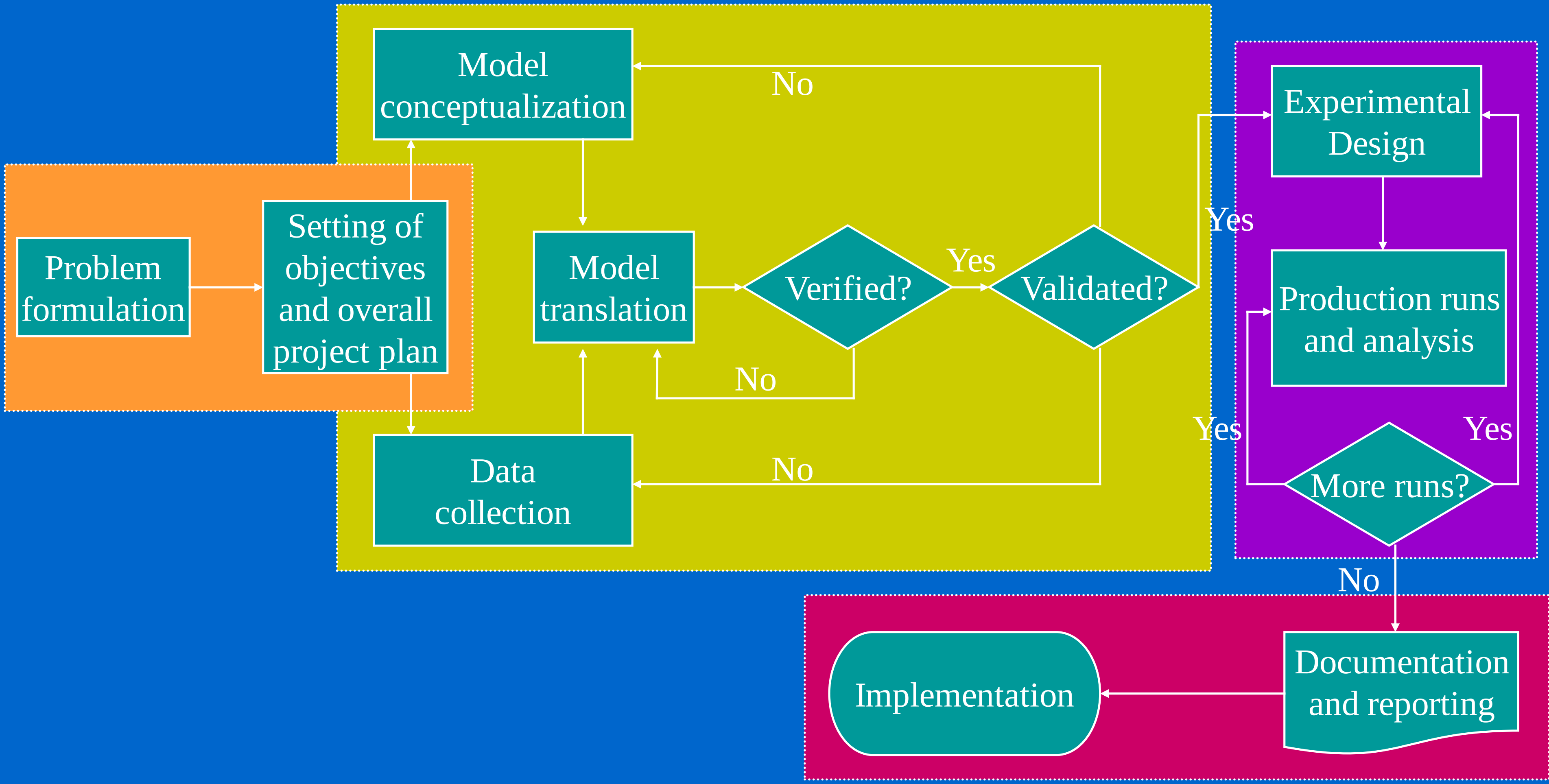
LOGICAL (FLOWCHART) MODEL

- Shows the logical relationships among the elements of the model



L : # of entities in system
Q : # of entities in queue
B : # of entities in server

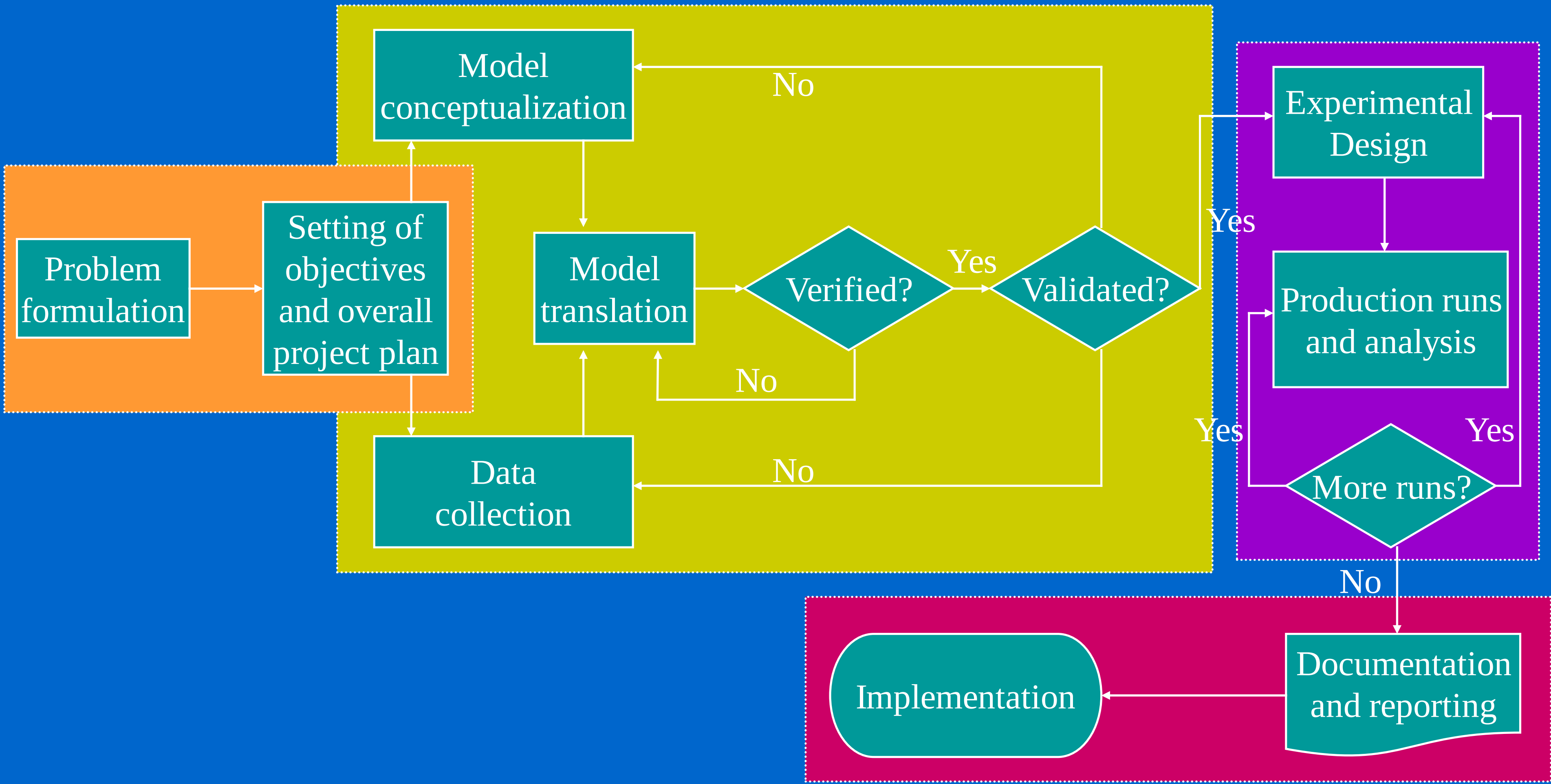
STEPS IN A SIMULATION STUDY



DATA COLLECTION & ANALYSIS

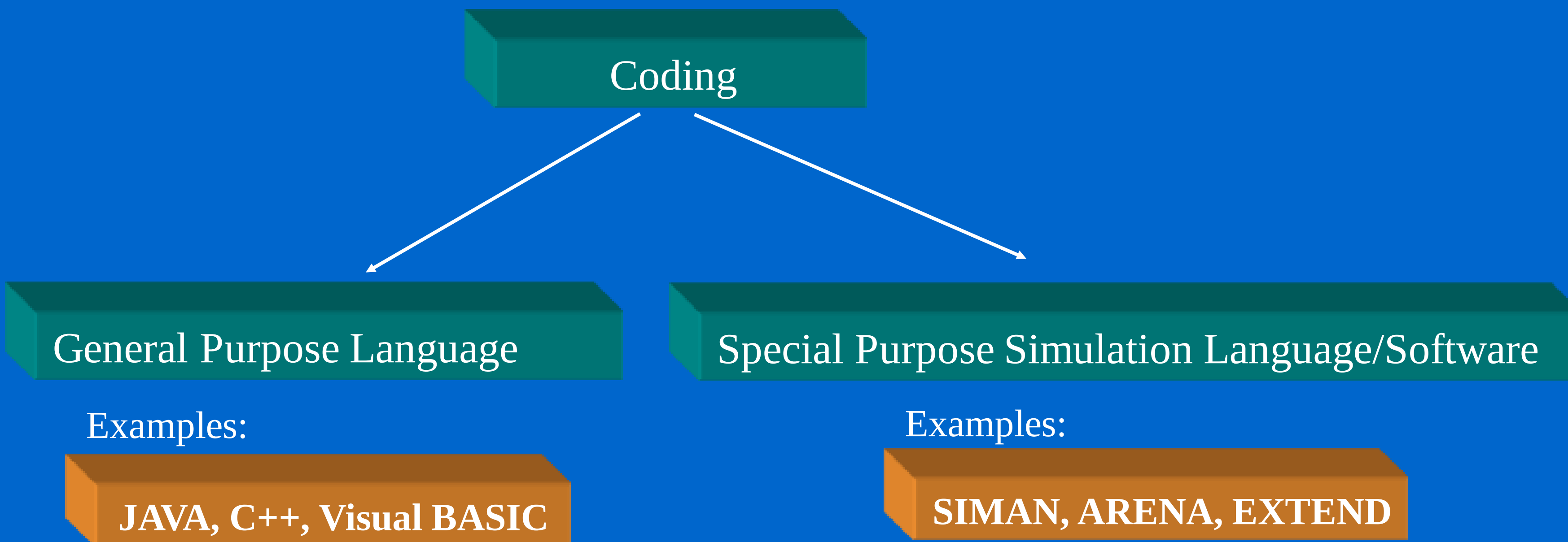
- Collect data for input analysis and validation
- Analysis of the data
  - Determine the random variables
  - Fit distribution functions

STEPS IN A SIMULATION STUDY

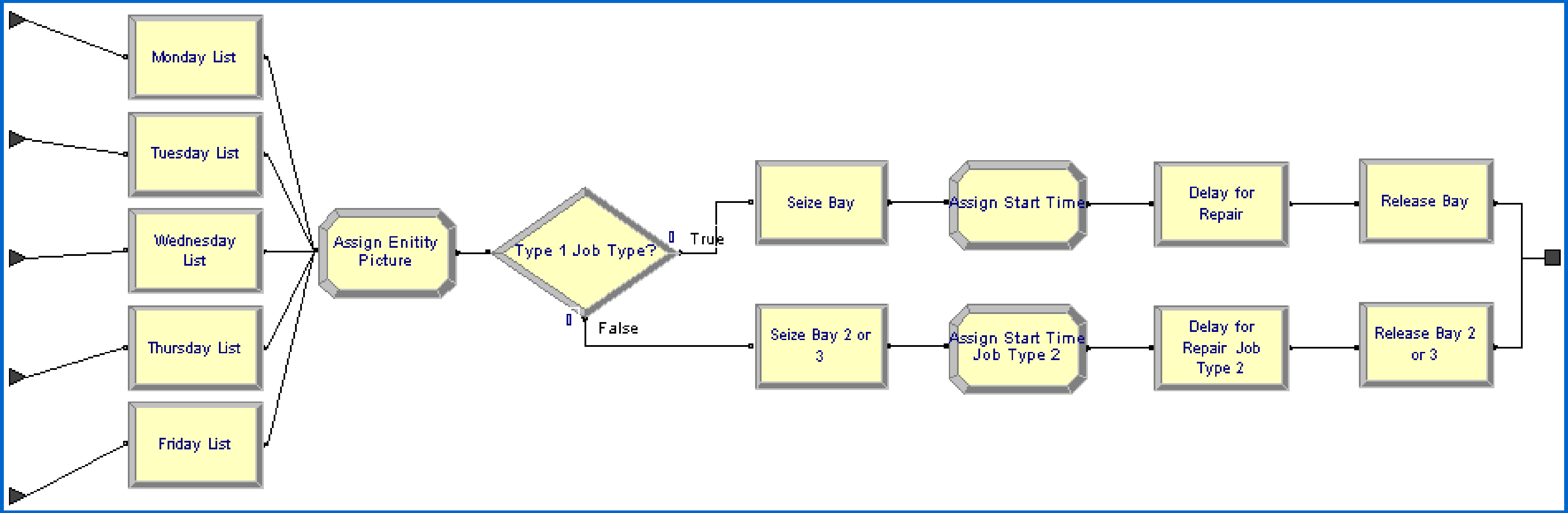


MODEL TRANSLATION

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



ARENA EXAMPLE



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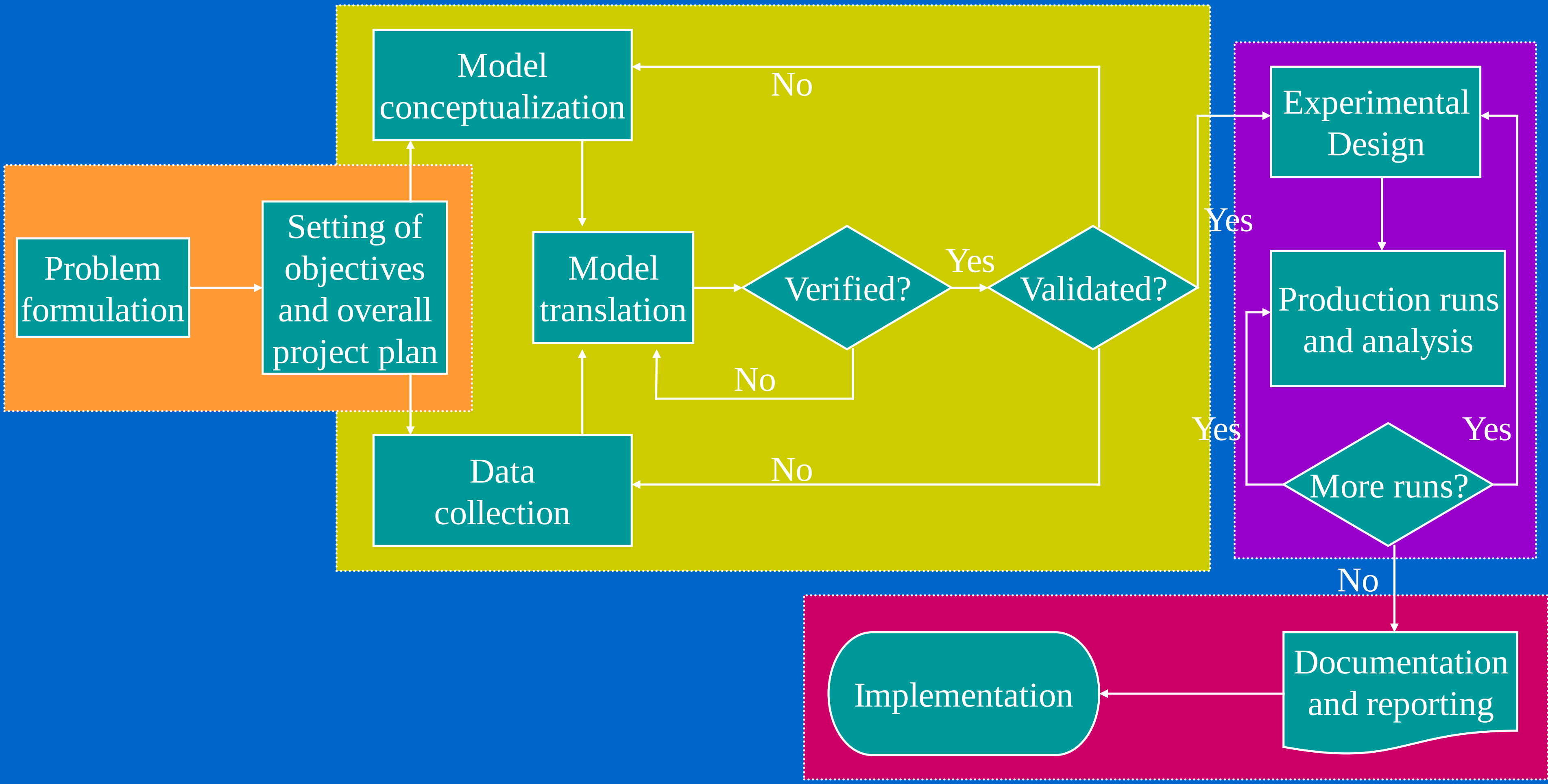
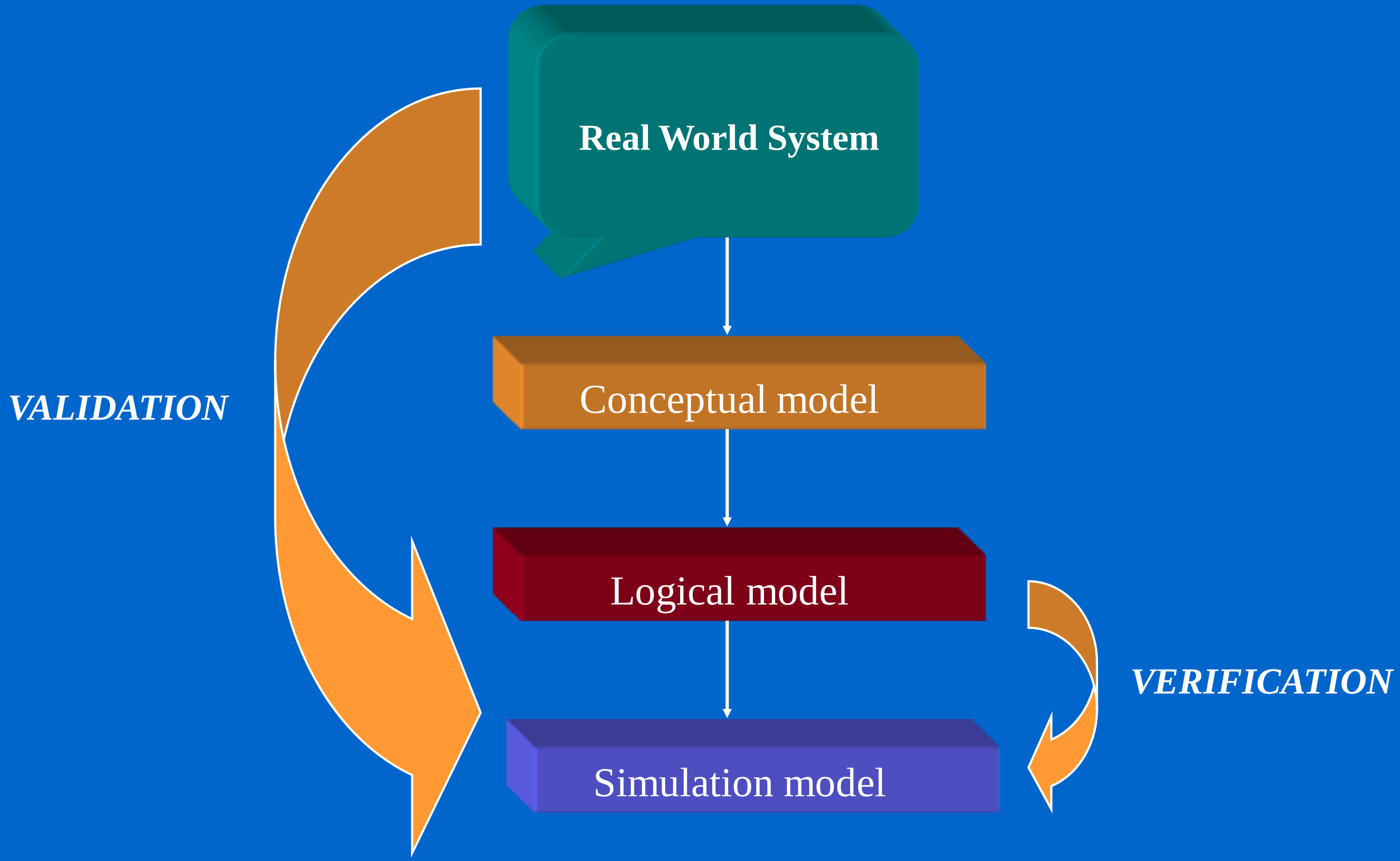


VERIFICATION AND VALIDATION

- ***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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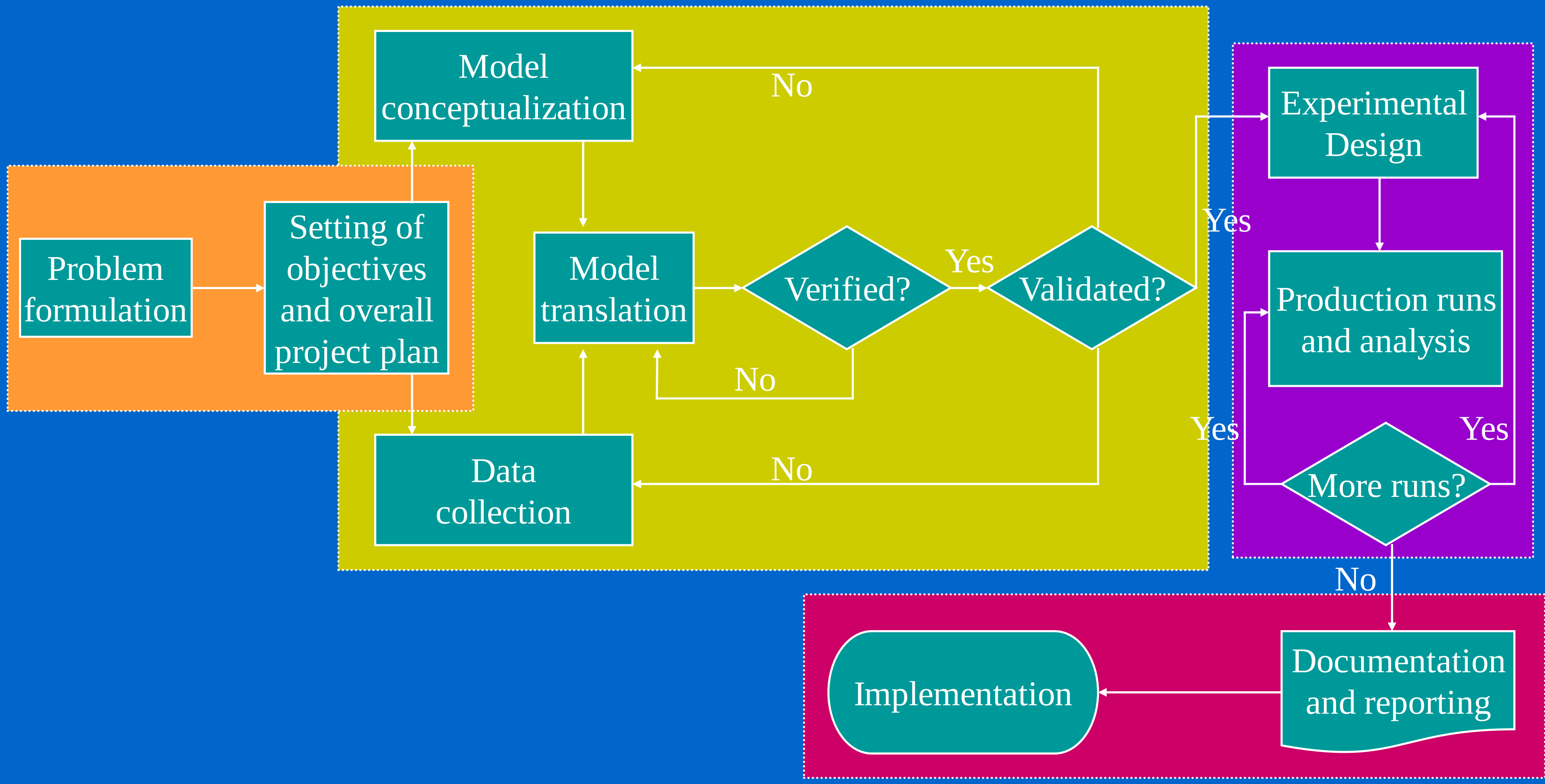


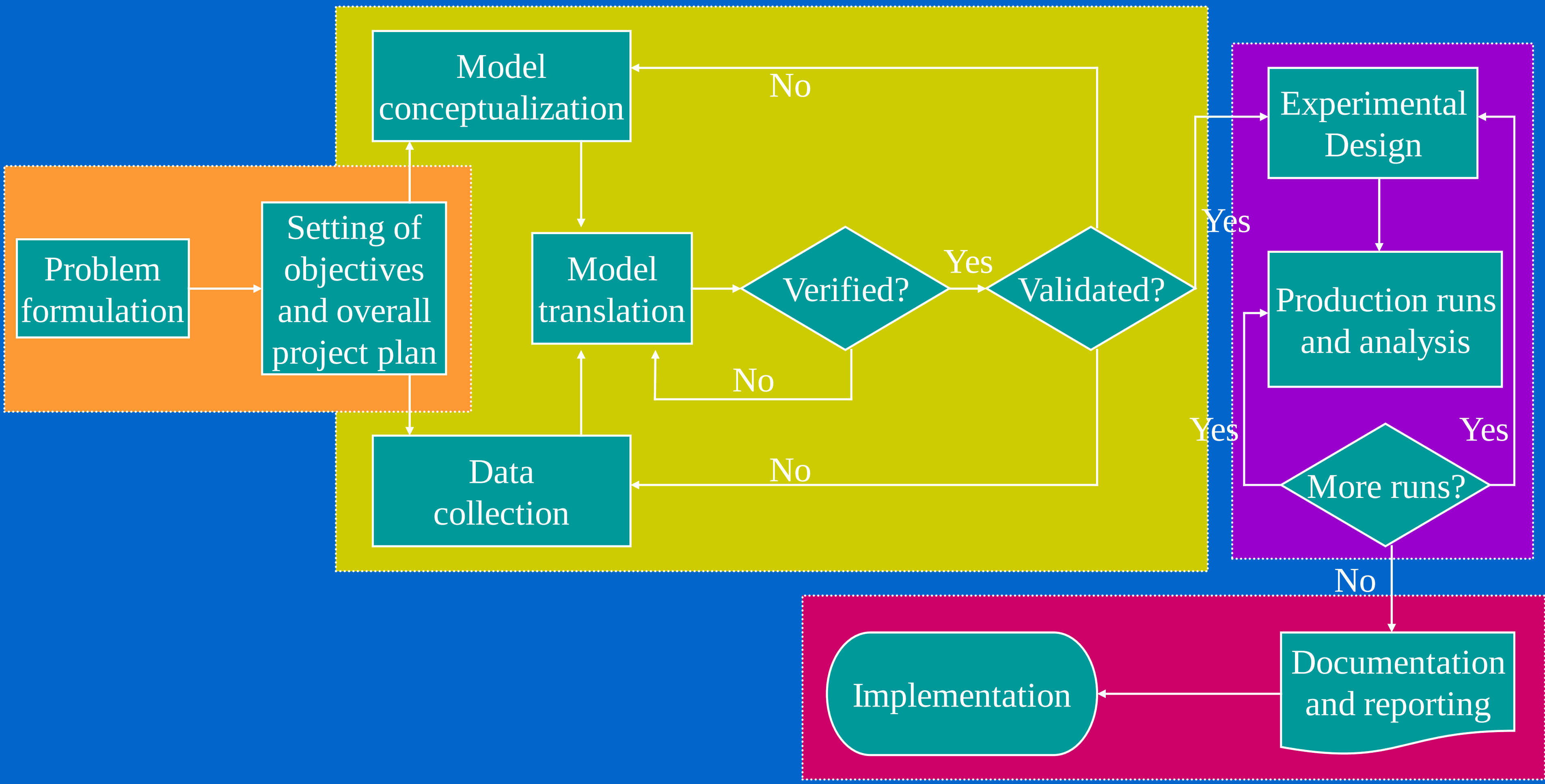
EXPERIMENTAL DESIGN

- Alternative scenarios to be simulated
- Type of output data analysis (steady-state vs. terminating simulation 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?

STEPS IN A SIMULATION STUDY



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

IMPLEMENTATION