

## Introduction

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## What is Simulation?

- **To Simulate**, according to Webster's Dictionary, is:  
“To feign, to attain the essence of without the reality”
- **To Simulate**, in simple terms, implies to imitate or mimic.
- **Simulation** is the act of executing, experimenting with or exercising a model or a set of models for a specific objective (intended use) such as
  - Problem Solving
  - Training
  - Acquisition
  - Entertainment
  - Research
  - Education

## Terminology

- A simulation must always have a model and modeling is part of a simulation. To emphasize the modeling involved in a simulation, simulation is commonly referred to as **Modeling and Simulation (M&S)** especially in the U.S. Department of Defense (DoD).
- Since DoD is the largest sponsor and user of simulation in the whole world, the M&S acronym has been in wide use.
- The **Society for Computer Simulation International (SCS)** has changed its name in 2002 to **The Society for M&S International**. See <http://www.scs.org/>
- You can refer to “model and simulation” as an **M&S Application**.
- Some suggested acronyms:
  - **M&S** = Modeling and Simulation
  - **M/S** = Model and/or Simulation
  - **Ms/Ss** = Models and/or Simulations

## The M&S Discipline

- **Modeling and Simulation (M&S)** is a discipline (a branch of knowledge) consisting of many areas such as discrete M&S, continuous M&S, Monte Carlo M&S, Agent-based M&S, and System Dynamics M&S.
- **M&S is used in almost all disciplines** similar to how mathematics is used in other disciplines.
- M&S is a large and diverse discipline used for providing solutions to complex problems encountered in almost every field such as
  - engineering
  - business
  - sciences (e.g., agricultural, biological, medical, social)
  - military
  - government
- **Some universities offer B.S., M.S. and Ph.D. degree programs in M&S. [Click here to see a list of universities offering degrees in M&S.](#)**

# M&S Areas

## M&S Areas

### A. Based on Model Representation:

1. Discrete M&S
2. Continuous M&S
3. Monte Carlo M&S
4. System Dynamics M&S
5. Gaming-based M&S
6. Agent-based M&S
7. AI-based M&S
8. VR-based M&S

### B. Based on Model Execution:

9. Distributed / Parallel M&S
10. Web-based M&S

### C. Based on Model Composition:

11. Live Exercises
12. Live Experimentations
13. Live Demonstrations
14. Live Trials

### D. Based on What is in the Loop:

15. Hardware-in-the-loop M&S
16. Human-in-the-loop M&S
17. Software-in-the-loop M&S

M&S areas differ from each other depending on how the simulation model is **architected**, **designed**, and **executed**.

## High-Level Intended Uses

- Problem Solving
- Training
- Acquisition
- Entertainment
- Research
- Education



Use of these different M&S areas spans dozens of different disciplines for many different intended uses such as the ones listed above.

## M&S Intended Use (Objective): Problem Solving

- **Evaluation:** e.g., Evaluation of a proposed system design for the purpose of assessing its quality characteristics such as operational effectiveness, integrated system effectiveness, deployment readiness, performance, interoperability, and security.
- **Comparison:** Comparing competitive systems designed to carry out a specified function, or comparing several proposed operating policies or procedures.
- **Prediction:** Forecasting the behavior of a system under some projected set of conditions.
- **Sensitivity Analysis:** Determining which of many factors are the most significant in affecting overall system behavior.
- **Optimization:** Determining exactly which combination of factor levels will produce the optimal overall behavior of the system.
- **Ranking and Selection:** Ranking  $N$  number of alternatives (e.g., operating policies) and selecting the best one.

## **M&S Intended Use (Objective): Training**

**Video of Demonstration of Distributed Interactive Simulation (DIS)  
for Military Training**

**[Click Here to Play the Video](#)**



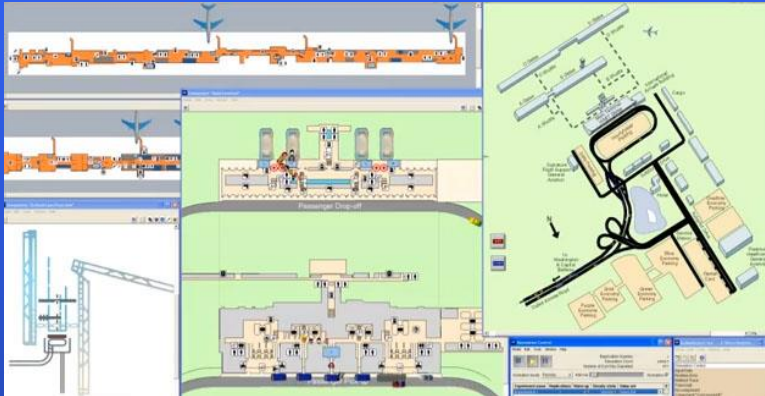
## This course focuses on **Discrete M&S**

- **Discrete M&S** is the one which uses a model built in terms of **logic** and the simulation **time** is represented as a **discrete** variable.
- **Discrete M&S** is typically used in disciplines such as computer science, systems engineering, industrial engineering, operations research, business, civil engineering, and management science.
- This type of M&S is commonly referred to as **Discrete Event Simulation**.
  - The “event” in the name comes from the traditional use of the Event Scheduling simulation programming approach.
  - However, other approaches exist based on activity, process, object, and agent.
  - Therefore, the term “event” should be dropped from the name so as to include all possible programming approaches.

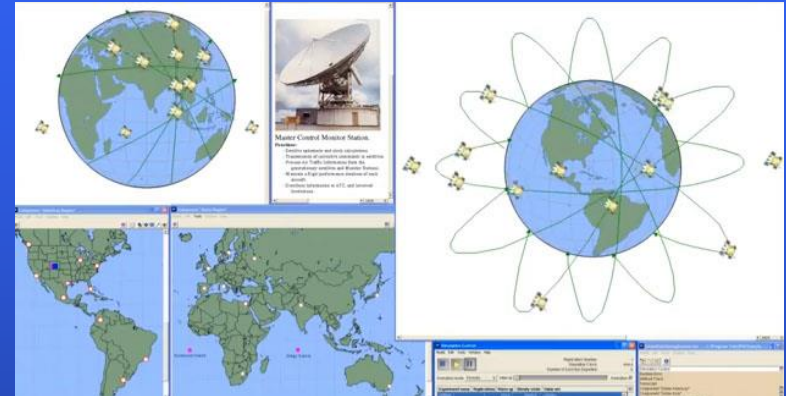
# Example Discrete M&S Applications

Click title to see the video of the M&S application

## Visual Simulation of Dulles Airport



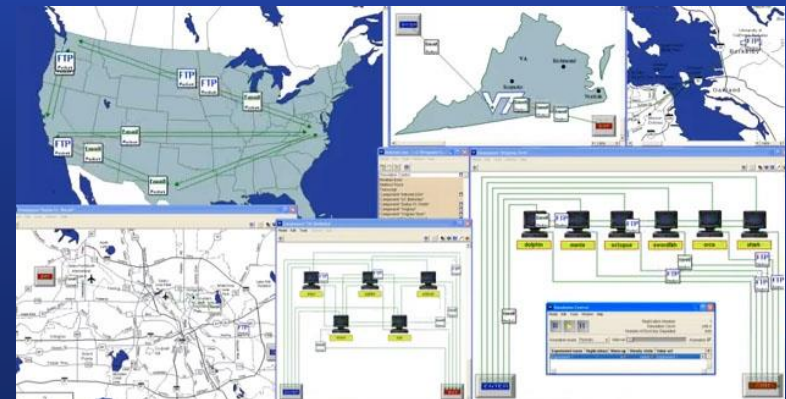
## Global Positioning System Simulation



## Visual Simulation of Blacksburg Traffic Network



## Internet Simulation



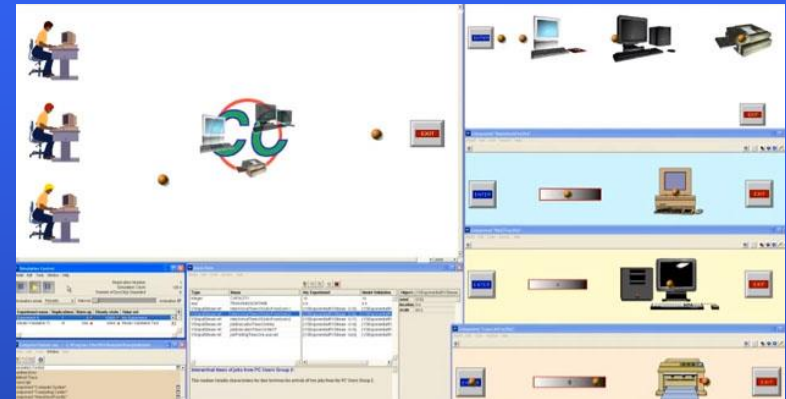
# Example Discrete M&S Applications

Click title to see the video of the M&S application

## Gulf War Simulation



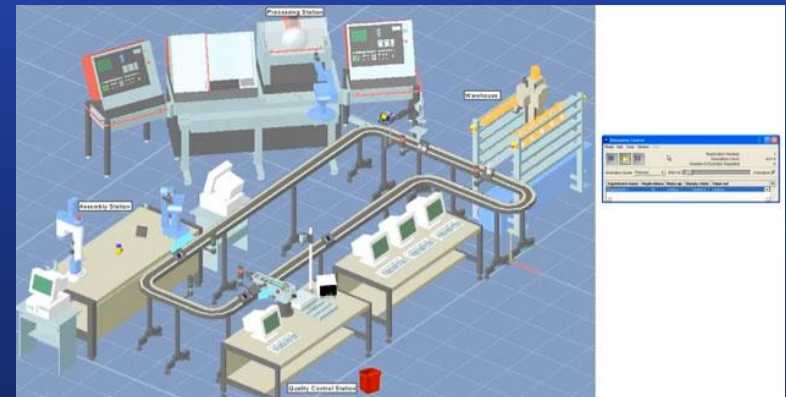
## Computer System Simulation



## Health Care Clinic Simulation



## Manufacturing System Simulation



[Click here to see more videos of Discrete M&S Applications.](#)

## Continuous M&S

- **Continuous M&S** is the one which uses a model consisting of **differential equations** and the simulation **time** is represented as a **continuous variable**.
- **Continuous M&S** is typically used in disciplines such as
  - aerospace engineering
  - computational fluid dynamics
  - computational solid mechanics
  - computational engineering
  - computational physics
  - materials science and engineering
  - heat transfer

## Monte Carlo M&S

- **Monte Carlo M&S** is the one which uses a model built based on **statistical random sampling**. The model typically does not represent time-varying relationships.
- **Monte Carlo M&S** is typically used in disciplines such as
  - Chemistry
  - Computational Engineering
  - Financial Probabilistic Modeling
  - Mathematics
  - Nuclear Engineering
  - (Computational, Nuclear, Statistical) Physics
  - Reliability Engineering [Click here to see videos of Continuous M&S Applications.](#)

## System Dynamics M&S

- **System Dynamics M&S** is the one which uses a model representing cause-and-effect relationships in terms of causal-loop diagrams, flow diagrams with levels and rates, and equations. The equations are used for simulating system behavior.
- **System Dynamics M&S** is typically used in disciplines such as
  - Business
  - Decision Sciences
  - Economics
  - Management
  - Organizational Sciences
  - Policy Studies
  - Social Sciences
  - System Sciences

## Gaming-based M&S

- **Gaming-based M&S** is the one which uses humans as part of its model. It is intended to train, educate or entertain people, e.g.,
  - **Classroom Gaming** is performed for educational purposes.
  - **Management Gaming** is performed to train/educate managers.
  - **War Gaming** is performed to train/educate military personnel.
  - **Video Gaming** is performed for entertainment and educational purposes.
- **Gaming-based M&S** is typically used in disciplines such as
  - Business
  - Education
  - Management
  - Training
  - Entertainment Industry

## Agent-based M&S

- **Agent-based M&S** is the one which uses a model representing agents and their interactions. An agent is “intelligent”, adaptive, autonomous, goal/self-directed, has the ability to learn, and can change its behaviors based on experience.
- **Agent-based M&S** draws characteristics from **AI-based M&S** and **object-oriented M&S**.
- An **Agent** is represented by attributes, behavioral rules, memory, resources, decision making rules, and rules to modify behavioral rules. An Agent is similar to an **object** in object-oriented M&S.
- **Agent-based M&S** is typically used in disciplines such as
  - Biological Sciences, Cognitive Sciences, Computational Sciences, Economics, Organizational Sciences, Physical Sciences, Social Sciences, Sociology

## Artificial Intelligence-based M&S

- **Artificial Intelligence (AI)** is a kind of **simulation** that involves a model intended to represent human intelligence or knowledge.
- An **AI-based simulation model** typically mimics human intelligence such as reasoning, learning, perception, planning, language comprehension, problem-solving, and decision making.
- Rule-based knowledge representation is commonly used for building AI-based simulation models.
- An **Expert System** is also a kind of **simulation** of some knowledge, typically constructed using rule-based knowledge representation.
- **Artificial Intelligence** is typically used in disciplines such as
  - Cognitive Science, Computer Science, Engineering, Language Translation, Neuroscience, Philosophy, Psychology, Game Playing, Robotics.

## Virtual Reality-based M&S

- **Virtual Reality** is the use of **modeling and simulation** to enable a person to interact with a three-dimensional visual representation of a real or imaginary system in an immersive, multi-sensory, and interactive manner.
- The user wears goggles, headsets, gloves, or body suits to interact with the simulation. The motion sensors pick up the user's movements and adjust his or her view and action accordingly during the interaction, usually in real-time.
- **Virtual Reality** is typically used in disciplines such as
  - Architecture, Computer-aided Design and Manufacturing, Education, Entertainment (Movies, Video Games), Human-Computer Interaction, Medical Science, Real Estate, Training

## Distributed / Parallel M&S

- **Distributed M&S** is the one which executes its model parts (e.g., federation of models, submodels, model components, subcomputations) on geographically or locally distributed computers.
- **Distributed M&S** enables geographically dispersed people to interact with the running simulation typically for training purposes.
- **Parallel M&S** is the one which executes its model parts (e.g., submodels, model components, subcomputations) on different processors (CPUs) of the same (clustered) computer for the purpose of achieving faster execution time.
- [Click here to see the video of Demonstration of Distributed Interactive Simulation \(DIS\) for Military Training.](#)

## Web-based M&S

- A **Network-Centric M&S application** is the one, the components of which run on different server computers and communicate over a network (e.g., Internet, virtual private network, wireless network) using the TCP/IP, HTTP, RMI or another protocol.
- The server computers running the models or model components of a network-centric M&S application can be geographically dispersed or be part of a local area network.
- A **Web-based M&S application** is a network-centric M&S application, which uses the HyperText Transfer Protocol (HTTP) for the communication among its components over a network.
- Users use client computers to access or interact with the M&S application running on server computer(s).
- **Client-Server Architecture** and **Service-Oriented Architecture** are popular ones for building network-centric M&S applications.
- Java Platform, Enterprise Edition (**Java EE**) and Microsoft **.NET** framework are two industry standard platforms for building network-centric M&S applications.

## Live Exercises

- A **Live Exercise** is conducted in real-time in a synthetic environment consisting of hardware, software, and humans under **simulated scenarios** for objectives such as
  - training,
  - operational test and evaluation,
  - interoperability assessment,
  - technology assessment, or
  - acquisition.

## Live Experimentations

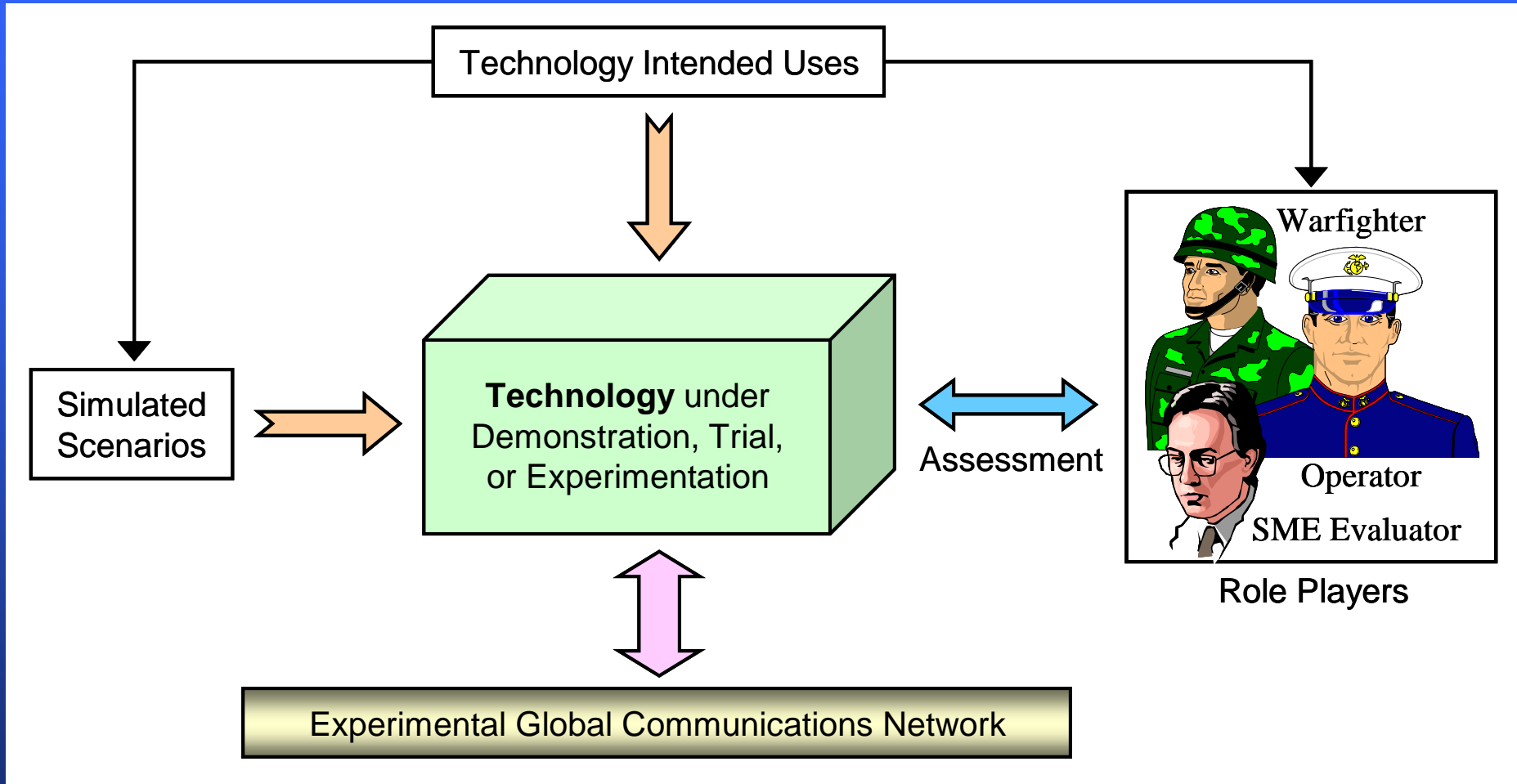
- A **Live Experimentation** is conducted in real-time in a synthetic environment consisting of hardware, software, and humans under **simulated scenarios** for objectives such as
  - operational effectiveness assessment,
  - interoperability assessment, or
  - technology (readiness) assessment.
- **Example:**
  - FORCENet “**Trident Warrior** (TW),” Naval Network Warfare Command, Norfolk, Virginia.
  - TW is an operational annual event that creates a synthetic environment integrating stand-alone systems and efforts to achieve substantially enhanced capability, and experiments with, demonstrates, or tests these capabilities in both laboratory and operational environments, and evaluates their effectiveness under simulated scenarios.

## Live Demonstrations

- A **Live Demonstration** is conducted in real-time in a synthetic environment consisting of hardware, software, and humans under **simulated scenarios** for the purpose of demonstrating that a complex system possesses a set of quality characteristics.
- **Example: Coalition Warrior Interoperability Demonstration (CWID)**
  - **CWID UK, CWID US, CWID NATO**
  - CWID is conducted annually for the purpose of evaluating technologies and capabilities for the interoperability quality characteristic under a set of prescribed simulated scenarios.
- CWID evaluates technologies and capabilities for exchanging information among coalition partners, military services, government agencies, first responders, and U.S. combatant commanders under simulated scenarios using role players.

# Live Demonstrations

## CWID Technology Assessment under Simulated Scenarios



Osman Balci and William F. Ormsby (2007), "Scenario Simulation for Network-Centric Technology Assessment," In *Recent Advances in Modeling and Simulation Tools for Communication Networks and Services*, A.N. Ince and A. Bragg, Eds, Springer, New York, NY, Chapter 10, pp. 203-226.

## Live Trials

- A **Live Trial** is conducted in real-time in a synthetic environment consisting of hardware, software, and humans under **simulated scenarios** for objectives such as
  - interoperability assessment, or
  - technology assessment.
- **Example:**
  - Coalition Warrior Interoperability Demonstration (CWID)
- For example, at CWID, a technology (e.g., Voice over IP – VoIP) is tried to assess how well it enables interoperability among the coalition military forces under **simulated scenarios** and a set of intended uses.

## CWID 2007 A Sample List of Interoperability Trials (ITs)

<i>IT No.</i>	<i>System Title</i>
IT 6.04	Tactical Emergency Asset Management (T.E.A.M.)
IT 2.06	Italian Navy Maritime Command & Control Information System
IT 5.08	Joint Strike Fighter Off-board Mission Support Environment
IT 3.09	Global Personnel Recovery System (GPRS)
IT 3.14	Coalition Secure Management and Operations System (COSMOS)
IT 3.31	Coalition Infrared Data Processing (CIDP)
IT 5.32	Joint AirSpace Management and Deconfliction (JASMAD)
IT 3.50	Chem/Bio Coalition Interoperability (US/UK CBIS)
IT 5.52	Joint Coordinated Real-Time Engagement (JCRE)
IT 6.53	WMD Collaborative Advisory Response System II (WMD CARS II)
IT 6.64	Unmanned Vehicle IP Communications Tactical Data Link
IT 1.69	Multi-Level Secure Voice Communications (MLSVC)
IT 3.70	Coalition open Joint Operations Picture ( CoJOP)
IT 3.71	MobiKEY Identity Management & Secure Access (MobiKEY)

## Hardware-in-the-Loop M&S

- **Hardware-in-the-loop M&S** can be viewed as **Simulation-based Hardware Evaluation**.
- A **hardware** system can be operated under **simulated** input conditions for the purpose of evaluating how well the hardware functions under such input conditions.
- For example, a **space vehicle** can be operated under **simulated** input conditions for the purpose of **evaluating the vehicle's autopilot mode**.
- **Hardware-in-the-loop M&S** is a cost-effective method for evaluating a complex, mission-critical hardware before it is used in the real world.

## Human-in-the-Loop M&S

- **Human-in-the-loop M&S** is also called **Simulation-based Training**.
- A simulation model of a system, e.g.,
  - airplane
  - air traffic control center
  - emergency management plan
  - military operationis developed for the purpose of training people.
- Trainees interact with the visual simulation model for the purpose of learning, e.g.,
  - how to fly an airplane (using the flight simulator)
  - how to control air traffic at an airport
  - how to manage an emergency in response to a disaster
  - how to make military decisions
- **Human-in-the-loop M&S** can also be used as a cost-effective method for **evaluating human performance and behavior for a proposed system design**.

## Software-in-the-Loop M&S

- **Software-in-the-loop M&S** can be viewed as **Simulation-based Software Evaluation**.
- A **software** system can be executed under **simulated** input conditions for the purpose of evaluating how well the software system functions under such input conditions.
- For example, the software used to display the common operating picture (COP) in a combat operation on a handheld computer can be executed under **simulated** input data (e.g., video, voice, images, text) received from many different sources for the purpose of **evaluating how well the software satisfies its requirements**.
- **Software-in-the-loop M&S** is a cost-effective method for evaluating a complex, mission-critical software system before it is used in the real world.

# Example M&S Intended Uses for each M&S Area

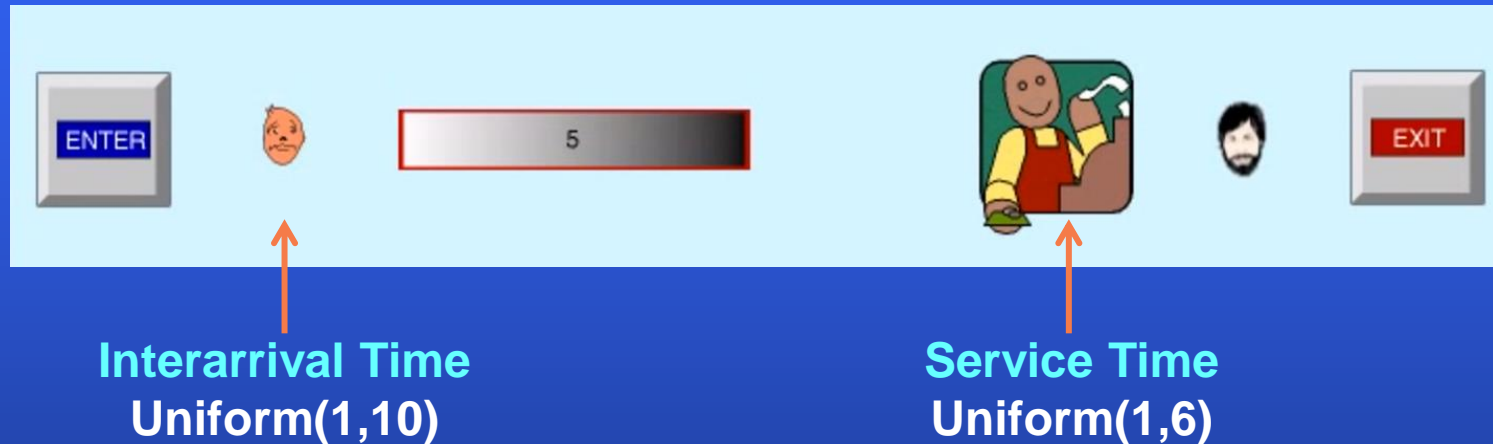
M&S Areas		Example M&S Intended Uses (Objectives)
<b>A. Based on Model Representation:</b>		
1. Discrete M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Acquisition, Entertainment, Research, Education</b>
2. Continuous M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Acquisition, Entertainment, Research, Education</b>
3. Monte Carlo M&S		<b>Problem Solving based on statistical random sampling</b>
4. System Dynamics M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Research</b>
5. Gaming-based M&S		<b>Training, Education, Entertainment</b>
	a. Classroom Gaming	<b>Education of students</b>
	b. Management Gaming	<b>Training, Education of managers</b>
	c. War Gaming	<b>Training, Education of military personnel</b>
	d. Video Gaming	<b>Entertainment, Education</b>
6. Agent-based M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Entertainment, Research, Education</b>
7. Artificial Intelligence-based M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Entertainment, Research, Education</b>
8. Virtual Reality-based M&S		<b>Problem Solving</b> (e.g., evaluation, comparison, prediction, sensitivity analysis, optimization, ranking and selection), <b>Training, Acquisition, Entertainment, Research, Education</b>
<b>B. Based on Model Execution:</b>		
9. Distributed M&S		<b>Improve execution efficiency; Enable geographically dispersed users to use the M&amp;S application over a network</b>
10. Web-based M&S		<b>Enable geographically-dispersed users to use the M&amp;S application over a network</b>
<b>C. Based on Model Composition:</b>		
11. Live Exercises		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>
12. Live Experimentations		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>
13. Live Demonstrations		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>
14. Live Trials		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>
<b>D. Based on What is in the Loop:</b>		
15. Hardware-in-the-loop M&S		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>
16. Human-in-the-loop M&S		<b>Operational Test &amp; Evaluation, Training</b>
17. Software-in-the-loop M&S		<b>Operational Test &amp; Evaluation, Acquisition, Training</b>

# Example Discrete M&S Applications

1. Air traffic control and space systems: analysis, evaluation, comparison, prediction, and training
2. Air traffic controllers training
3. Airport operational effectiveness evaluation
4. Business process reengineering and workflows: analysis, evaluation, comparison, and prediction
5. Computer and communication networks: analysis, evaluation, comparison, and prediction
6. Computer system performance evaluation, performance tuning, and capacity planning
7. Emergency response management and planning: analysis, evaluation, comparison, prediction, and training
8. Health care systems: analysis, evaluation, comparison, and prediction
9. Homeland defense and security: analysis, evaluation, comparison, prediction, and training
10. Manufacturing systems: analysis, evaluation, comparison, and prediction
11. Military / combat systems: analysis, evaluation, comparison, prediction, and training
12. Nuclear power plant operators training
13. Operational test and evaluation
14. Risk analysis and estimation
15. Satellite and wireless communications systems: analysis, evaluation, comparison, and prediction
16. Service systems: analysis, evaluation, comparison, and prediction
17. Supply chain management: analysis, evaluation, comparison, and prediction
18. System (of systems) / enterprise architecture assessment
19. System deployment readiness assessment
20. System design evaluation
21. System integration effectiveness evaluation
22. System operational effectiveness evaluation
23. System reliability / safety / security engineering: analysis, evaluation, comparison, and prediction
24. Training managers, commanders, operators, and war fighters
25. Transportation systems: analysis, evaluation, comparison, and prediction

# Manual Discrete Simulation of Cashier Service

[Click here to see a video of the visual simulation of the cashier system.](#)



## ■ Questions:

- What is the average time (both waiting and being serviced) a customer spends at the Cashier?
- What is the percent of time the Cashier is idle?

# Manual Discrete Simulation of Cashier Service

Cus No.	Random IAT Since Last Arrival (min)	Random Service Time (min)	Customer Arrival Time	Service Starts	Service Ends	Customer Wait Time (min)	Cashier Idle Time (min)
1	-	1	0:00	0:00	0:01	1	0
2	3	4	0:03	0:03	0:07	4	2
3	7	4	0:10	0:10	0:14	4	3
4	3	2	0:13	0:14	0:16	3	0
5	9	1	0:22	0:22	0:23	1	6
6	10	5	0:32	0:32	0:37	5	9
7	6	4	0:38	0:38	0:42	4	1
8	8	6	0:46	0:46	0:52	6	4
9	8	1	0:54	0:54	0:55	1	2
10	8	3	1:02	1:02	1:05	3	7
11	7	5	1:09	1:09	1:14	5	4
12	3	5	1:12	1:14	1:19	7	0
:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:

IAT – Inter Arrival Time

TotalWT

TotalIT

Average Waiting Time = TotalWT / N

N = Number of customers simulated

% Cashier Idle = (100 x TotalIT / T) %

T = Simulation duration time

