

Discrete Event Simulation

Discrete Event Simulation

- ❑ Imitating the operation of a system over time.
- ❑ Typical objective- Support decisions related to the use of limited resources.

Discrete Event Simulation - Outline

- To understand how and why we simulate such systems we will cover:
 - Analysis options.
 - The mechanics of how a simulation is implemented on a computer.
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- Modeling views/orientations.
- The steps of a simulation study.
- Analyzing input and output data.
- Simulating randomness.

Analysis Options

- Utilize the simplest fastest methods that provide adequate decision support



Analysis Options

- ❑ Resource allocation decisions – It may suffice to examine resource utilizations and WIP.

Example

- A workstation has two machines in parallel that can process jobs at a rate of 15 JPH. Jobs arrive over time at a rate of 25 JPH.
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Analysis Options

- Unless a system has very high relative variability, utilizations $< 90\%$ will lead to “reasonable” queue sizes.
 - Demo

In-class Exercise

- Two types of jobs (A and B) arrive to a single machine for processing. The arrival rate of type A jobs is 5 per hour, and 2.5 per hour for type B jobs. Type A jobs have an average service time of 5 minutes, and type B jobs have an average service time of 11 minutes.
 - What is the utilization of the machine?
-

Analysis Options

- At the next level of detail queuing models may be applied.
 - More information than utilization calculations.
 - Difficult skill to apply.
 - Some G/G/m models were covered in IE 368.

Discrete Event Simulation - Basics

- ❑ Fundamental components/terminology.
- ❑ Simulation mechanics
 - Manual execution of a simulation.
- ❑ Performance measures.

Terminology

□ We will simulate stochastic dynamic discrete-event systems.

■ Stochastic –



■ Dynamic –



Terminology

- Discrete event –

- System state –

- Examples

Terminology

- Entities – Objects that move through the simulated system.
 - Examples
 -
- Entities can be combined and split.
- Attributes – Parameters, data specific to an entity.
 - Examples
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- The same concept as objects (entities) and object data (attributes) in Object Oriented Programming

Terminology

- Global variables/parameters – System wide values accessible by all entities and resources.
 - Examples
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- Resources – Items that are used by entities and found in limited amounts.
- Queues – Spaces where entities wait for resources.

Terminology

- Events – Actions that cause the system state to change.
 - Examples
 -

Mechanics of Simulation

- Event calendar and the passage of simulated time.
 - Simulations maintain an event calendar that functions like the control center of the simulation.
 - The event calendar is a time sorted list of events and the times that they occur.
 - When the event at the top of the list occurs, simulated time is advanced and specific logic is initiated.
 - This logic changes the state, updates statistics, and schedules additional events.

Event Calendar

Event	Time
1	t_1
2	t_2
n	t_n

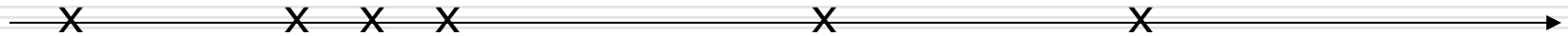
Main

Procedures/
Functions

Computer Program

Simulation Clock

- ❑ Simulation time does not advance uniformly unless controlled.



- ❑ Arena demo

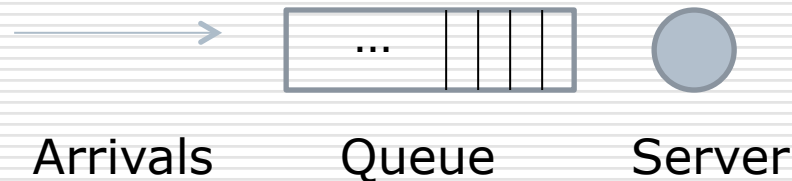
Manual Simulation

- ❑ We will execute a manual simulation on paper to understand the fundamentals of simulation mechanics.
- ❑ You will execute what the computer carries out in a simulation.

Example System

- A “single server queuing system with infinite queue capacity”.
- System description
 - Customers (jobs) arrive one at a time to be processed by a server who can serve a single customer at a time. If the server is idle when a customer arrives the customer immediately starts service, otherwise the customer waits in an infinite capacity queue and is served in first-in-first-out (FIFO) order.

Example System



For some fixed simulated time:

- How many customers are processed?
 - What's the average customer queue time?
 - What's the average customer system time?
 - What is the average number in queue?
 - What is the server utilization?
 - What are max observed values for
 - Queue time?
 - Time in system?
 - Number in queue?
-

Manual Simulation

- Will use pseudo code and a table to implement the simulation.
- See handout.

<p> 1.1 Introduction 1.2 Background 1.3 Objectives 1.4 Scope 1.5 Methodology 1.6 Results 1.7 Conclusion 1.8 References 1.9 Appendix 1.10 Index 1.11 Glossary 1.12 Abbreviations 1.13 Acronyms 1.14 Footnotes 1.15 Endnotes 1.16 References 1.17 Appendix 1.18 Index 1.19 Glossary 1.20 Abbreviations 1.21 Acronyms 1.22 Footnotes 1.23 Endnotes 1.24 References 1.25 Appendix 1.26 Index 1.27 Glossary 1.28 Abbreviations 1.29 Acronyms 1.30 Footnotes 1.31 Endnotes 1.32 References 1.33 Appendix 1.34 Index 1.35 Glossary 1.36 Abbreviations 1.37 Acronyms 1.38 Footnotes 1.39 Endnotes 1.40 References 1.41 Appendix 1.42 Index 1.43 Glossary 1.44 Abbreviations 1.45 Acronyms 1.46 Footnotes 1.47 Endnotes 1.48 References 1.49 Appendix 1.50 Index 1.51 Glossary 1.52 Abbreviations 1.53 Acronyms 1.54 Footnotes 1.55 Endnotes 1.56 References 1.57 Appendix 1.58 Index 1.59 Glossary 1.60 Abbreviations 1.61 Acronyms 1.62 Footnotes 1.63 Endnotes 1.64 References 1.65 Appendix 1.66 Index 1.67 Glossary 1.68 Abbreviations 1.69 Acronyms 1.70 Footnotes 1.71 Endnotes 1.72 References 1.73 Appendix 1.74 Index 1.75 Glossary 1.76 Abbreviations 1.77 Acronyms 1.78 Footnotes 1.79 Endnotes 1.80 References 1.81 Appendix 1.82 Index 1.83 Glossary 1.84 Abbreviations 1.85 Acronyms 1.86 Footnotes 1.87 Endnotes 1.88 References 1.89 Appendix 1.90 Index 1.91 Glossary 1.92 Abbreviations 1.93 Acronyms 1.94 Footnotes 1.95 Endnotes 1.96 References 1.97 Appendix 1.98 Index 1.99 Glossary 1.100 Abbreviations 1.101 Acronyms 1.102 Footnotes 1.103 Endnotes 1.104 References 1.105 Appendix 1.106 Index 1.107 Glossary 1.108 Abbreviations 1.109 Acronyms 1.110 Footnotes 1.111 Endnotes 1.112 References 1.113 Appendix 1.114 Index 1.115 Glossary 1.116 Abbreviations 1.117 Acronyms 1.118 Footnotes 1.119 Endnotes 1.120 References 1.121 Appendix 1.122 Index 1.123 Glossary 1.124 Abbreviations 1.125 Acronyms 1.126 Footnotes 1.127 Endnotes 1.128 References 1.129 Appendix 1.130 Index 1.131 Glossary 1.132 Abbreviations 1.133 Acronyms 1.134 Footnotes 1.135 Endnotes 1.136 References 1.137 Appendix 1.138 Index 1.139 Glossary 1.140 Abbreviations 1.141 Acronyms 1.142 Footnotes 1.143 Endnotes 1.144 References 1.145 Appendix 1.146 Index 1.147 Glossary 1.148 Abbreviations 1.149 Acronyms 1.150 Footnotes 1.151 Endnotes 1.152 References 1.153 Appendix 1.154 Index 1.155 Glossary 1.156 Abbreviations 1.157 Acronyms 1.158 Footnotes 1.159 Endnotes 1.160 References 1.161 Appendix 1.162 Index 1.163 Glossary 1.164 Abbreviations 1.165 Acronyms 1.166 Footnotes 1.167 Endnotes 1.168 References 1.169 Appendix 1.170 Index 1.171 Glossary 1.172 Abbreviations 1.173 Acronyms 1.174 Footnotes 1.175 Endnotes 1.176 References 1.177 Appendix 1.178 Index 1.179 Glossary 1.180 Abbreviations 1.181 Acronyms 1.182 Footnotes 1.183 Endnotes 1.184 References 1.185 Appendix 1.186 Index 1.187 Glossary 1.188 Abbreviations 1.189 Acronyms 1.190 Footnotes 1.191 Endnotes 1.192 References 1.193 Appendix 1.194 Index 1.195 Glossary 1.196 Abbreviations 1.197 Acronyms 1.198 Footnotes 1.199 Endnotes 1.200 References</</p>
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Notation

t = simulation time

t_{before} = prior event simulation time.

$Q(t)$ = # in queue at time t

$B(t)$ = 1 if the server is busy, and 0 if the server is idle

P = the number of customers/jobs processed after each event

N = the number of customers/jobs that have passed through the queue

$\sum WQ$ = the sum of the queue times observed for customers

WQ^* = Max queue time observed

$\sum TS$ = the sum of the system times (queue + service) observed for customers

TS^* = Max system time observed

$\int Q$ = the area under the $Q(t)$ curve through time t

Q^* = Max value for the number in queue observed

$\int B$ = the area under the $B(t)$ curve through time t

[illegible]

	Interarrival Times			Service Times
			Customer	
First Arrival	0.0		1	2.9
1	1.73		2	1.76
2	1.35		3	3.39
3	0.71		4	4.52
4	14.28		5	4.46
5	0.7		6	4.36

[illegible]

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“Simulation Performance Measures”

- Simulation performance measures
 - Tally statistics – “Tally” is an Arena term.
 -

“Simulation Performance Measures”

- Simulation performance measures.
 - Counters – Incremented when specific events occur.
 - E.g., Completed jobs.
 - Time average measures – Arena calls these “Time persistent”
 -

“Simulation Performance Measures”

- Simulation performance measures.
 - Maximums and minimums – Changed when specific comparisons indicate.
 - E.g., Maximum jobs in queue.

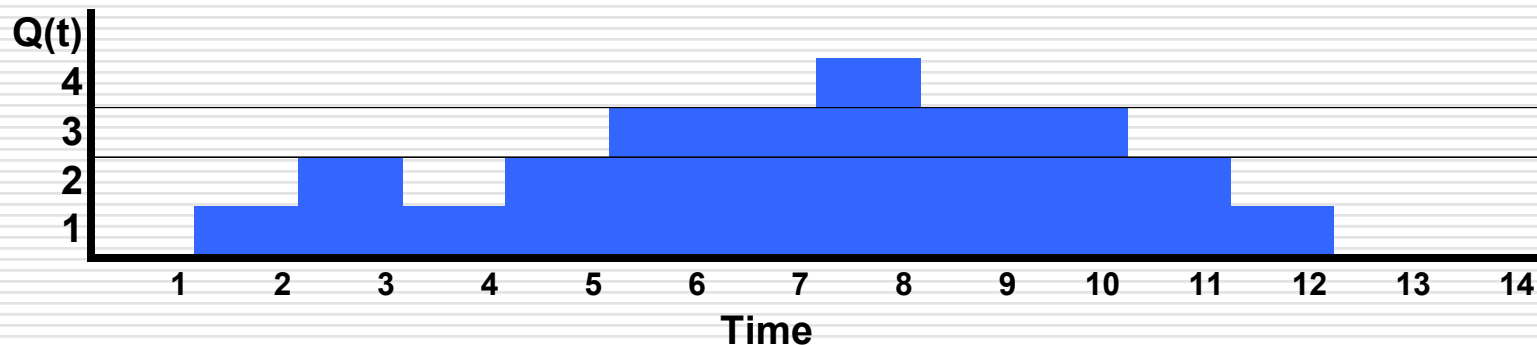
“Simulation Performance Measures”

- The average time a part spends in the system.
 - Tally or Time average?
- Utilization of a machine.
 - Tally or Time average?

In-class Exercise

- Compute the average number in system, and average time in system through $T = 14$ (assume first-in-first-out).

No simultaneous arrivals/completions occur



In-class Exercise

Simulation Modeling Views

- The manual simulation looked at the system dynamics by examining the events that occur.
 - This is called event orientation.
- Event orientation
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Simulation Modeling Views

- ❑ Process orientation – The focus on defining the system dynamics is on entities and how they flow through the system.
- ❑ Manual simulation.
 - Arrive-> Queue -> Machine -> Depart
- ❑ Arena is process orientated simulation system.
- ❑ Process orientation tends to be easier when modeling large systems.
- ❑ Most simulations are implemented in an event driven manner (including Arena).

Initial Steps in a Simulation Study

- ☐ Define the objectives of the study.
 -
- ☐ Write a description of the system.
 -
- ☐ List assumptions if any.
- ☐ Write a report introduction.
- ☐ From the system description identify
 - Data collection needs
 - ☐

Intermediate Steps

- Begin model development.
 -
- Fit distributions to data for use in the model.
 -
- Verify and validate the model.
- Experimentation and analysis.
 -

Final Steps

- Report writing.
- Presentations.
 - Animation if necessary
- Other points.
 - On going communication throughout the study.
 - Observation/face time.