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INCOSE Webinar Series

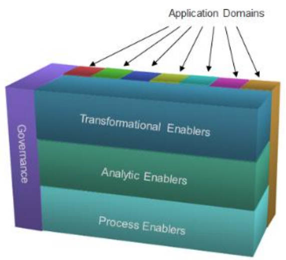
Wednesday 10th July 2019 – Webinar 126

Simulation Modeling for Systems Engineers

Rainer Dronzek

INCOSE®

INCOSE is offering Webinars…



- To provide a forum for experts in the field of Systems Engineering to present information on the “State of the Art”
- To explain how INCOSE works, and how to make the most out of INCOSE membership

INCOSE Systems Engineering Professional PDU Credit

Please note that you can claim 1PDU credit towards your Systems Engineering Professional re-certification by attending this webinar. INCOSE webinars may also apply to the PDU requirements of other organizations, depending on the subject matter

To qualify, you must have attended through at least 75% of the webinar for webinars that last less than one hour, or through 45 minutes of the webinar for webinars that last for 1 hour or longer.

Here is the link to details about certification renewal, including information on PDUs.
http://www.incose.org/certification/CertProcess/CertRenew

Choreography

1. Andy Pickard (your host) will introduce the Webinar and the speaker
2. Rainer will speak for about 40 to 45 minutes
3. During his talk, participants can write questions using the Webex Q&A window
4. After Rainer completes his talk, he will spend 10 minutes answering questions that Andy selects from those submitted by the audience
5. Andy Pickard will provide information about upcoming Webinars and then end this session
6. This Webinar is being recorded and will be made available on the INCOSE website to members and employees of CAB organizations

Rainer Dronzek

10 July 2019

Simulation Modeling for Systems Engineers

Rainer Dronzek: Biography

- Engineering and management positions in the aerospace, oil & gas and consulting industries
- Began systems engineering career on the Space Shuttle Program at the Kennedy Space Center. First introduction to the art and science of simulation modeling
- Managed projects and standing teams, founded a simulation consulting firm, and organized events and conferences around simulation modeling
- Sales Director – North America for The AnyLogic Company
- B.S. in Electrical Engineering from Bradley University

Agenda

- Simulation Modeling
- Multi-Method Modeling
- Application of Simulation Modeling to the Systems Engineering Experience Areas
- Simulation Model Data
- Other Considerations

Simulation Modeling

One Definition of Simulation Modeling

- A computer-based dynamic business model that combines mathematical and logical concepts to create a representation of an existing or proposed system for the purposes of analysis, visualization and performance prediction
- Used for
  - Requirements definition
  - Design and analysis
  - Daily operational management
  - Sales and marketing
  - Training

On Models

The best material model of a cat is another, or preferably the same, cat.

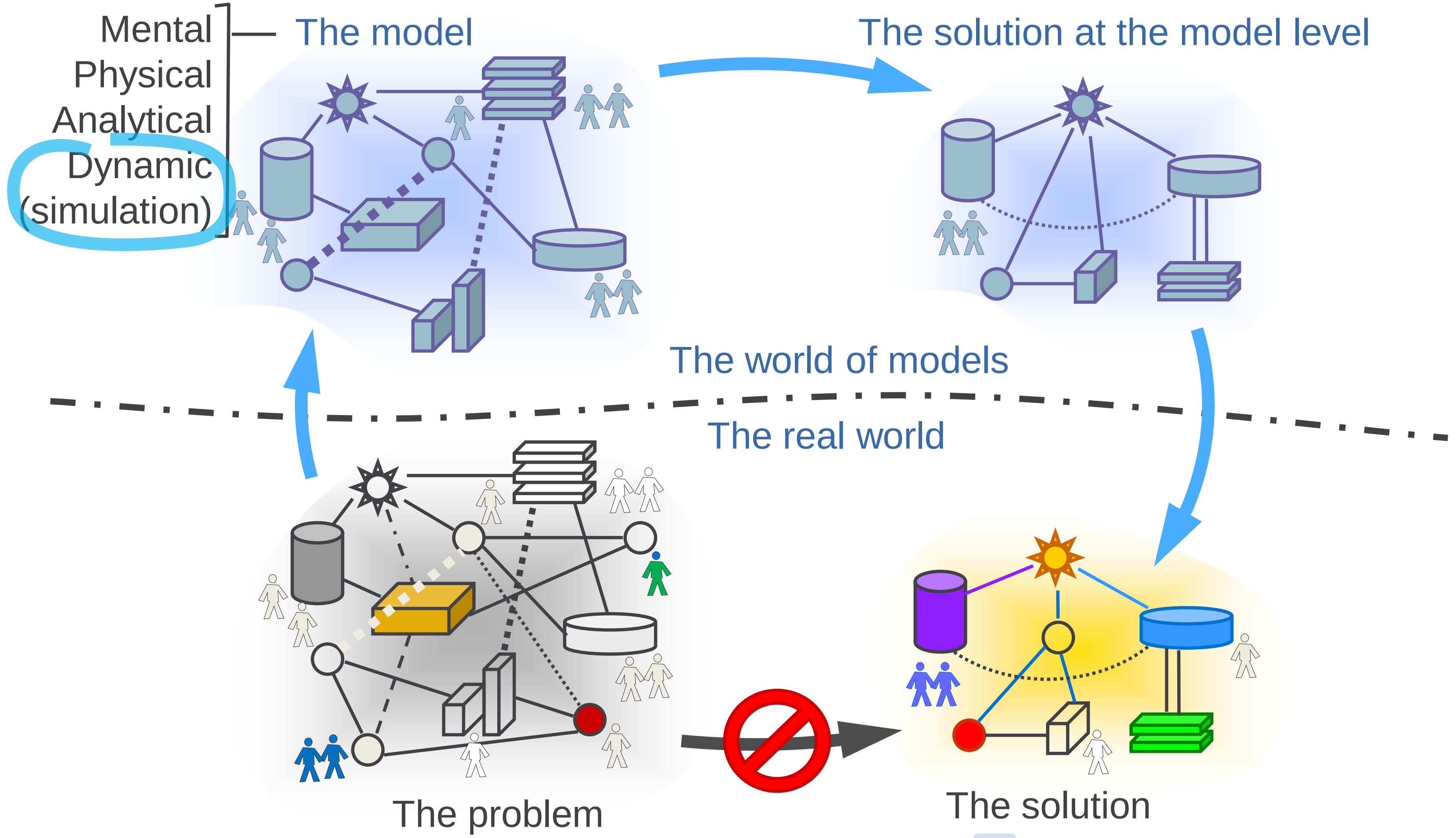
Norbert Wiener, mathematician (1945)

More On Models

All models are wrong.

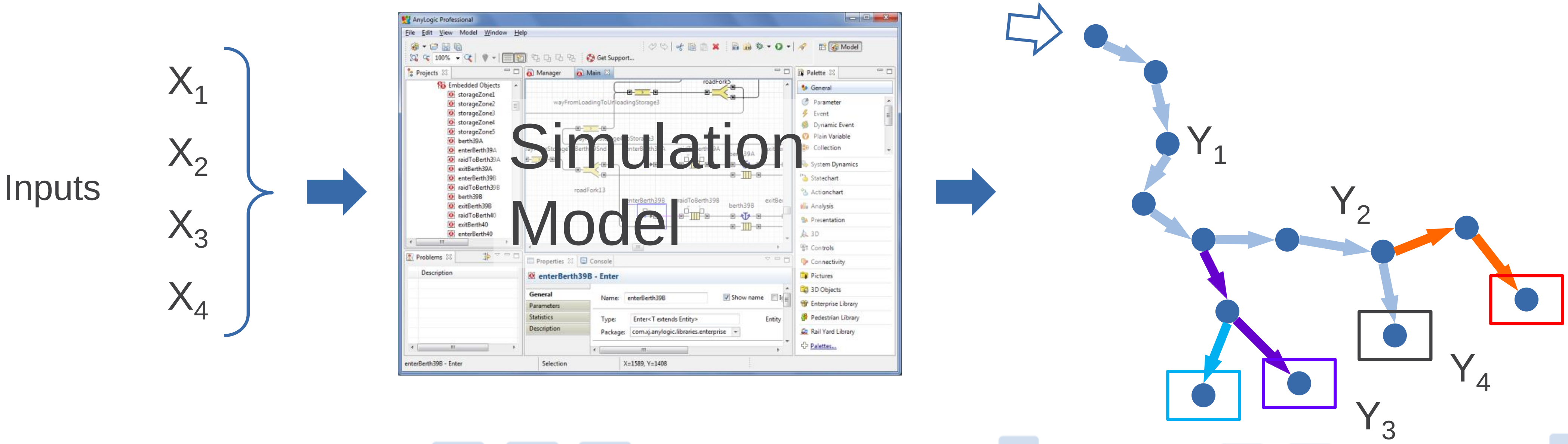
George Box, mathematician (1971)

Solutions in a Risk-Free Space



Dynamic Simulation Modeling

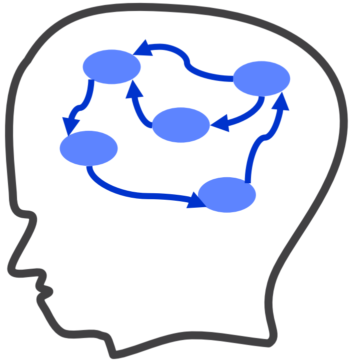
- A dynamic simulation model is an *executable* model
  - Rules determine the next state of the system in time from the current state
- The model produces a trajectory of the system state in time
  - Changing outputs are *observed* as time advances



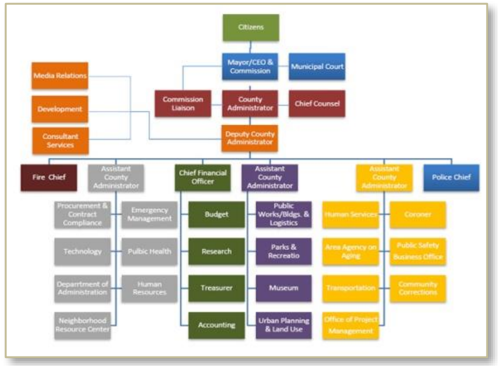
Model Types

INCOSE

Mental Models

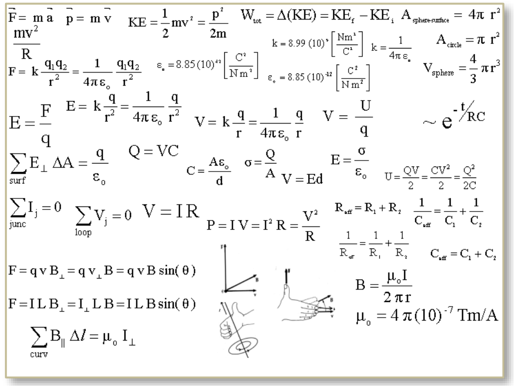


Connected Boxes

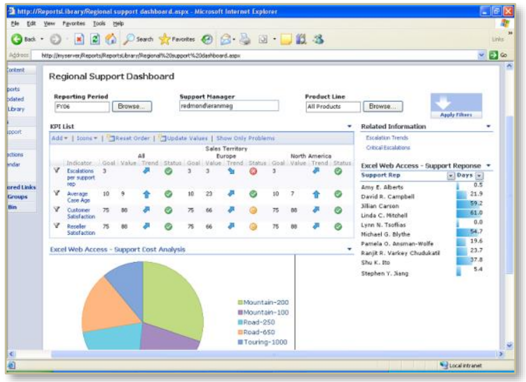


Physical Models

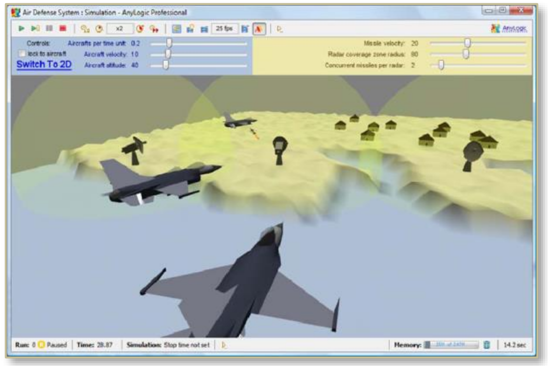
Formulas



Spreadsheets

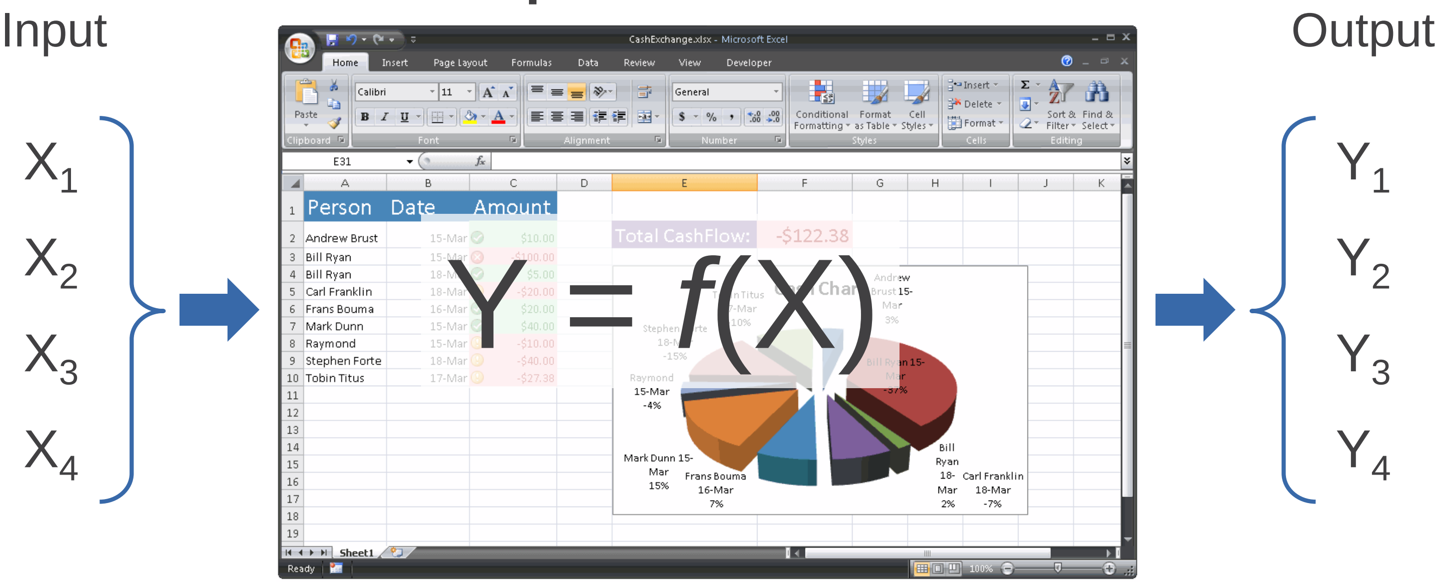


Simulation Models



The Most Popular Modeling Tool

Spreadsheet



Analytical solution (formulas and scripts)

Maybe A Spreadsheet is Sufficient

- An analytical solution can be found if:
  - Number of parameters is manageable
  - Behavior is linear
  - Dependencies are clear
  - A mental model may be easily defined

- But, what if:
  - Too many parameters
  - Non-linear, non-obvious influences
  - Time and causal dependencies
  - Counter-intuitive behavior
  - Uncertainty (stochasticity)

Example: Bank Teller

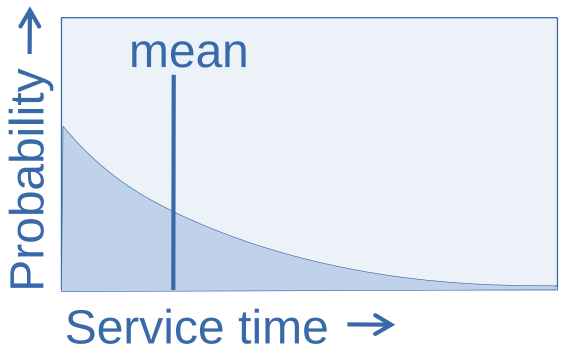
- A simplistic case:
  - On average 10 clients per hour
  - Only one teller at the counter
  - Mean service time is 5 minutes
- We want to determine:
  - Mean waiting time in the queue
  - [Other metrics can be derived from that one]

Mean waiting time* $w = \dfrac{\lambda b^2}{1-\lambda b}$, where λ - arrival rate, b - mean service time

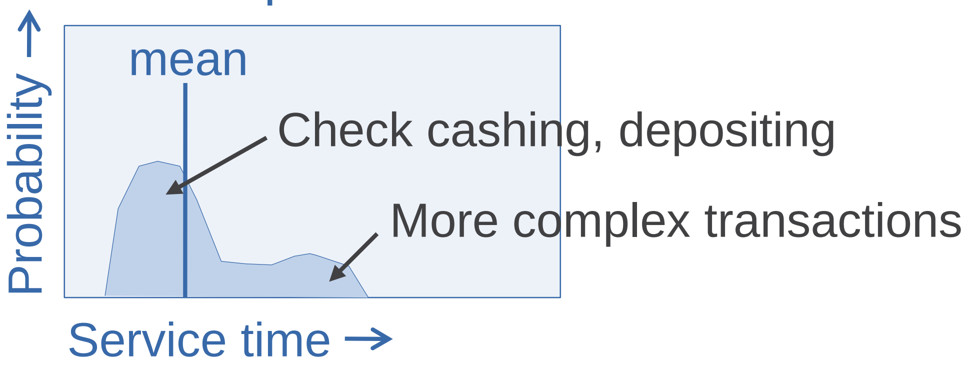
This holds only for a Poisson stream of clients (i.e., independent arrivals with a constant rate) and an exponentially distributed service time

Bank Teller: Assumptions

- Independent arrivals of clients? OK assumption for a bank
- Exponentially distributed service time? This is far from reality



Distribution shape is more like:



- Need another formula:

$$w = \frac{\lambda b^2 (1 + C_b^2)}{2(1 - \lambda b)}$$, where C_b - coefficient of variation of service time

Bank Teller: More Complexity

- Let there be several (*K*) tellers
  - This is so-called “multi-server queue model”. The analytic solution*:

$$w = \frac{Pb}{K(1-\rho)}$$, where $\rho = \frac{\lambda b}{K}$ - system utilization,

$$P = \frac{(K\rho)^K}{K!(1-\rho)} P_0$$, where $P_0 = \left[\frac{(K\rho)^K}{K!(1-\rho)} + \sum_{i=0}^{K-1} \frac{(K\rho)^i}{i!} \right]^{-1}$

- probability of all tellers being busy

- probability of no customers in the bank

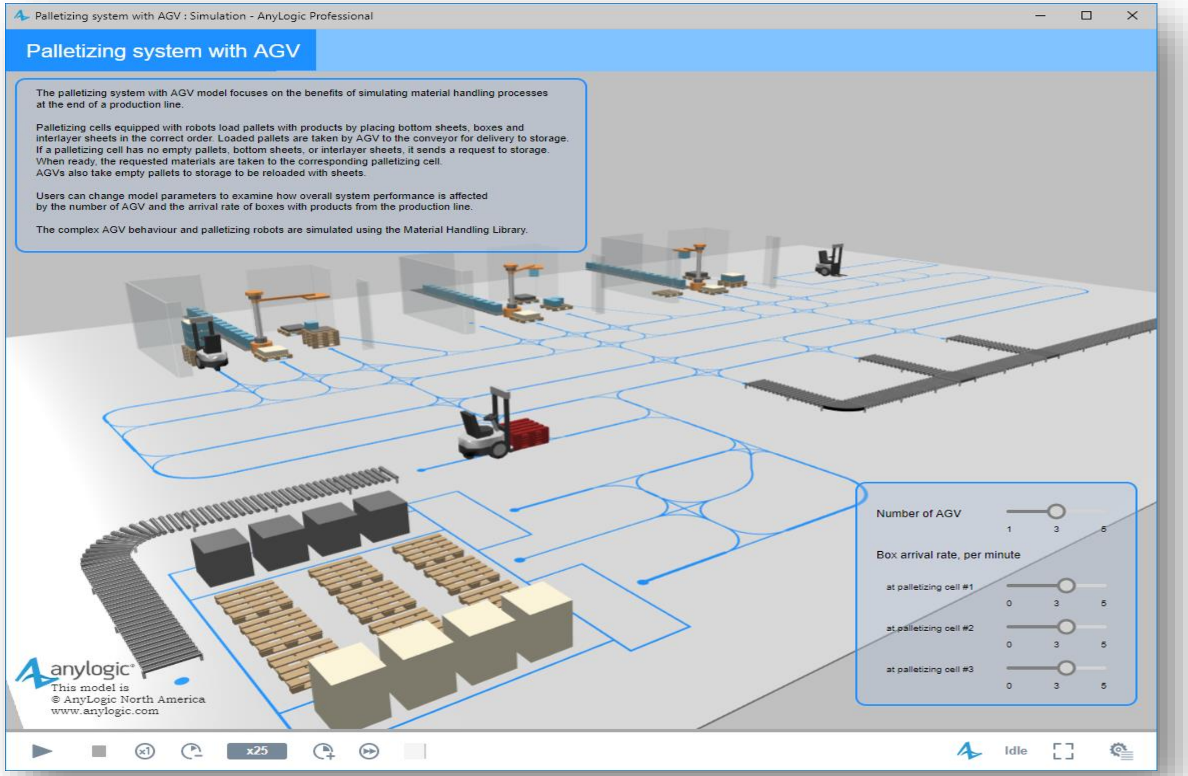
* Only valid for Poisson stream of clients and exponentially distributed service time

- And what if service time has a different distribution?
  - Even for such a simple system there is no analytic solution

Bank Teller: Conclusion

- A real bank process is far more complex. For example:
  - Some transactions may only be performed by specific employees
  - Customers may be redirected to other employees
  - Tellers may share resources (e.g., printer, cash counter)
  - Employees have different skill and performance levels
- The analytic solution probably does not exist
  - Even if it does exist, who can find it?
  - Any process change voids the previous analytic solution
- The only analysis method for such systems is simulation modeling

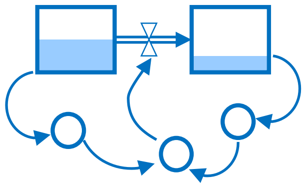
Example Model



Robotic Palletizing & Automated Guided Vehicles (AGVs)

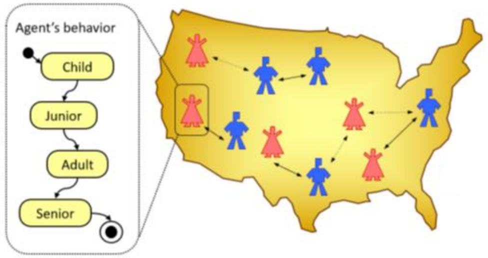
Multi-Method Modeling

Simulation Modeling Methods



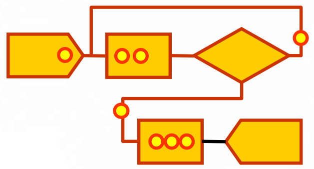
System Dynamics

Nonlinear behavior of complex systems using stocks, flows and internal feedback loops



Agent Based

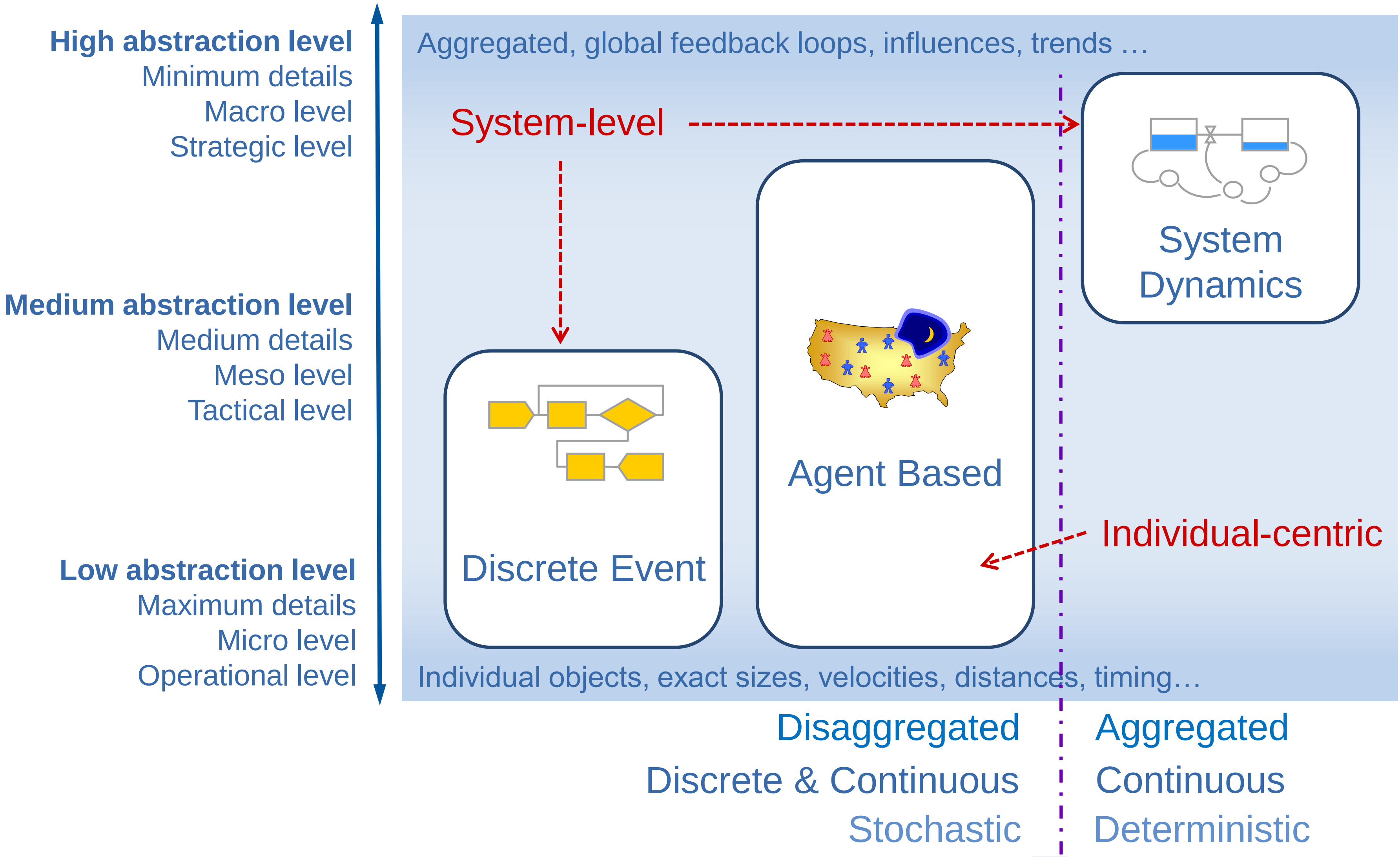
Individual objects with dynamic behavior that interact with other agents & their environment



Discrete Event

Entities moving through a process that encounter queues and use limited-capacity resources

Simulation Modeling Methods



Application Areas

High abstraction level
[minimum details
macro level
strategic level]

Medium abstraction level
[medium details
meso level
tactical level]

Low abstraction level
[maximum details
Micro level
Operational level]

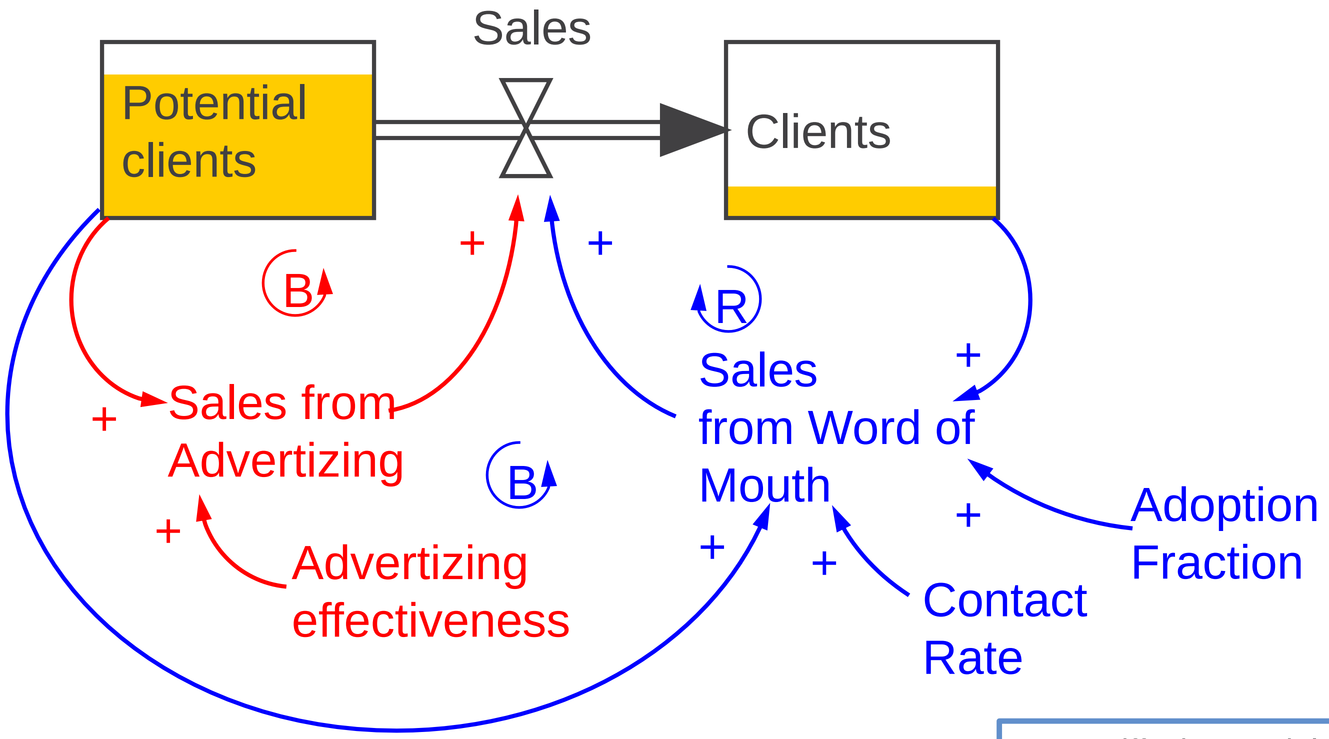
Aggregates, global feedback loops, influences, trends …

- Market and competition
- Social systems
- Project/product management
- Ecosystems
- HR dynamics
- Health economics
- Energy supply networks
- Asset management
- Supply chains
- Transportation
- Healthcare
- Business processes
- Service systems
- Manufacturing
- Battlefield, command and control
- Warehouse logistics
- Pedestrian dynamics
- Computer hardware
- Physical control systems

Individual objects, exact sizes, velocities, distances, timing…

System Dynamics: 1950s

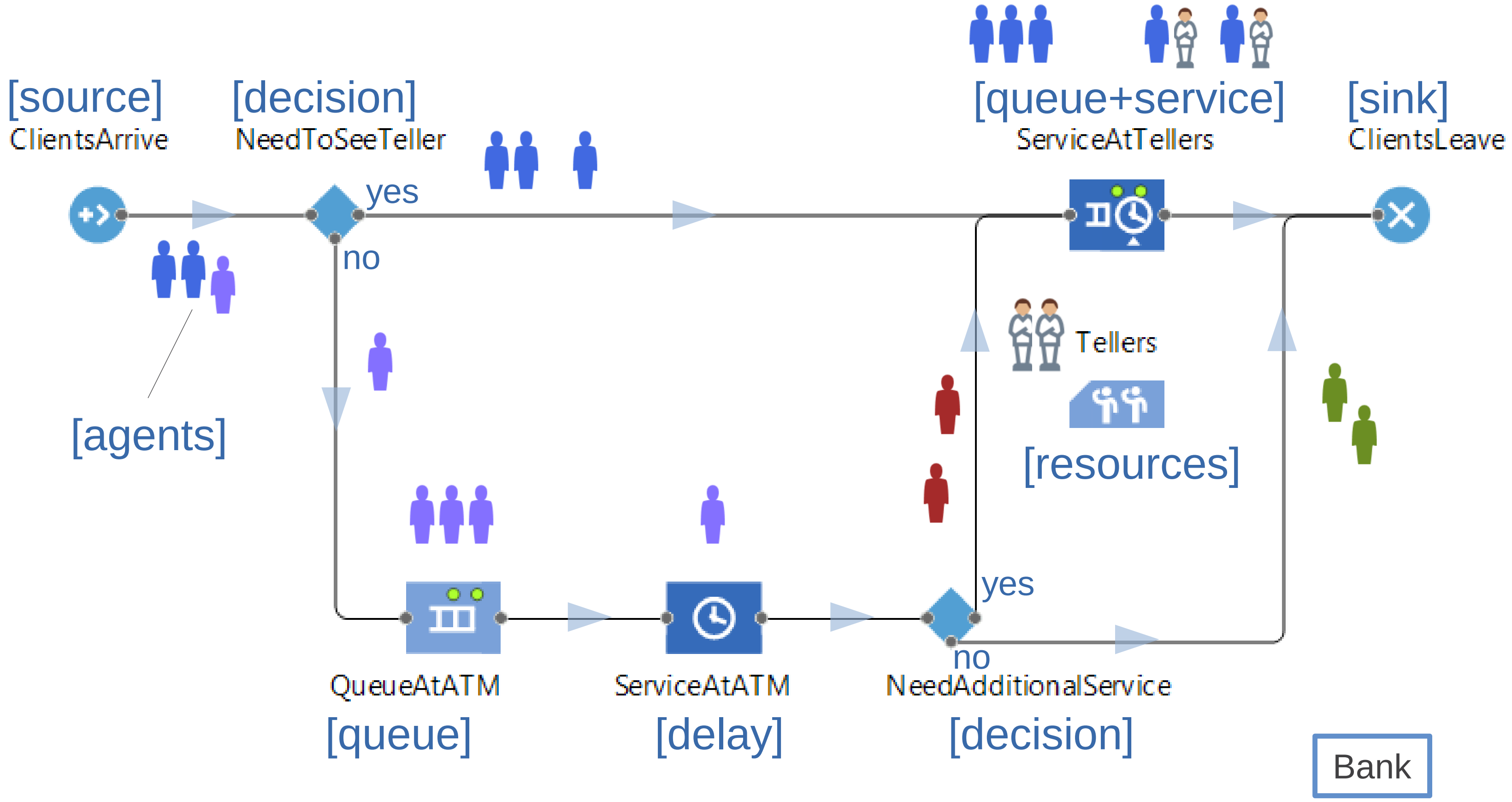
Stocks, flows & interacting feedback loops



Bass Diffusion Model

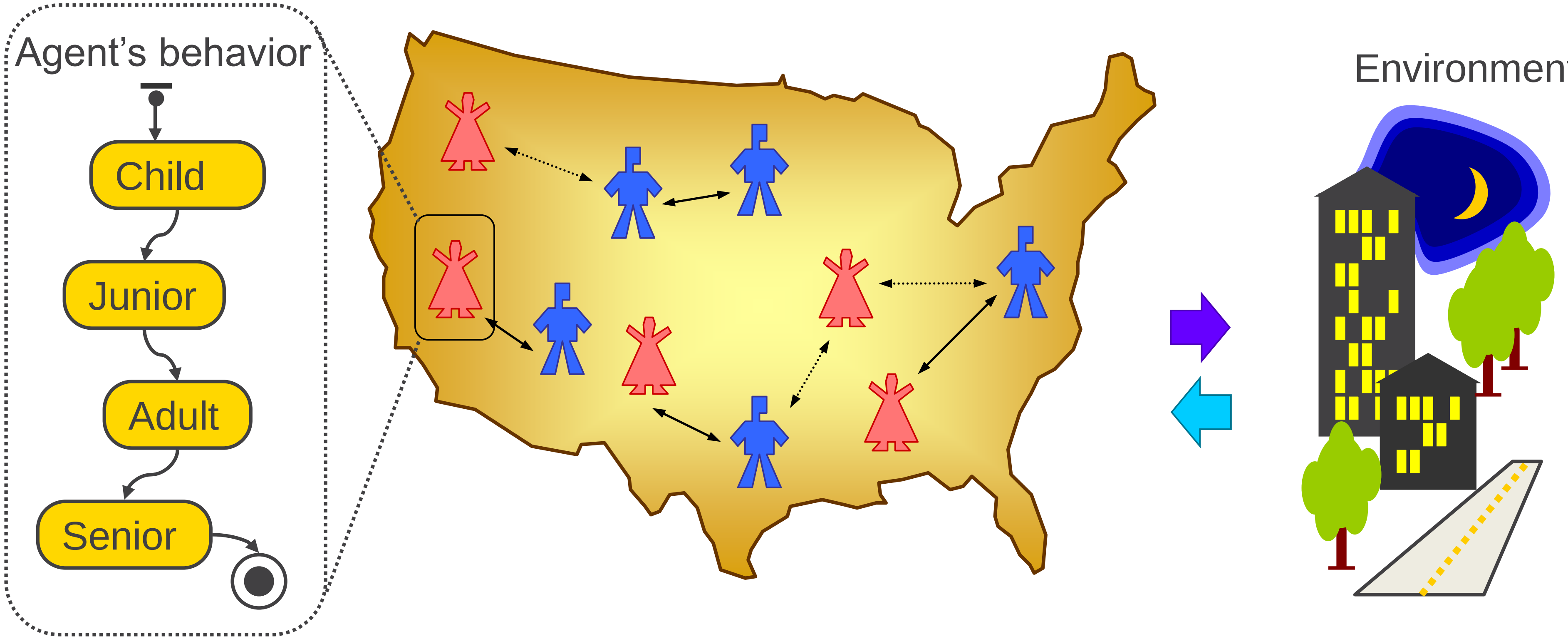
Discrete Event: 1960s

Process flow, entities, resources, queues and delays



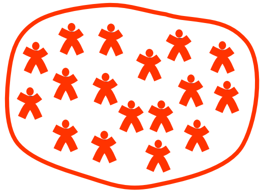
Agent Based: 1970s

Individual objects, behaviors, rules, environment dynamics

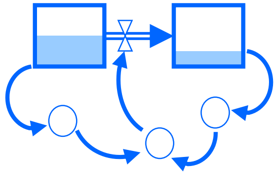


Model Architectures

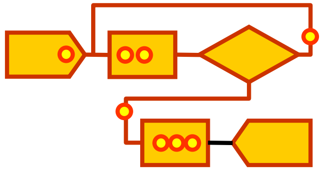
AB



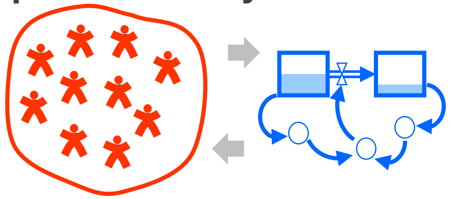
SD



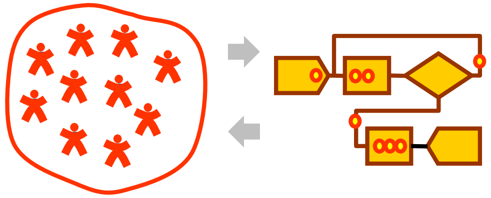
DE



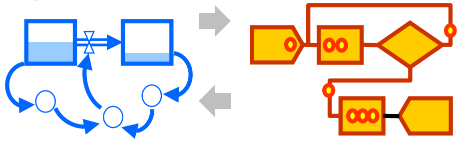
AB + SD
(e.g., population + city infrastructure)



AB +DE
(e.g., clients + services)

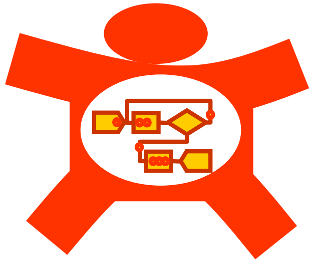


SD + DE
(e.g., demand + production)

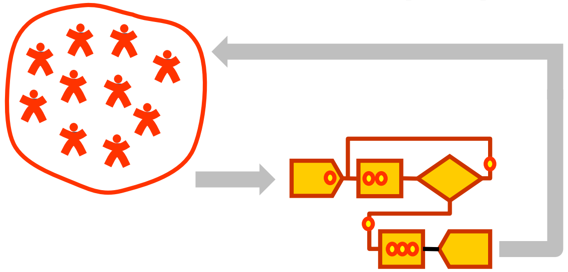


SD inside Agent
(e.g. consumer decision making)

DE inside Agent
(e.g. business process in a company in a bigger supply chain model)



Agents become entities
(e.g., patients with chronic diseases return to hospital)



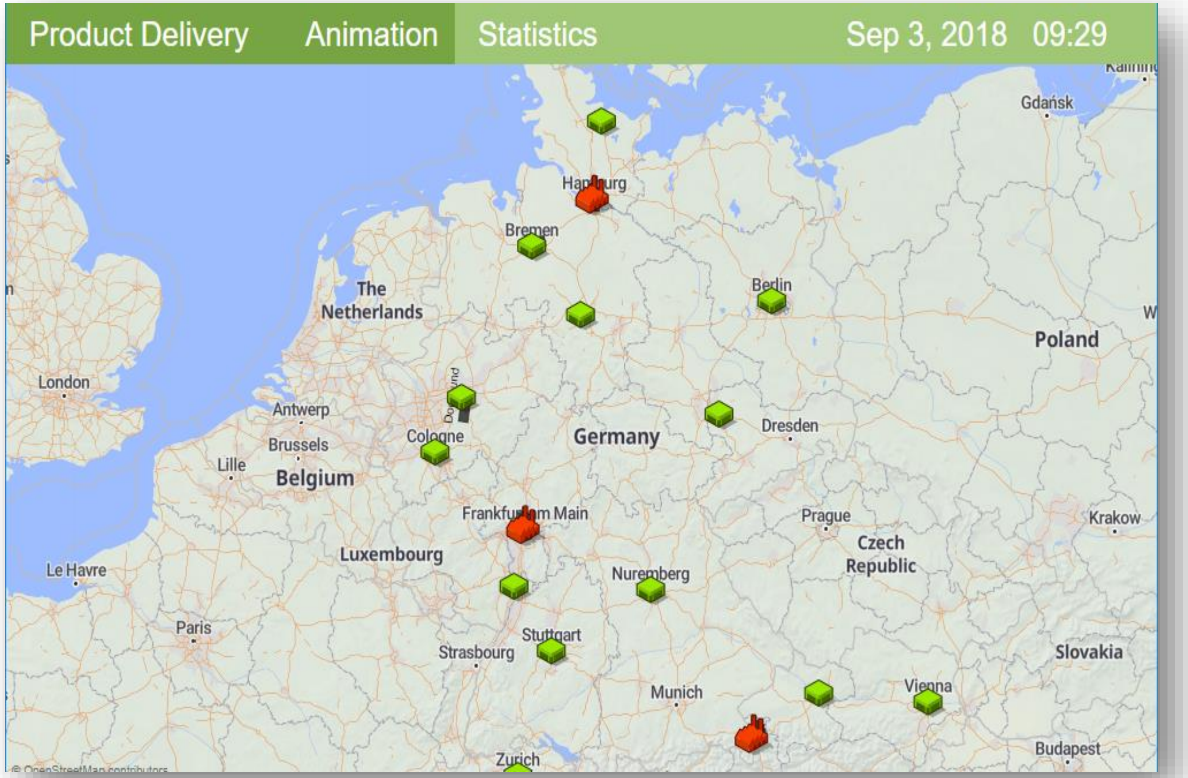
and so on in any combination…

Which approach to use?

- If the problem requirements fit well into the DE or SD modeling paradigms, consider these traditional approaches
- In cases where the modeled system contains active objects (people, business units, animals, vehicles, or projects, stocks, products, etc.) with timing, event ordering or other individual, autonomous behavior, consider applying the AB approach
- Sometimes these requirements are at the sub-model level. Then consider mixing different approaches in one model and applying the most appropriate technique where needed

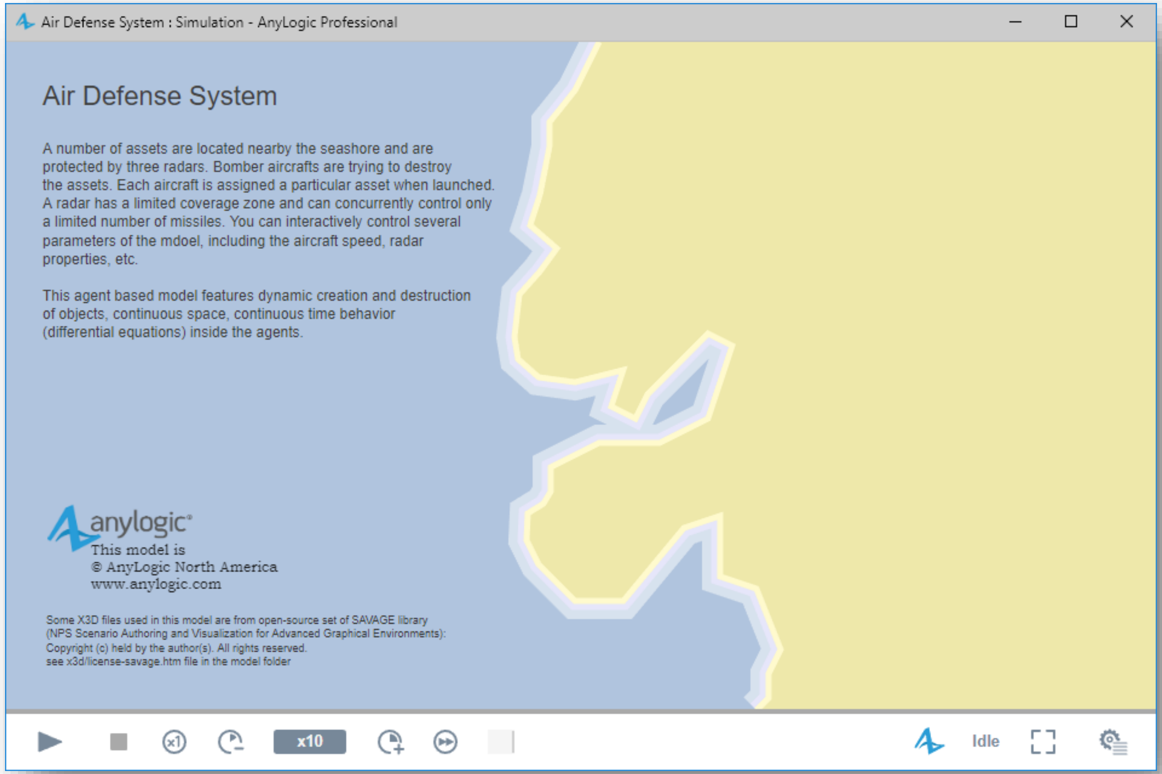
Example Model

Product Delivery



Example Model

Air Defense System



INCOSE

Systems Engineering Experience Area	Principle SE Activities associated with the SE experience area
Requirements Engineering	Preparing for or managing a Business or Mission analysis; Defining a Problem or opportunity space; Characterizing a solution space; Evaluating alternative solution classes; Preparing for Stakeholder Needs & Requirements Definition; Defining stakeholder needs; Developing Operational Concept and other Life Cycle concepts; Transforming needs into stakeholder requirements; Analyzing Stakeholder Requirements; Managing Stakeholder needs and requirements definition; Preparing for System Requirements Definition; Defining System Requirements; Analyzing System Requirements; Managing System Requirements.
System and Decision Analysis	Preparing, performing and managing a system analysis; Decision Management, including Preparing for System Engineering Decisions; Analyzing decision information; Making and managing SE decisions.
Architecture/ Design Development	Preparing for architecture definition; Developing architecture viewpoints; Developing models and views of candidate architectures; Relating architecture to design; Assessing candidate architectures; Managing the selected architecture; Preparing for design definition; Assessing alternatives for obtaining system elements; Establishing design characteristics and design enablers; Managing a system design;
Systems Integration	Preparing, performing and managing system element implementation; Identifying, agreeing and managing system-level interfaces; Preparing and performing Integration; Managing integration results.
Verification and Validation	Preparing and performing Verification; Managing verification results; Preparing and performing Validation; Managing Validation results; Preparing for, and performing System Transition; Managing results of System Transition; Obtaining Qualification, Certification and Acceptance.
System Operation and Maintenance	Preparing for Operation; Managing results of Operation; Performing and supporting System/ Product Operation; Preparing for and performing Maintenance; Performing Logistics Support; Managing results of maintenance and logistics; Preparing for, performing and finalizing system disposal.
Technical Planning	Defining an SE project; Planning an SE project and its technical management; Activating an SE project; Identifying and recording tailoring influences and mandated structures; Obtaining input from parties affected by the tailoring strategy; Making Tailoring decisions and selecting life cycle processes.
Technical Monitoring and Control	Planning for SE project assessment and control; Assessing SE projects; Controlling projects from an SE perspective; Preparing for and performing System Measurement; Preparing for system Quality Assurance; Performing system product or service evaluations;
Acquisition and Supply	Acquisition, including: Preparing for system/element acquisition; Advertising the acquisition and selecting the supplier; Establishing, maintaining and monitoring an acquisition agreement; Accepting a product or service from a supplier; Supply, including: Preparing for supply; Responding to a tender; Establishing, maintaining and executing a supply agreement; Delivering and supporting a product or service.
Information and Configuration Management	Planning Configuration Management; Performing Configuration Identification; Performing Configuration Change Management; Performing Configuration Status Accounting; Performing Configuration Evaluation; Performing Release Control; Information Management, including Preparing for and performing information management.
Risk and Opportunity Management	Planning technical risk and opportunity management; Managing the technical risk profile; Analyzing, Treating and Monitoring technical risks and opportunities
Lifecycle Process Definition and Management	Establishing Lifecycle Processes including defining and implementing Lifecycle Models; Assessing Lifecycle Processes and Models; Improving Lifecycle Processes and Models.
Specialty Engineering	Performing professional-level systems engineering activities associated with one or more Specialty Engineering area(s). Typical Specialty Engineering areas include but are not limited to those identified in the INCOSE SE Handbook V4.0, namely: Affordability/Cost- Effectiveness/Life Cycle Cost analysis; Electromagnetic Compatibility Analysis; Environmental Engineering/Impact Analysis; Interoperability Analysis; Logistics Engineering; Manufacturing and Produceability Analysis; Mass Properties Engineering; Reliability, Availability and Maintainability analysis; Resilience Engineering; System Safety Engineering; System Security Engineering; Training Needs Analysis; Usability Analysis/Human Systems Integration; Value Engineering.
Organizational Project Enabling Activities	Infrastructure Management, including establishing and maintaining the Infrastructure; HR Management, including identifying and developing SE Skills, acquiring and providing SE skills for projects; Quality Management including planning and assessing Quality Management, Performing Quality Management corrective and preventative actions; Knowledge Management, including Planning Knowledge Management, Sharing Knowledge and skills throughout the organization, Managing Knowledge, skills and knowledge assets; Project Portfolio Management at Organizational level, including defining and authorizing SE projects, evaluating a portfolio of SE projects and terminating SE projects.
Other	Other functions and activities performed that you can justify as Systems Engineering activities.

Application of Simulation Modeling to the Systems Engineering Experience Areas

Systems Engineering Experience Areas

Systems Engineering Experience Area	Principle SE Activities associated with the SE experience area
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Other	Other functions and activities performed that you can justify as Systems Engineering activities.

Systems Engineering Experience Areas

Requirements Engineering Developing operational concepts
System and Decision Analysis Performing a system analysis
Architecture/ Design Development Assessing alternatives
Systems Integration Preparing … integration
Verification and Validation Preparing … verification
System Operation and Maintenance Preparing for … maintenance
Technical Planning
Technical Monitoring and Control Preparing for … system measurement
Acquisition and Supply Preparing for supply
Information and Configuration Management
Risk and Opportunity Management Analyzing … technical risks
Lifecycle Process Definition and Management
Specialty Engineering Affordability … life cycle cost analysis
Organizational Project Enabling Activities

Example Model

Transporters Moving in Free Space

Simulation Model Data

Characteristics of a Simulation Model

- Takes random (stochastic) behavior into account
- May model each agent moving through a system
- Handles complex interactions
- Not all system details are modeled
- Abstraction of the system to an appropriate level
- Compresses time
- May animate system explicitly or conceptually

Model Input Data

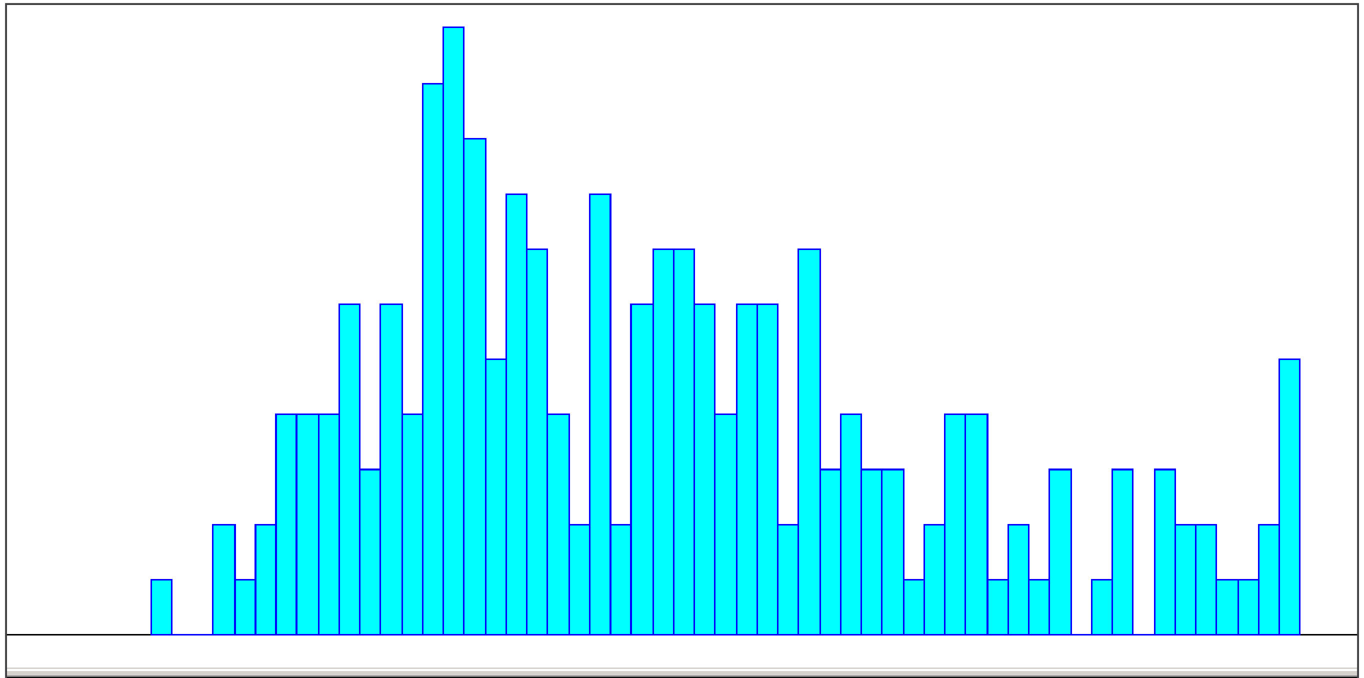
- On-line data, including real-time
- Direct observation, time study
- Check sheets
- Analysis of similar process
- Review of manual documentation
- Short-term automated data collection methods

Data Prep Example: Blood test turn-around-time

Example: Blood Test Turn-Around Time

Test Code: CBC				
Test Name: Complete Blood Count				
Collection Time	Receive Time	Result Time	Result - Receive	Result - Collection
0000	0031	0045	14	45
0001	0012	0021	9	20
0001	0011	0029	18	28
0001	0010	0030	20	29
0001	0018	0032	14	31
0005	0023	0036	13	31
0008	0022	0048	26	40
0010	0030	0047	17	37
0013	0039	0049	10	36
0035	0039	0055	16	20
0100	0113	0122	9	22
0102	0123	0136	13	34
0120	0136	0156	20	36
0124	0133	0141	8	17

CBC Data Histogram



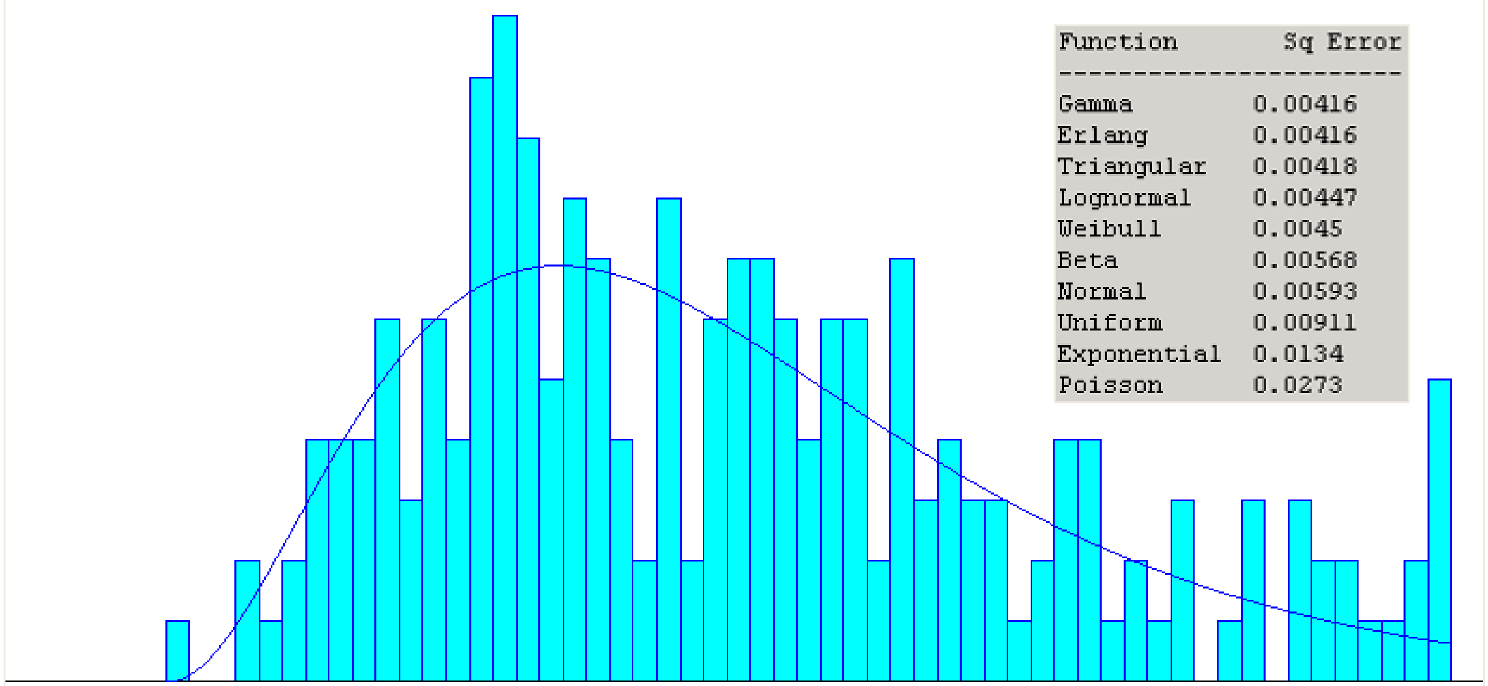
Data Summary

```
Number of Data Points   = 205
Min Data Value          = 5
Max Data Value          = 59
Sample Mean             = 28.9
Sample Std Dev          = 12.9
```

Histogram Summary

```
Histogram Range         = 4.5 to 59.5
Number of Intervals     = 55
```

CBC Data: Best Fit Function



Function	Sq Error
Gamma	0.00416
Erlang	0.00416
Triangular	0.00418
Lognormal	0.00447
Weibull	0.0045
Beta	0.00568
Normal	0.00593
Uniform	0.00911
Exponential	0.0134
Poisson	0.0273

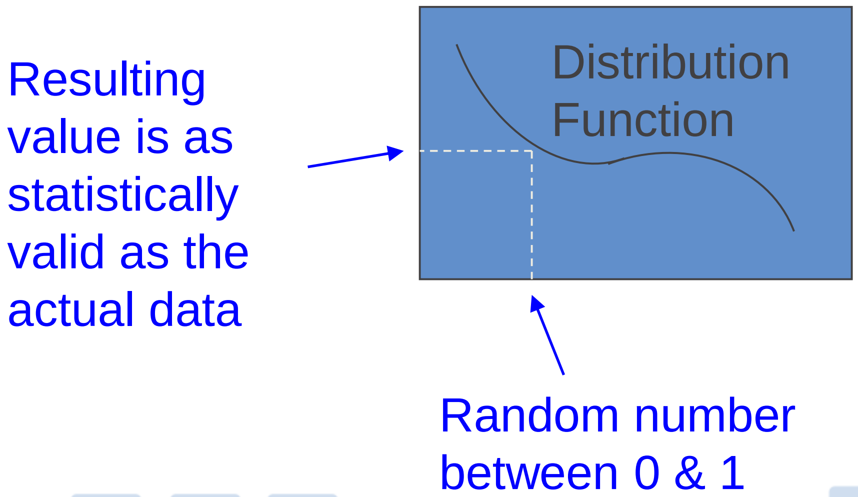
Distribution Summary

Distribution: Gamma
Expression: 4.5 + GAMM(7.66, 3.19)
Square Error: 0.004161

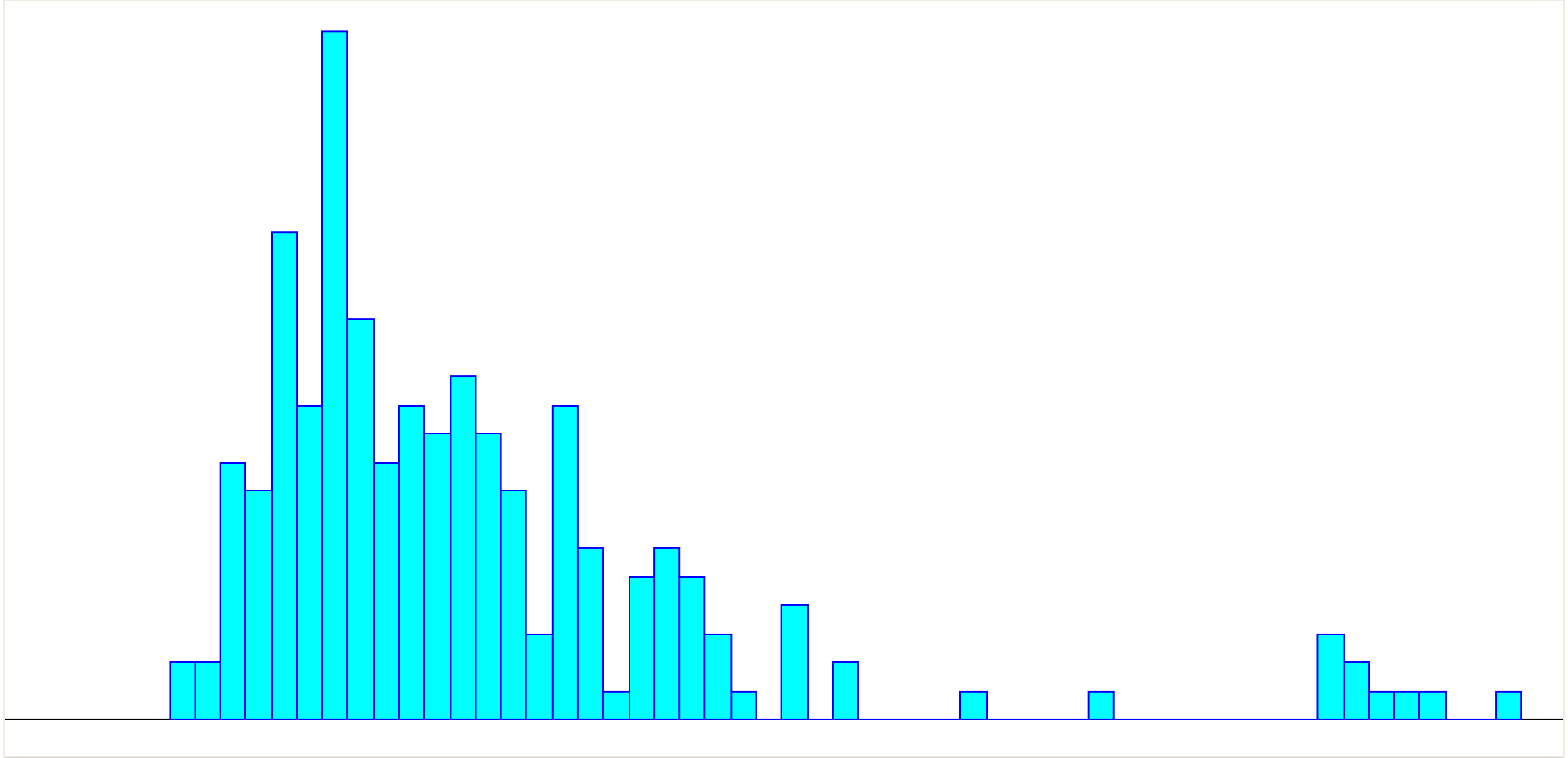
Chi Square Test
Number of intervals = 16
Degrees of freedom = 13
Test Statistic = 16.9
Corresponding p-value = 0.216

CBC Data: Use in the Model

- Simulation uses this probability density function {(4.5 + GAMM(7.66, 3.19)} each time a CBC is performed
- Random number (x) drives the generation of a CBC time
- Simulated turn-around-time statistically equal to actual time



CBC Data: Bimodal?

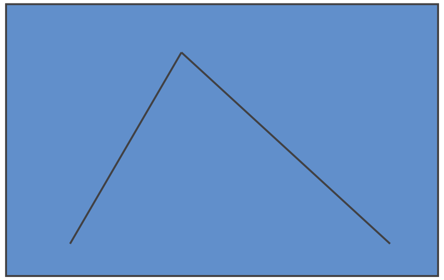


Data Summary

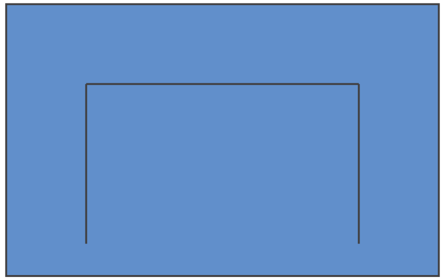
Number of Data Points = 205
Min Data Value = 2
Max Data Value = 54
Sample Mean = 13.6

Distributions: Types

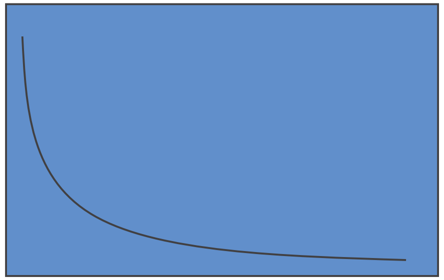
Triangular



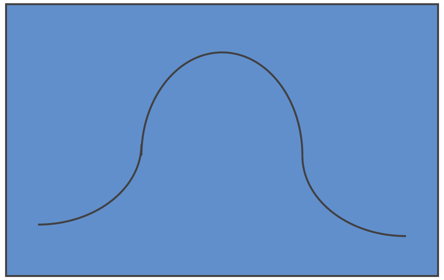
Uniform



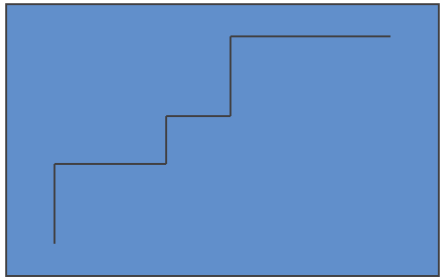
Exponential



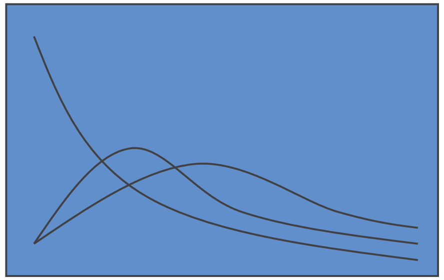
Normal



Discrete



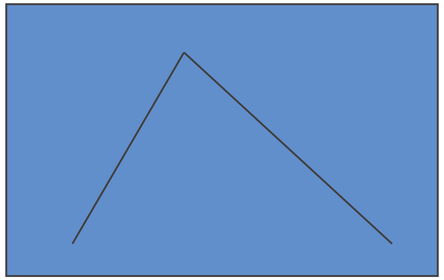
Erlang



Others: Beta, Gamma, Johnson, Weibull, Poisson, Continuous, Lognormal, User Defined

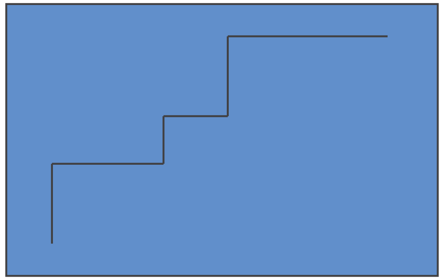
Distributions: Typical uses

Triangular



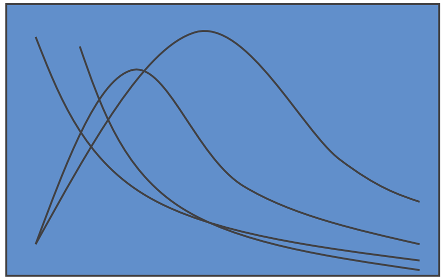
Distribution not known, but can estimate or guess minimum, maximum, and most likely

Discrete



Assignments such as attributes, sequences, batch sizes

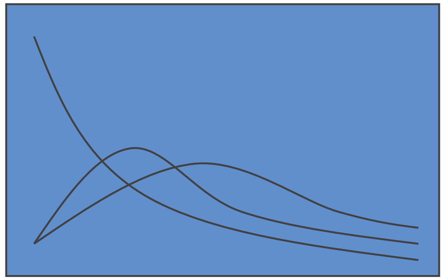
Weibull



Time between failures

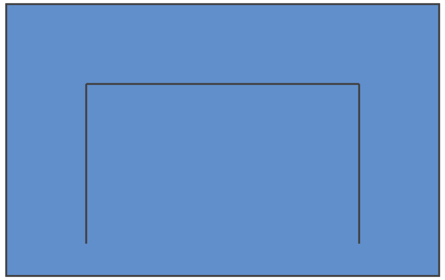
Distributions: Typical uses

Erlang & Gamma



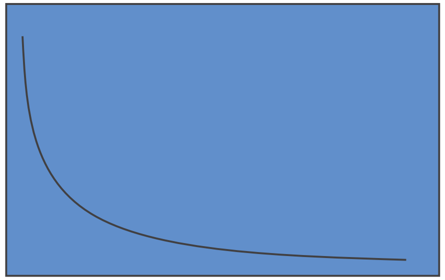
Often used to represent the time it takes to complete a task

Uniform



All values equally likely.
No information other than range available

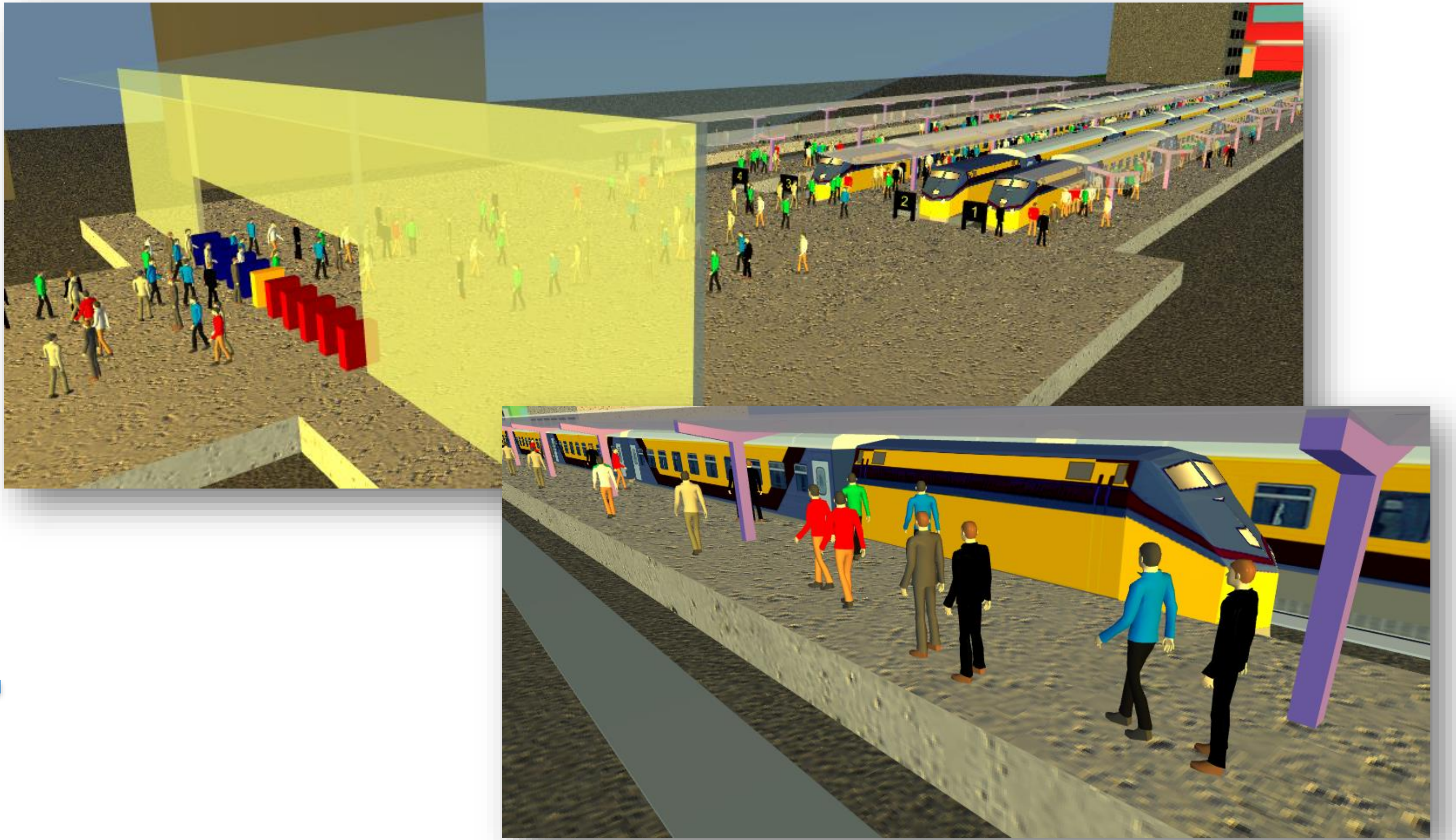
Exponential



Inter-event times in arrivals and breakdowns

Example Model

Railway Station



Other Considerations

Today’s Simulation Software

- Easier to user interface
- Industry-specific custom templates
- Improved model build and run time
- Used throughout system lifecycle
- Numerous simulation applications

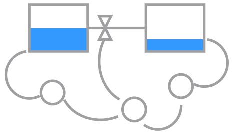
Software Considerations

- User interface
- Flexibility
- Upgrade progression
- Data exchange
- Animation (none, 2D, 3D)
- Run-time license or viewer
- Object-oriented design
- Custom object and template development
- Continuous and/or discrete
- Optimization
- Customer care
- Market breadth
- Price

Simulation Modeling Software

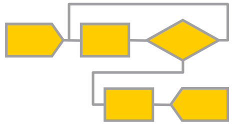
Partial list of tools and the modeling approaches supported

System dynamics



AnyLogic
iThink
PowerSim
Stella
VenSim

Discrete event modeling



AnyLogic
Arena
AutoMod
Enterprise Dynamics
ExtendSim
FlexSim
Promodel
Simio
SimProcess

Agent based modeling

AnyLogic
Open Source:
- ASCAPE
- NetLogo
- RePast
- Swarm

Simulation Project Key Success Factors

- Start small & with a pilot project
- Bound the project through defined scope
- Spend enough time developing and communicating assumptions
- Target the lowest fidelity level possible
- Validate the model with all constituents
- Consider the downstream user
  - Interface tailored to user
  - Re-use
  - Documentation
- Develop the *believable baseline*

More Information Sources

- Societies
  - Institute of Industrial & Systems Engineers (www.iise.org)
  - The Society for Modeling & Simulation International (www.scs.org)
  - Institute for Operations Research and the Management Sciences (www.informs.org)
- Conferences
  - The Winter Simulation Conference
  - INFORMS Annual and Analytics Conferences
  - Some vendors have user conferences
- Books & Periodicals
  - The Big Book of Simulation Modeling
  - AnyLogic in 3 Days
  - Conference Proceedings
- Search the web!

Speaker Contact Info

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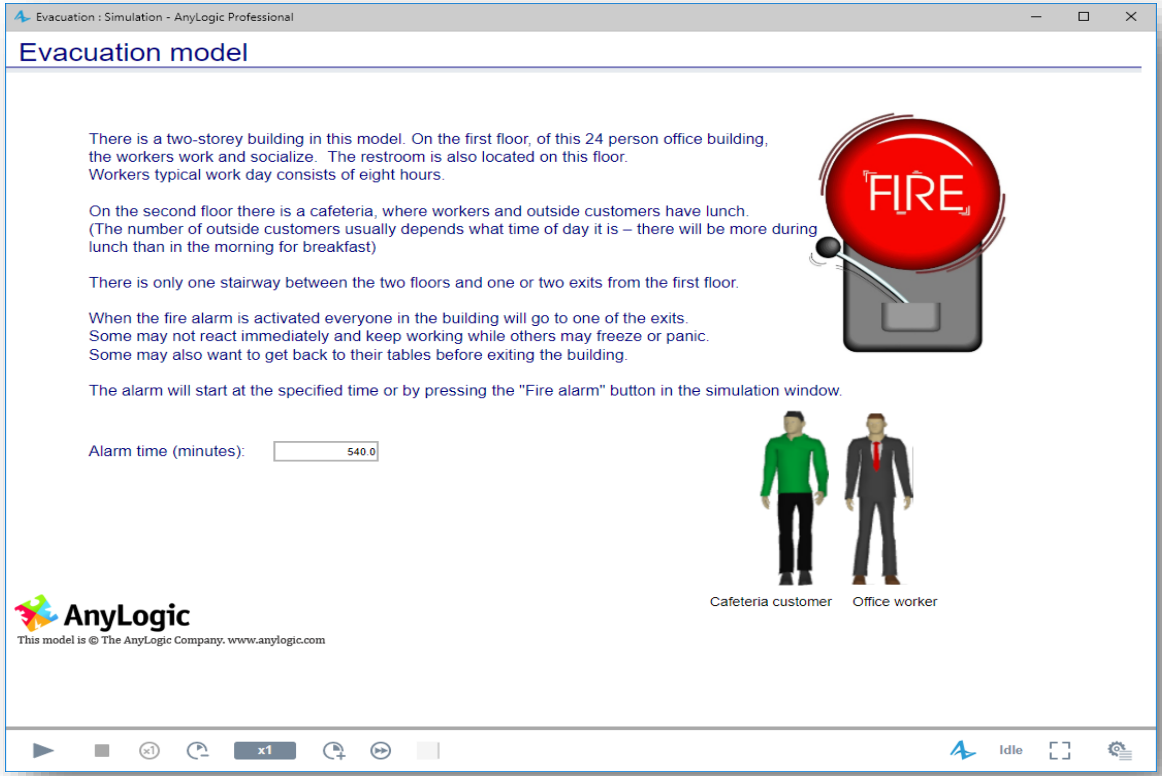
rdronzek@anylogic.com

Example Model

Evacuation Model



Upcoming Webinars (tentative schedule)

INCOSE

	What	When
Caitlin Kenney	Professional Licensing for Systems Engineers	Wednesday 17July 2019 at 11am EDT
Sarah Sheard	What Systems Engineers Should Know About Software, Part II	Wednesday, 14 August 2019 at 11am EDT

Invitations will be emailed in advance and informational updates will be placed on www.incose.org
Go to http://www.incose.org/products-and-publications/webinars for more info on the webinar series, including a way to view the last 125 Webinars and soon – this one!

Information on the webinars is now being posted in INCOSE Connect, in the INCOSE Library area, at https://connect.incose.org/Library/Webinars/Pages/INCOSE-Webinars.aspx . Joining instructions will added around two weeks before the webinar is scheduled to take place.

INCOSE IS 2019 – Orlando, FL, USA

https://www.incose.org/symp2019/home

IS 2019
July 20 – 25 2019
Orlando, FL, USA