Simulation In The System Engineering Process

"System Dynamics for System Engineering Process"

Dr. Warren W. Tignor Ph.D.

SAIC

Second Annual Workshop on Web Enabled Modeling and Simulation

Arlington, VA

October 12-15, 2004

Agenda

- WebSim 2003 Continuity to WebSim 2004
- System Dynamics (SD) Introduction
- SD and UML Synergy
- Case Study
- Findings
- Conclusions
- Literature Survey

WebSim 2003 Continuity to WebSim 2004

WebSim 2003 Keynote Speaker Items

Shaping Evolution of the Global Information Grid (GIG)

Dawn Meyerriecks
Chief Technology Officer
Defense Information Systems Agency
Meyerrid@ncr.disa.mil

SAIC
An Employee-Owned Company

Design Imperatives

the *New* Imperatives

How to **Improve Design** of large, complex Net-centric capabilities?

Dynamic

How to **Lower Risks** inherent in designing and deploying large, complex Net-centric capabilities?

- In early stages of design:
  - Dynamic models could be used to evaluate alternative concepts

Simulated Services

- In later stages of deployment:
  - Simulated services and applications could be used for fault ID and isolation of operational problems

New Approach

the *New* M&S Approach
Dynamic Models

- Dynamic models would:
  - Simulate actions taking place within the GIG (Allow "what if" exploration)
  - Evolve as greater detail is added
  - Provide Independent Validation and Verification (IV&V)

Bottom Line:

Ensure GIG capabilities function as envisioned

Summary of WebSim 2003 Issues

- Help improve design and lower risk at
  - Early in design
  - Later in implementation
- Support “What ifs”
- Evolve as add details
- Support IV&V
- Show continuous dynamics of the system

System Dynamics (SD) Introduction

System Engineering & System Dynamics (Modeling & Simulation)

Systems Engineering

- Organized interdisciplinary approach to enable systems.
- Focused on complete development cycle from requirements, to design and system validation.
- Integrated team effort that proceeds from concept to production, to operation.
- Considers both the business and the technical needs of all customers.

Modeling & Simulation

- Modeling investigates the important characteristics of a system in the early phases of the development cycle as well as in the operational phase.
- Simulation identifies bottlenecks in a system, evaluate system capacity, utilization and cost, and generate operational plans and schedules.

UML Modeling Diagrams

- **Structural Diagrams** - Class, Object, Component, and Deployment
- **Behavior Diagrams** - Use Case, Sequence, Activity, Collaboration, and State chart
- **Model Management Diagrams** - Packages, Subsystems, and Models.

SD Overview

- System Dynamics – a computer based approach that:
  - Models complex physical & social systems
  - Experiments with design policies for improved performance
  - Abstracts the system around a problematic pattern
  - Uses feedback loops as
    - Building blocks
    - Means to explain its behavior.

System Dynamics (SD) Perspective

- Holistic - System dynamicists look at things as a whole.
- Non-reductionist - Unlike others, who study the world by breaking it up into smaller and smaller pieces.

SD Scope

- Understand system's basic structure
- Understand system's behavior
- Use computer model to:
  - Perform complex simultaneous calculations
  - Compare results to human mental model

The SD Methodology Steps

- Identifies a problem
- Develops a dynamic hypothesis-(behavior)
- Builds a computer simulation model-(structure & behavior)
- Tests the model (reference to real-world)
- Devises and tests alternative policies that alleviate the problem-(what-ifs)

Some SD Domains

- Corporate planning and policy design
- Public management and policy
- Biological and medical modeling
- Energy and the environment
- Theory development in the natural and social sciences
- Dynamic decision making
- Complex nonlinear dynamics, emergence

SD and UML Synergy

SD & UML Synergy

- Unified Modeling Language™ specification addresses need to model the structure and performance of information systems (IS).

- Preliminary studies show UML2™ may not close performance simulation gap .

- *System Dynamics (SD) is based on system structure and behavior with simulation capability.*

Framing the Case Study

Hypothesis, Research Method, & Case

Hypothesis

- SD will leverage UML structure and behavior models
- System Engineers (SEs) may apply SD to IS structure and behavior simulation
- SD is a candidate to close gap in UML™ simulation capability

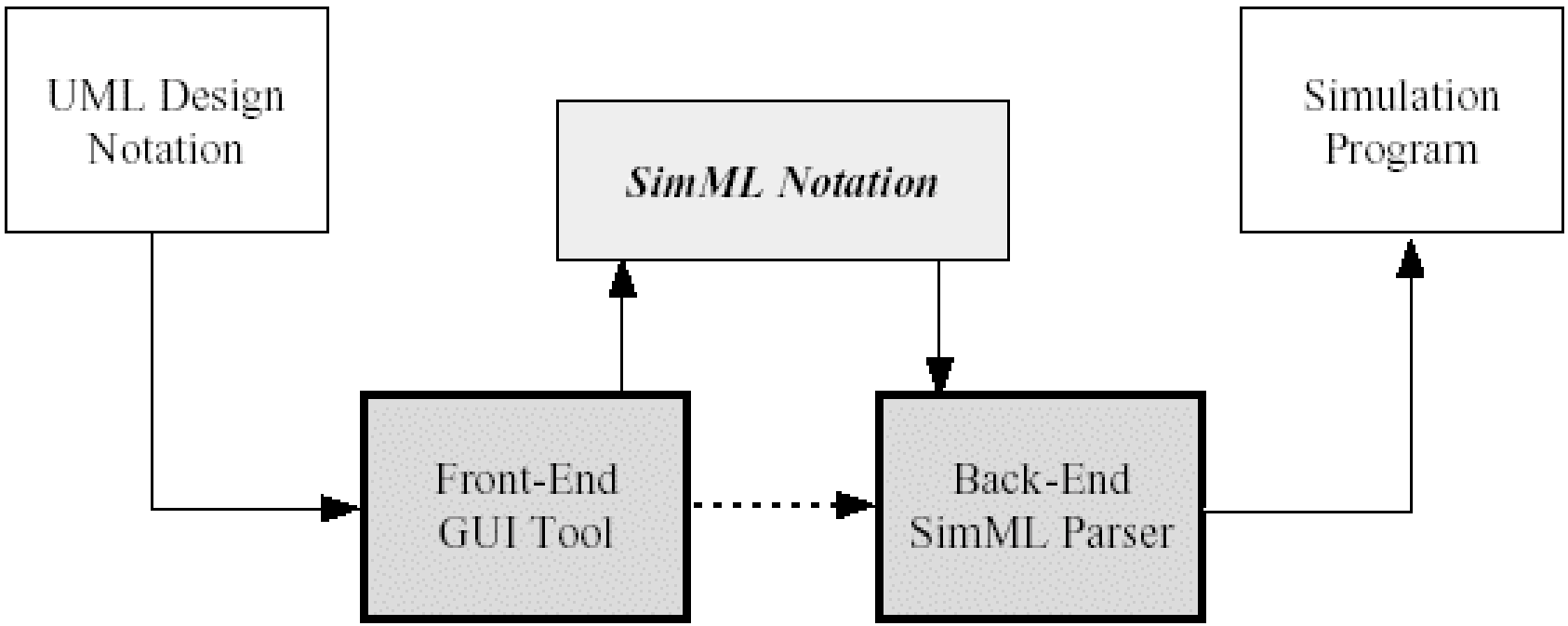
Research Method and Design

- Used a case study of a real-life problem described in UML™ and a non-system dynamics simulation language, Simulation Modeling Language (SimML), and recasts the UML™ into a System Dynamics model using Vensim.

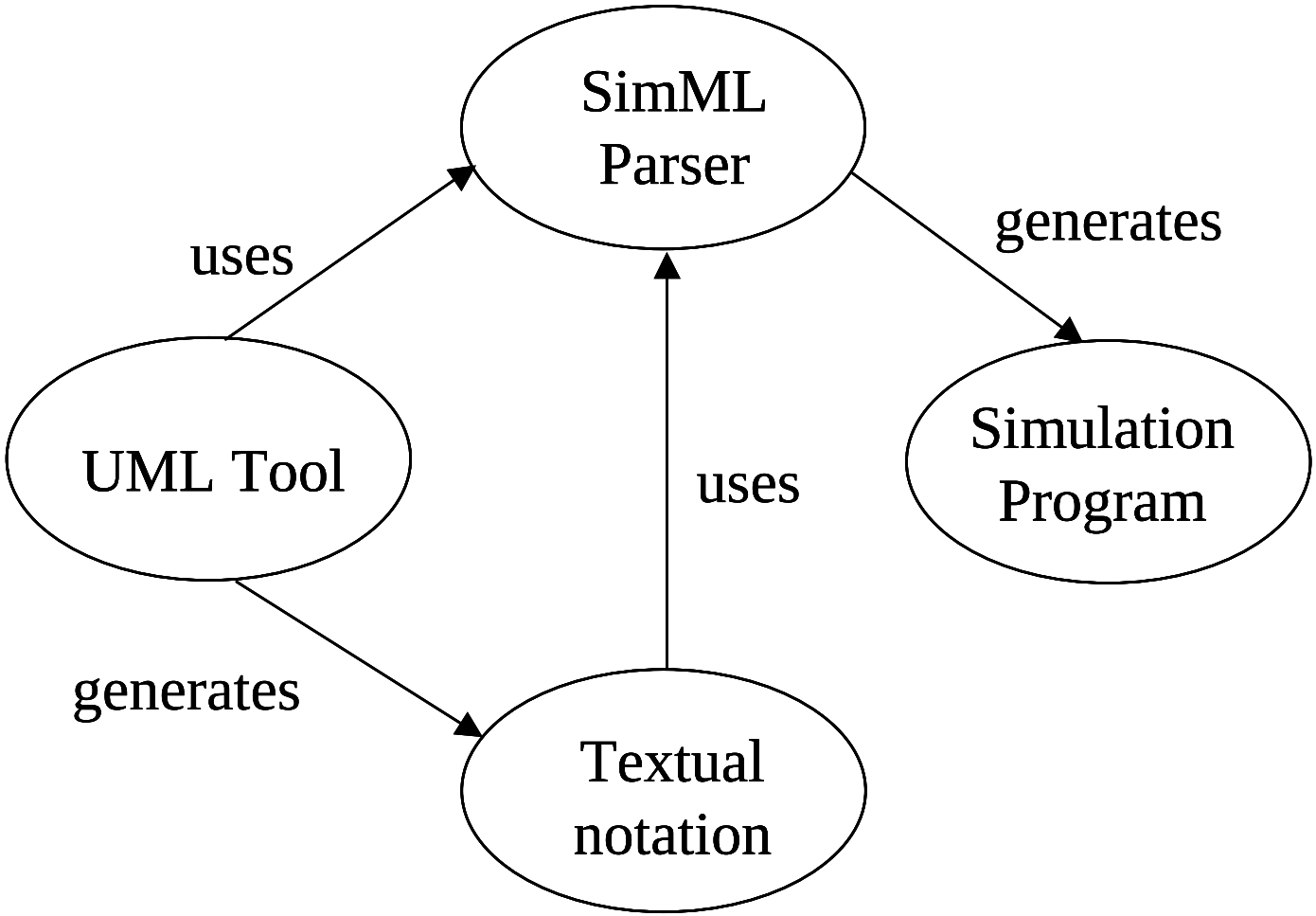
The Case

- Arief (2001) documents a British Telecom (BT) Intelligent Network (IN) case to:
  - Size the server capacity needed to make and receive calls
  - Accommodate capability for caller id, call blocking, billing and more.

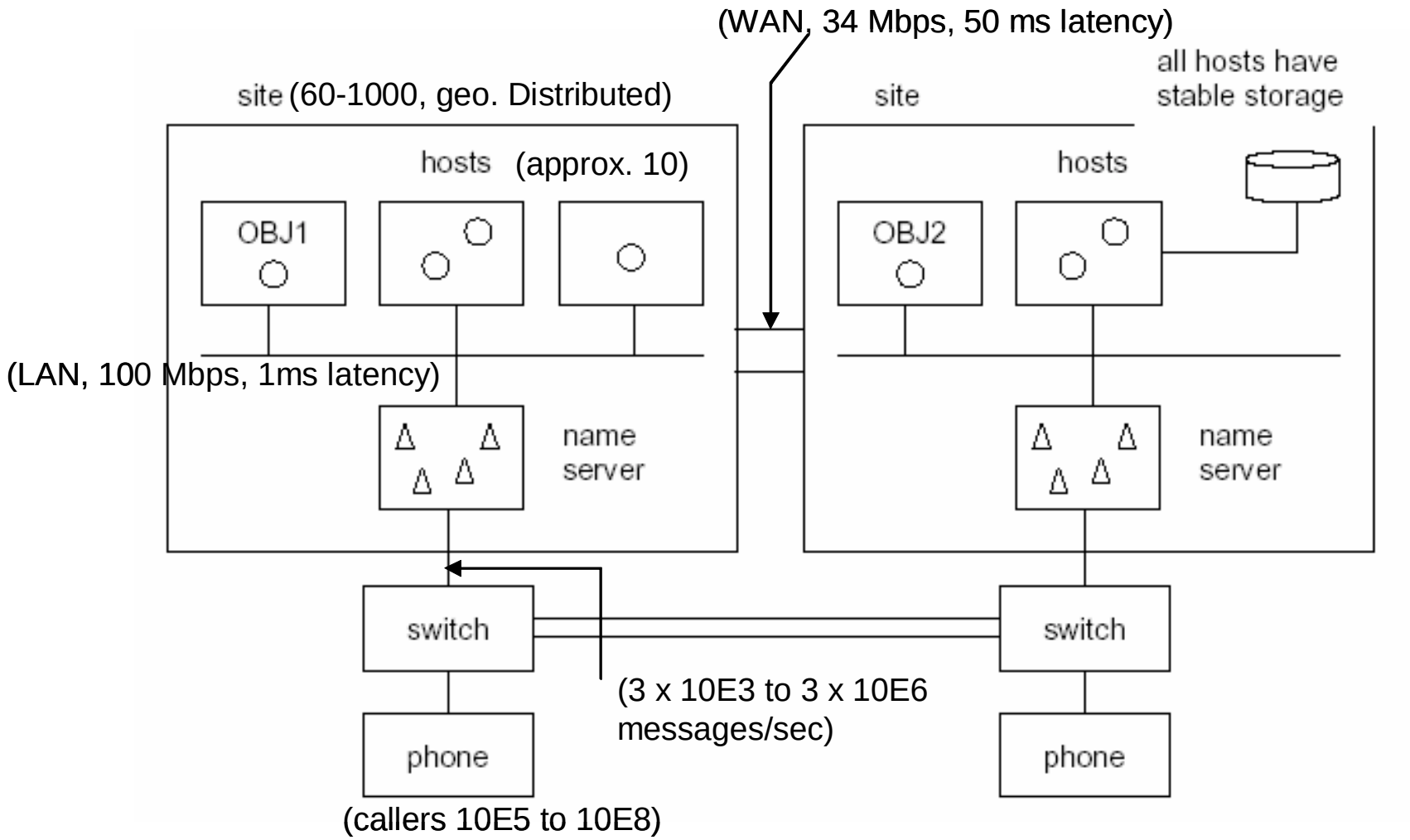
UML™ to Simulation Path – Arief (2001)



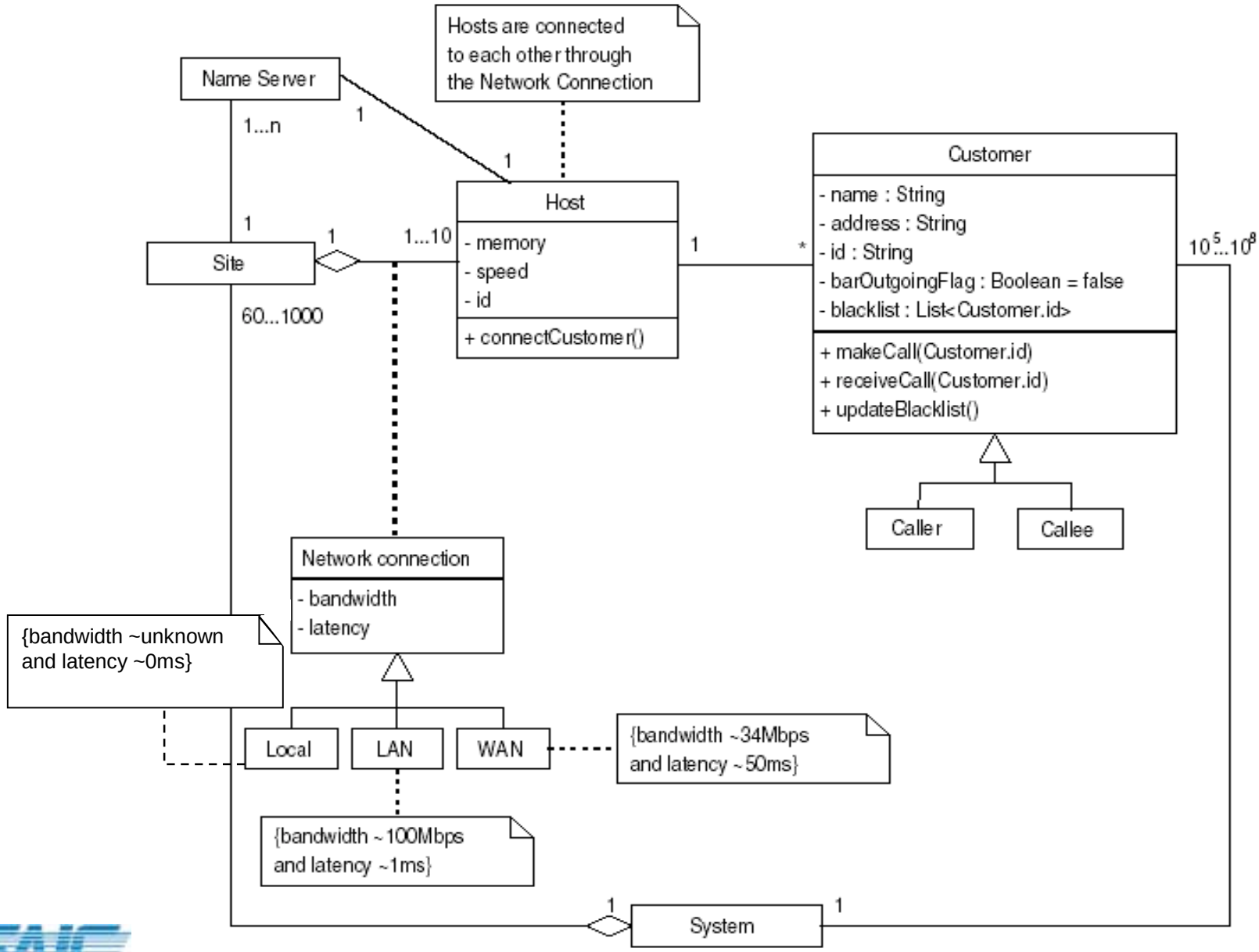
Simulation from UML™ - Arief (2001)



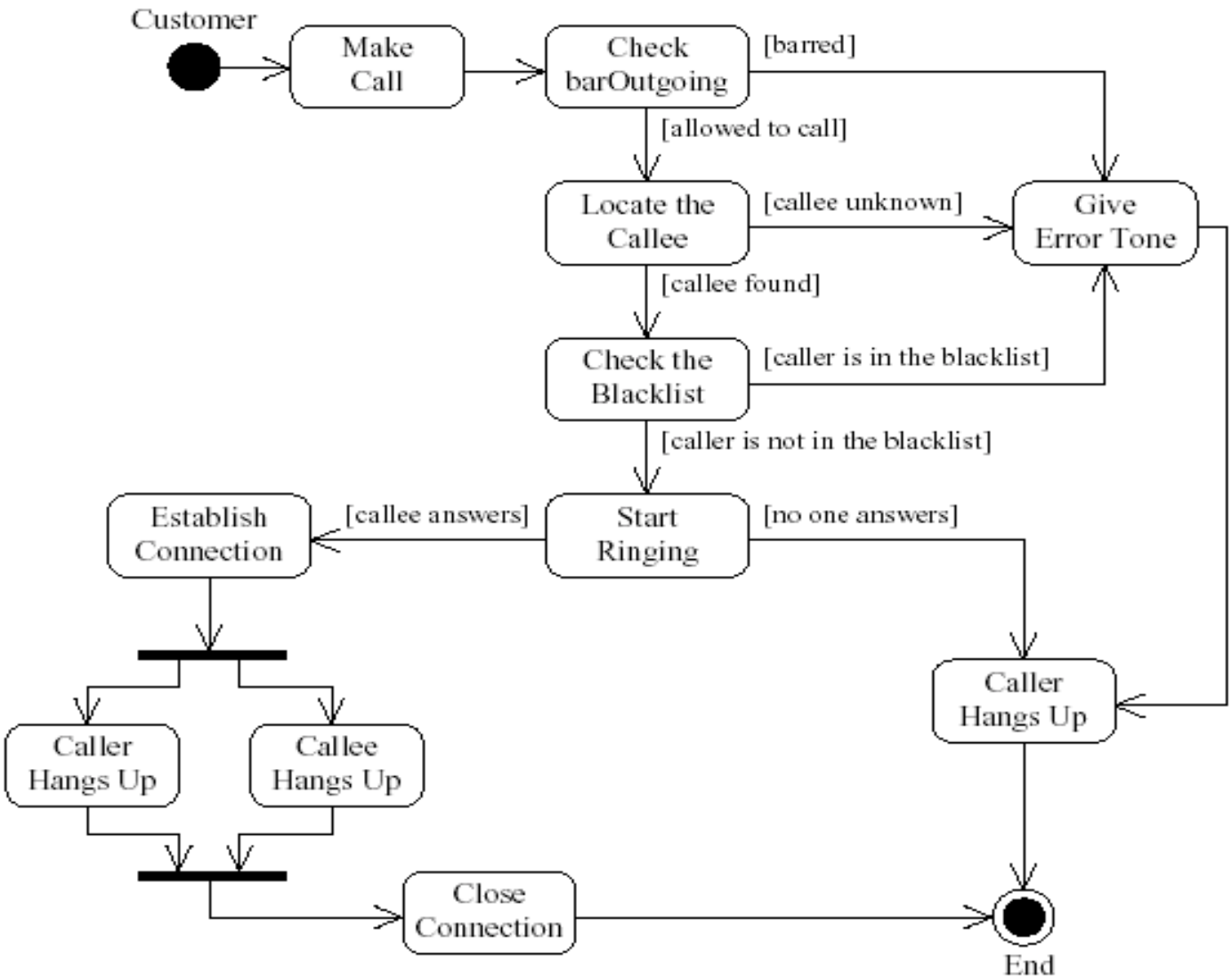
Architecture of BT IN – Arief (2001)



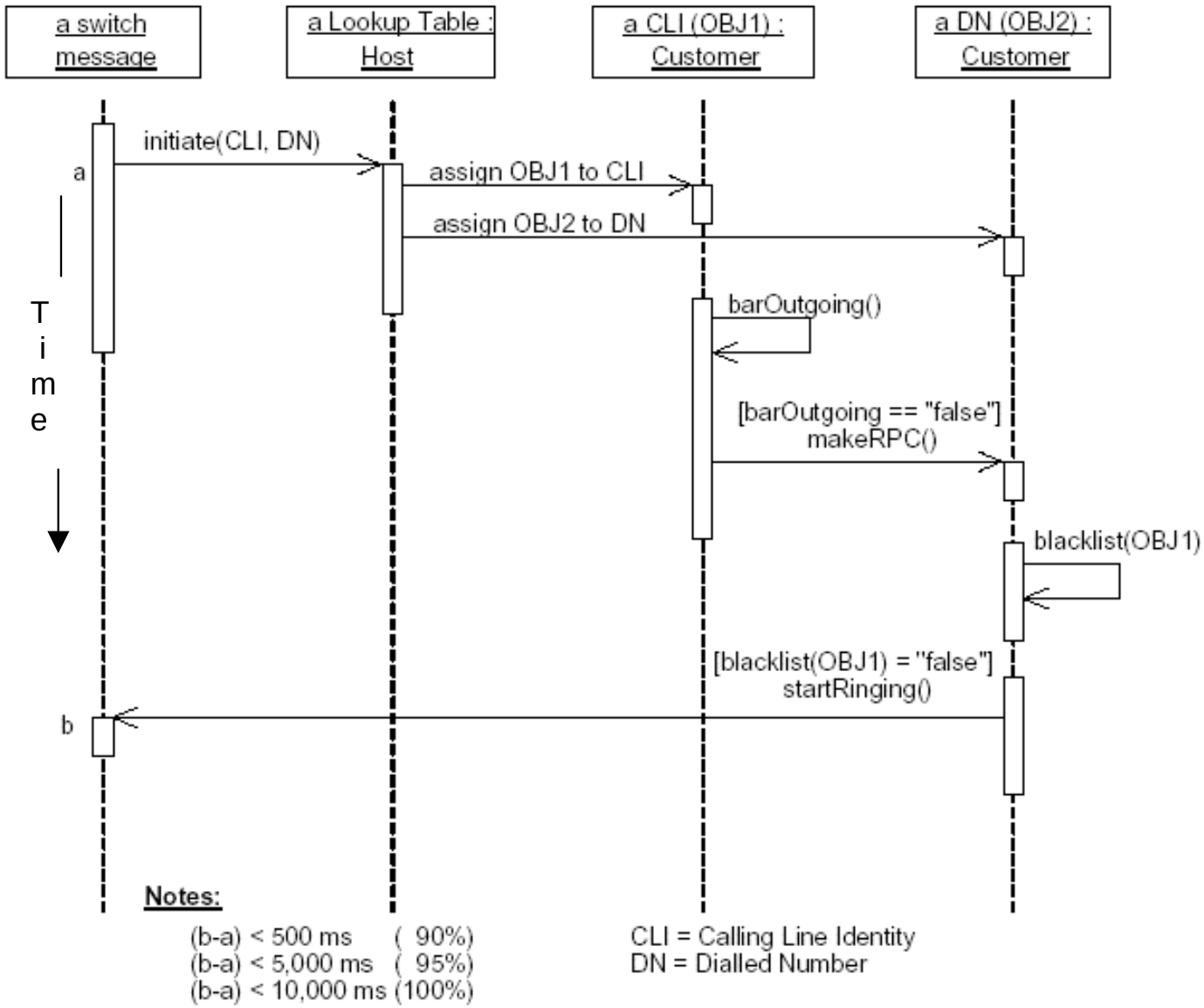
UML™ Class Diagram of BT IN – Arief (2001)



UML™ Activity Diagram – Arief (2001)



UML™ Sequence Diagram– Arief (2001)



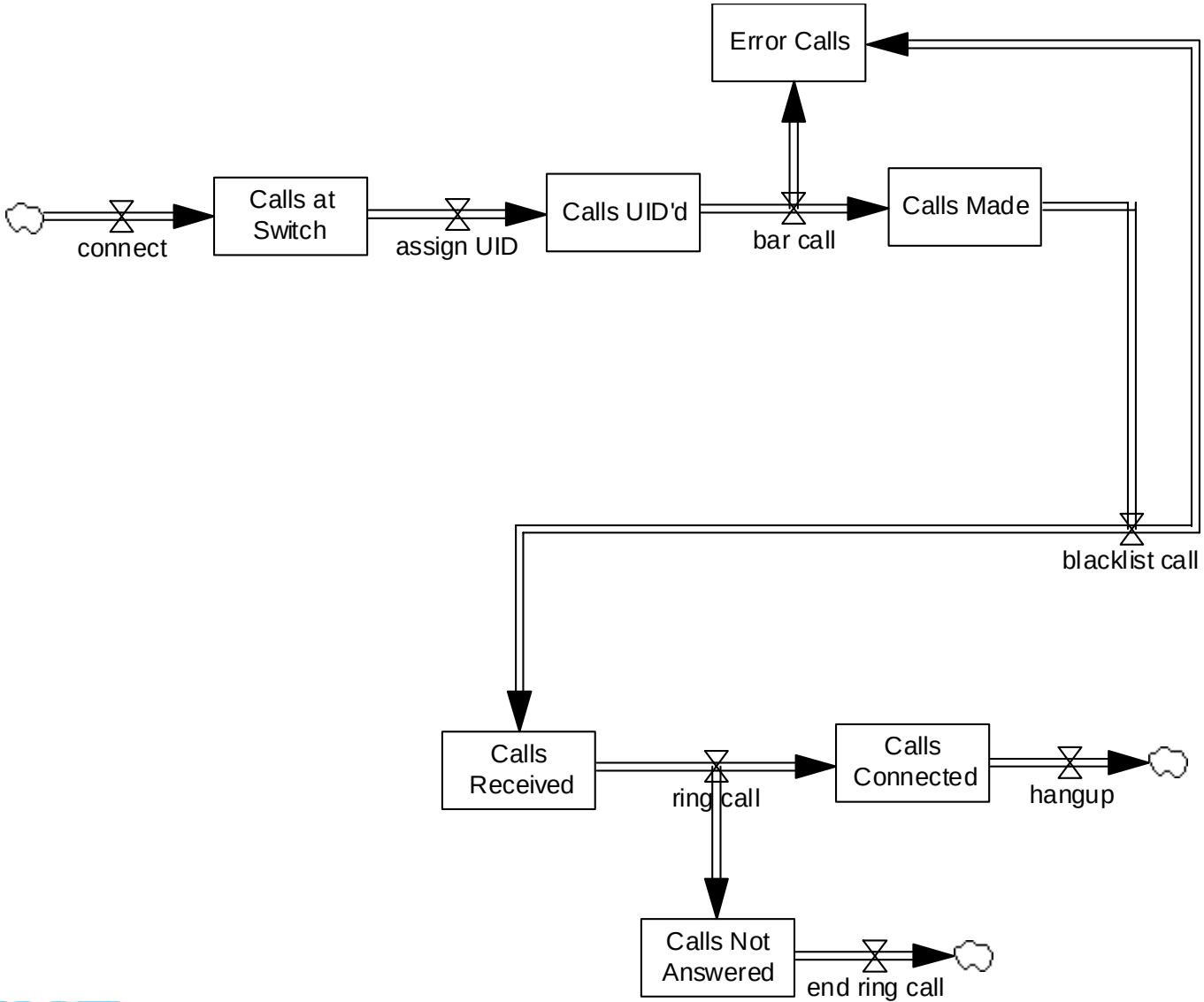
Variables Used – Arief (2001)

Name	Type	Explanation	Approx. Values
interArr	Exponential	The inter arrival time of the calls	1000 calls/sec
lookupTime	Exponential	The time taken by the Name Server to lookup for call identities	**Dependent Variable** ~ .0002 ms avg
readTime	Exponential	The time taken to perform the `barOutgoing` flag evaluation	.00023 ms avg
searchTime	Exponential	The time taken to check the `blacklist`	.0057 ms avg
localDelay	Exponential	The network latency for local call objects	~ 0
lanDelay	Exponential	The network latency for LAN call objects	1 ms
wanDelay	Exponential	The network latency for WAN call objects	50 ms
rndCallGen	Uniform	Used for randomly generating the local/LAN/WAN call types	
Run time	integer	Duration of simulation	100,000 ms

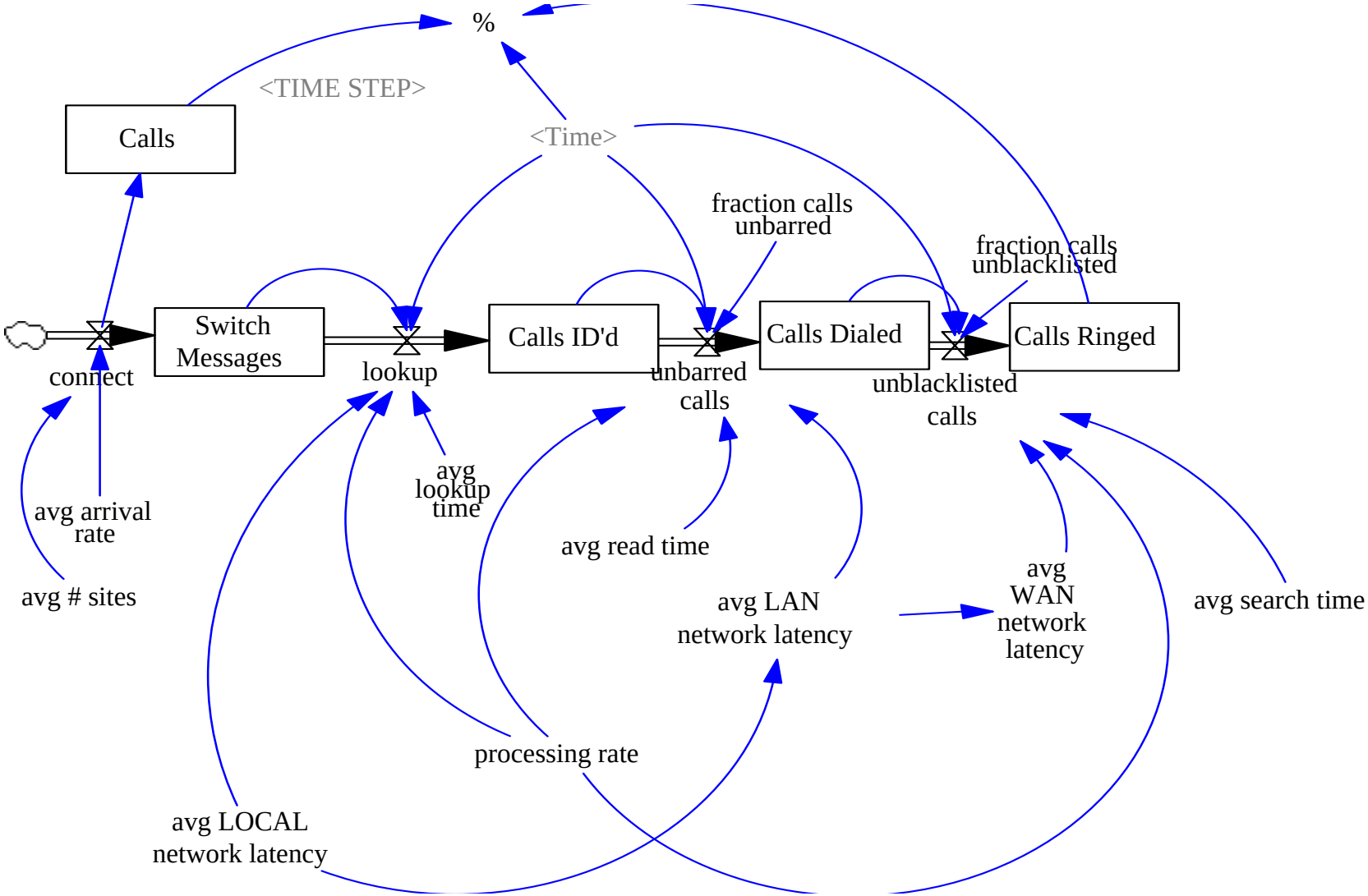
SimML results – Arief (2001)

lookup Time	average times			all calls		
	local	LAN	WAN	done	time	avgTime
20.00	523.80	526.02	719.90	299603	1.77E8	589.20
19.99	499.13	501.38	695.36	299748	1.69E8	564.58
19.98	474.39	476.76	670.77	299889	1.62E8	539.93
19.97	449.67	452.12	646.22	300053	1.55E8	515.29
19.96	424.88	427.49	621.68	300223	1.47E8	490.65
19.95	400.05	402.79	597.00	300353	1.40E8	465.91
19.94	375.25	378.10	572.33	300511	1.33E8	441.19
19.93	350.44	353.33	547.61	300650	1.25E8	416.42
19.92	325.60	328.58	522.87	300804	1.18E8	391.64
19.91	300.71	303.76	***498.13***	300945	1.10E8	366.83
19.90	275.83	278.94	473.33	301091	1.03E8	341.99

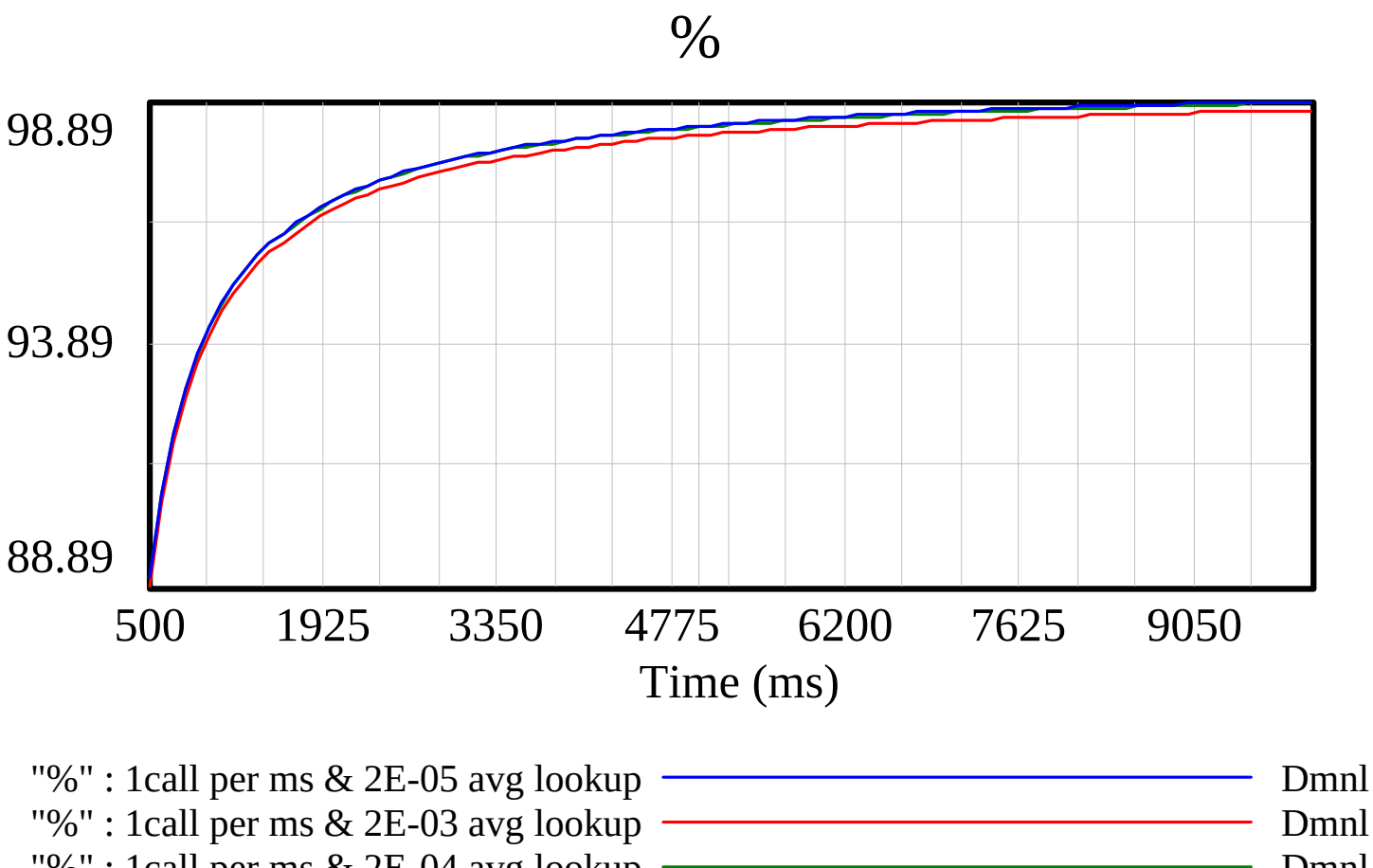
SD Stock and Flow Diagram



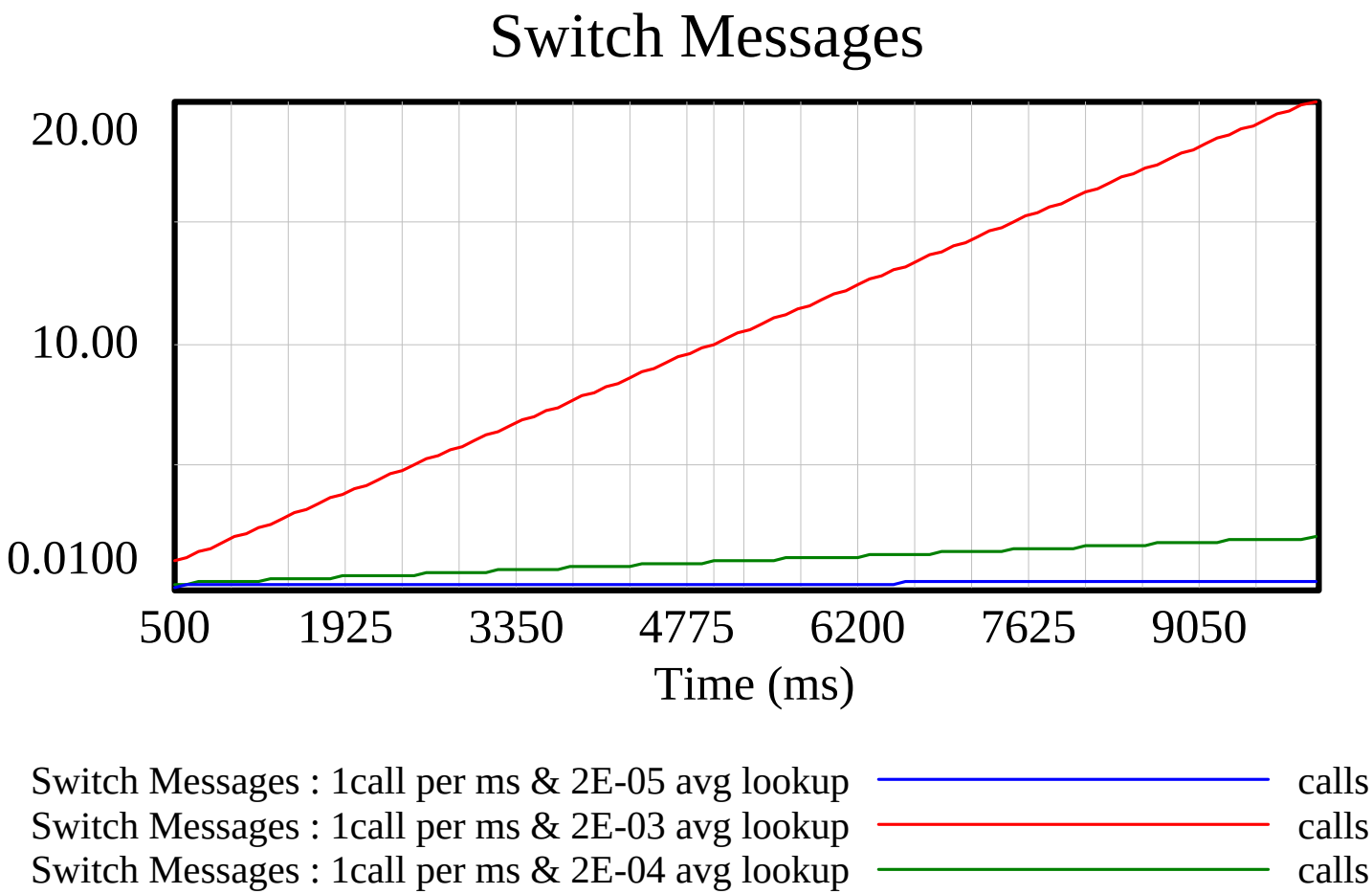
SD Stock and Flow Diagram with Parameters



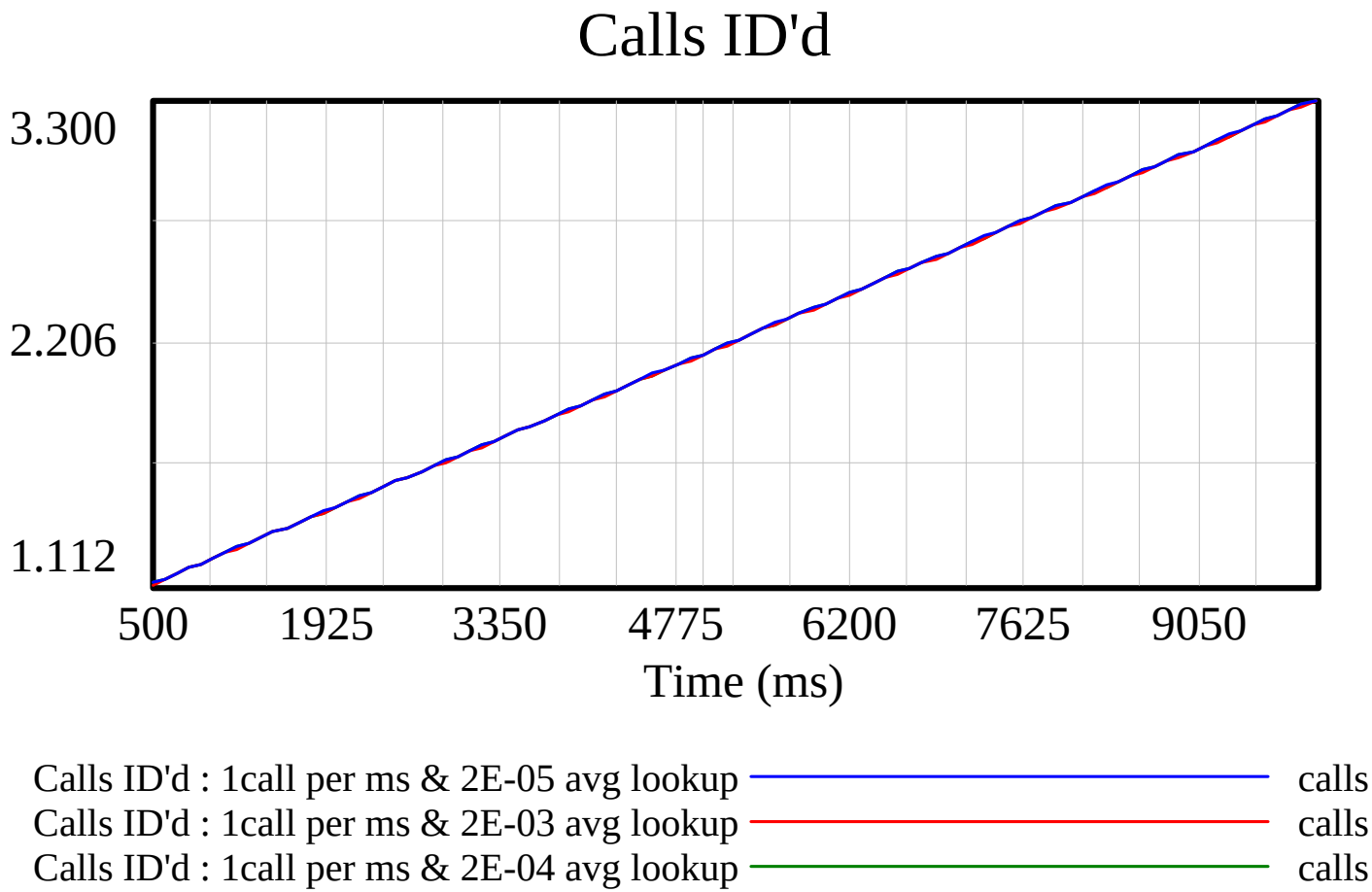
SD Model Percentage Performance with various average Lookups



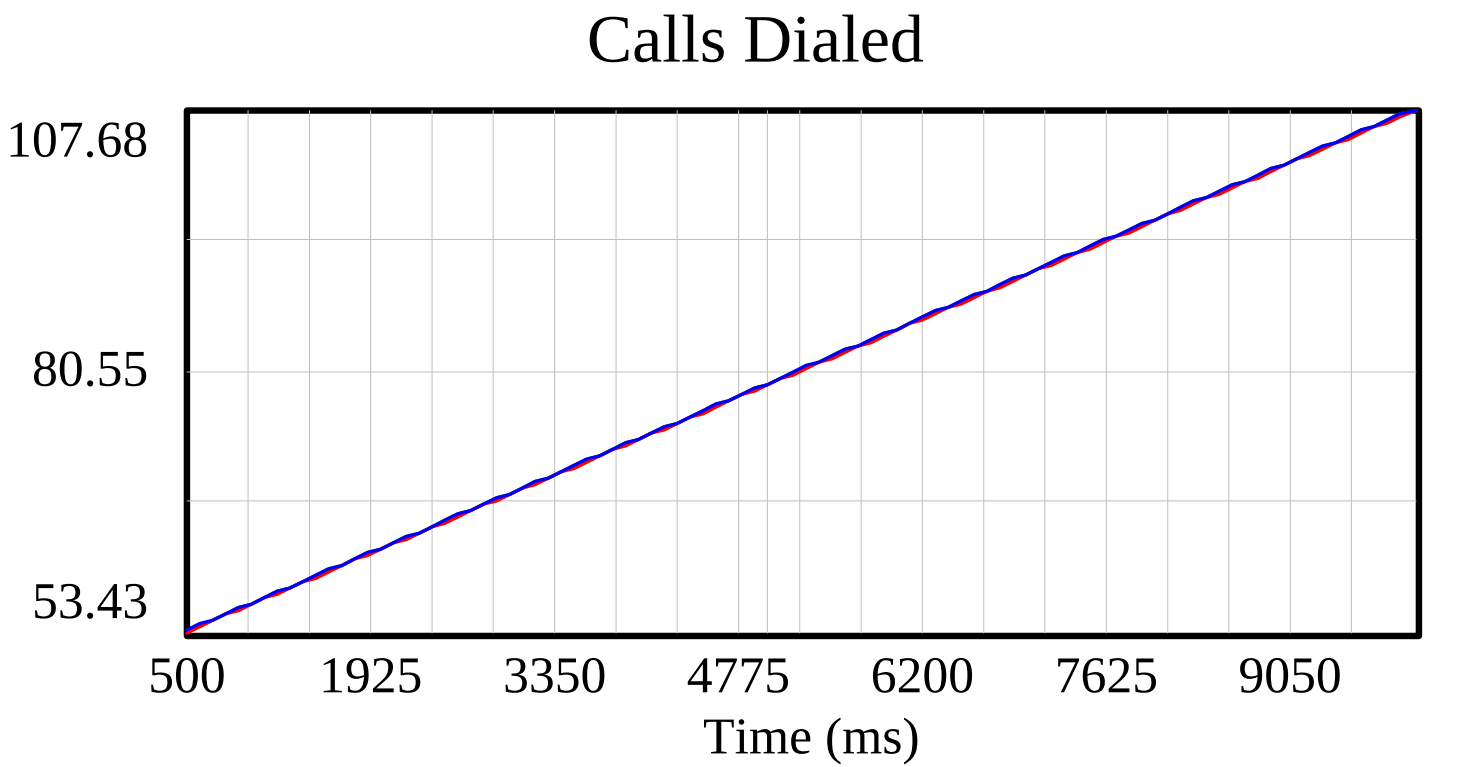
SD Model Switch Messages accumulations with various average Lookups



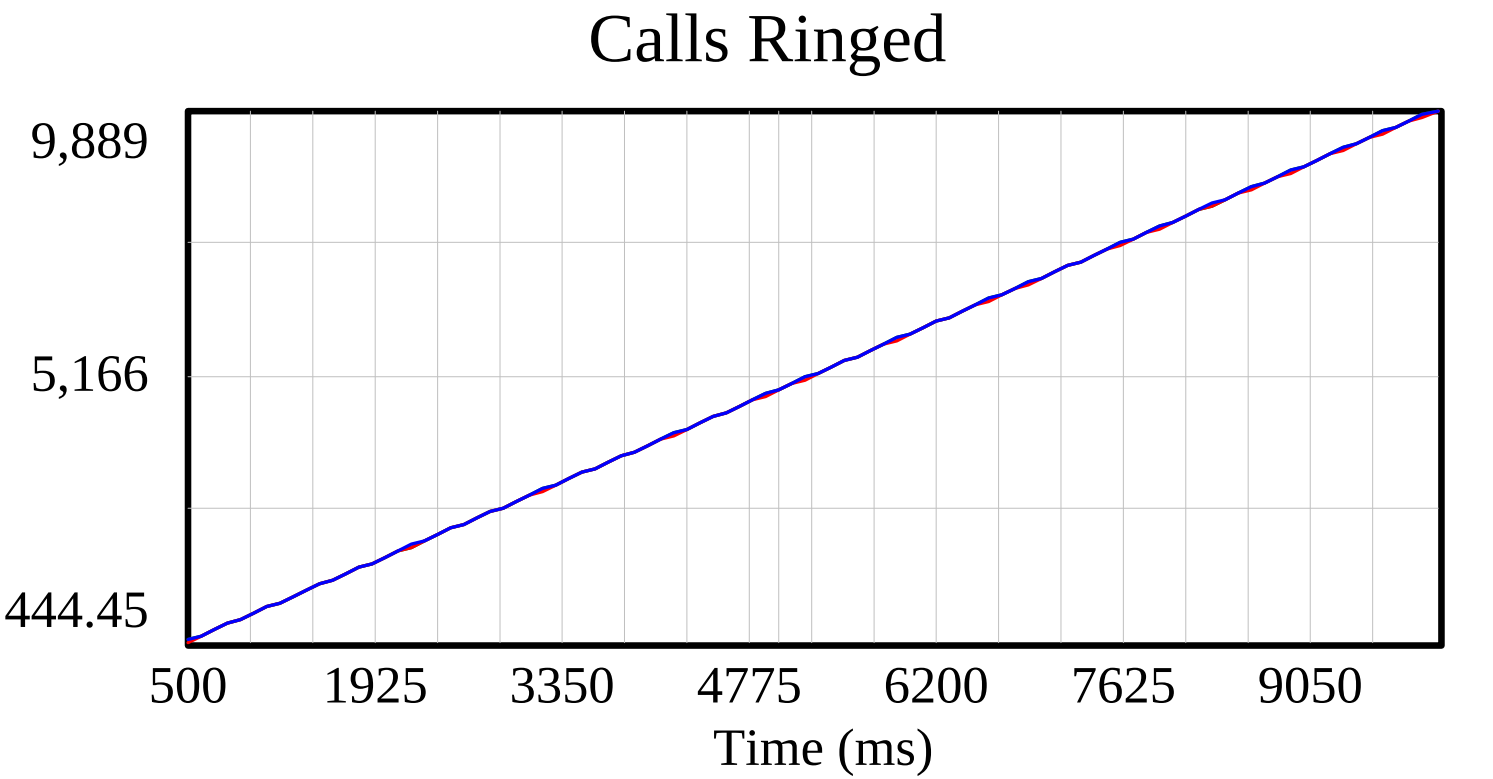
SD Model Calls ID’d accumulations with various average Lookups



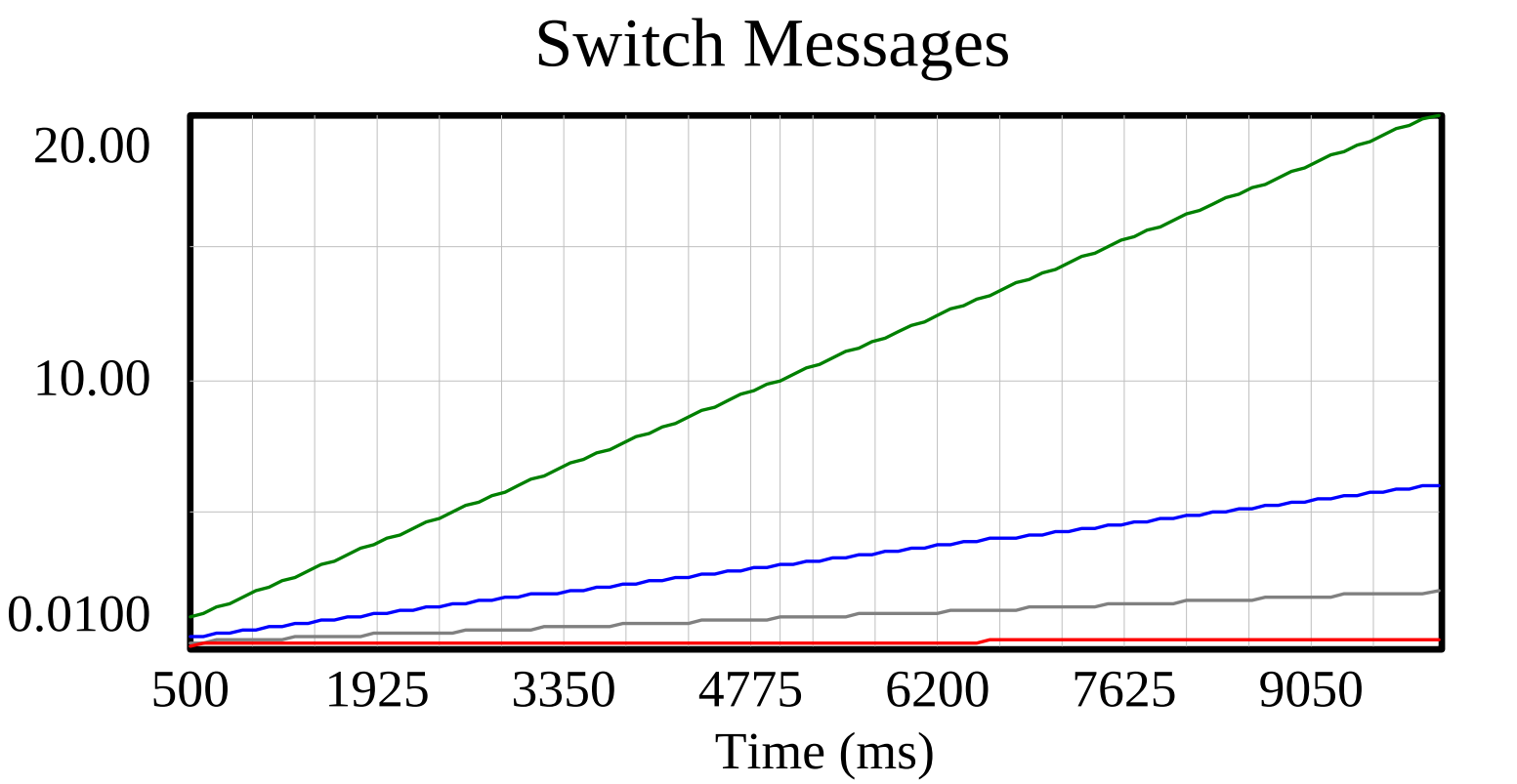
SD Model Calls Dialed accumulations with various average Lookups



Model Calls Ringed accumulations with various average Lookups



SD Model Switch Messages accumulations with various average Lookups & 3calls/ms



Major Findings & Conclusion

Major Findings and Significance

- UML and SD Models
  - SD VENSIM models do not solve translation of static UML™ diagrams into executable language as SimML automated this step
  - SD has power to support this concept – tools moving to XML interface

Major Findings and Significance

- Integrated View of Structure and Behavior
  - SD VENSIM shows integrated view of the structure and behavior of BT IN model
    - Lacking in UML™ models &
    - Lacking in SimML language
  - SD VENSIM shows interdependence of structure and behavior concurrently
    - Using stock and flow diagrams &
    - Using simulation results.

Major Findings and Significance

- Quality of Service (QoS) Requirements
  - SD models address QoS requirements such as availability or maintainability as auxiliary parameters either in soft (e.g. High medium, low) or hard form (e.g., .15 units).
  - UML™ is weak at best describing these non-functional requirements.

Major Findings and Significance

- Boundaries of the Reference Model
  - Several parameters such as host memory, message, and processing speed were not found in the SimML model.
  - Host memory, message size, and processing speed may have a significant impact on system throughput.

Major Findings and Significance – con't

- Similarly, call-barring, call-blacklisting and error-handling were not modeled.
- Handling the consequences of call-barring and call-blacklisting could have significant impact on the performance and should be studied
- Limiting the modeling simulation boundary to exclude what happens post "ring" looks reasonable

Sensitivity Analysis

- The SimML model included a very limited sensitivity analysis.
- SD VENSIM model readily lent itself to sensitivity analysis.
- In the case of this study, not looking at the sensitivity of the model to increased input volume may be a fatal flaw.

Sensitivity Analysis - con't

- The input volume was given as 3x10E3 to 3X10E6.
- SimML simulation was confined to the 10E3 magnitude case.
- Increasing the input volume using the SD VENSIM model showed
  - Accumulation of messages at the switch waiting for the "lookup ID" to be completed.
  - It is very likely that the switch will not have the memory capacity to sustain an accumulation of this nature; further investigation is warranted.

Conclusions

- Data analysis and findings support the problem statement that an information system described using static UML™ is translatable into a SD VENSIM simulation model.
- Rough comparison of the SD VENSIM model results to SimML case study show similar results.
- Using SD to model IS design before implementation has potentially significant cost benefits.

Conclusions – con't

System Dynamics has capability to:

- Improve design and lower risk
  - Early in design
  - Later in implementation
- Support "What ifs"
- Evolve as add details
- Support IV&V
- Show continuous dynamics of systems

Literature Survey

Literature Review Highlights - SD

- Forrester (1961) - SD…systems of information feedback control are fundamental to all life and human endeavor…

- Towell (1993) – SD applies to modeling of manufacturing, business, and similar systems that are part man and part machine…

- Caulfield & Maj (2001) - SD addresses building computer models of complex problem situations and then experimenting with and studying the behavior of the models over time.

Literature Review Highlights – UML

- Kortright (1997) - UML™ provided power to visualize a model, but the diagrams remained static.
  - To perform an executable simulation, UML™ required translation into another language, an executable language.
- Kobryn (1998) - showed UML™ concepts and techniques useful for IS for enterprise applications.
  - He concluded that UML™'s ability to support modeling architecture structure is strong, but modeling architectural behavior is relatively weak.

Literature Review Highlights – UML con't

- Miller (2002) - Object Management Group™ (OMG™) knew that UML™ was a compromise hence, the OMG™ initiated a request for proposal (RFP) in 2000 for the revision of UML™ as UML2™.

- Selic et al. (2002) - Evolve UML™ into UML2™ to extended modeling of complex behavior as needed to hierarchically compose and combine individual behavior specifications.

- Dori (2002) – Revolutionary reform of UML™ to UML2™ to integrate structure and behavior in a single user friendly manner.

Backup Diagrams

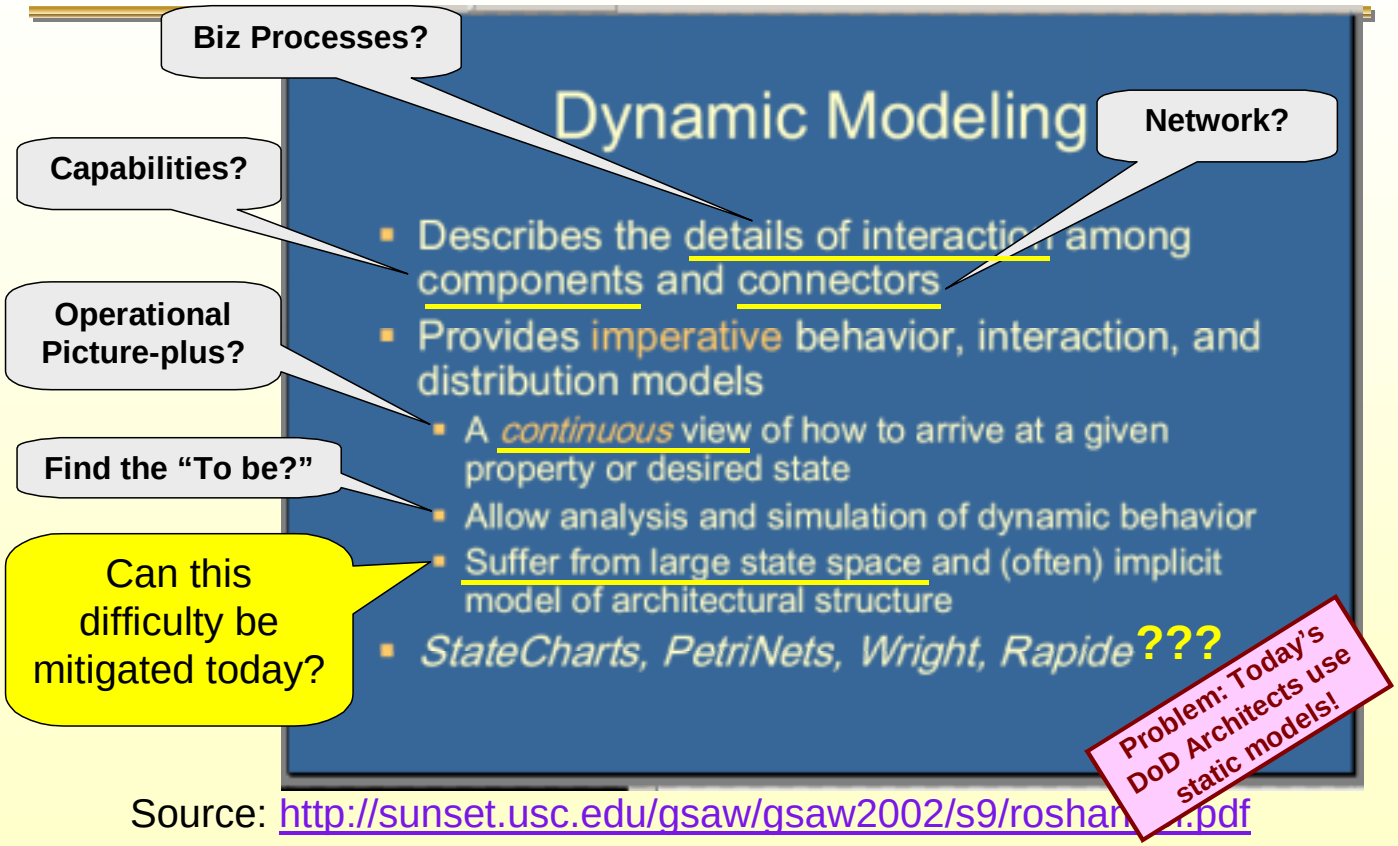
SD Central Concept

- Understanding how all the objects in a system interact with one another.
  - A system can be anything from a steam engine, to a bank account, to a basketball team.
- The objects and people in a system interact through "feedback" loops, where a change in one variable affects other variables over time, which in turn affects the original variable, and so on.

Model Shortfalls

Contemporary views on Modeling

We need your help!



Source: http://sunset.usc.edu/gsaw/gsaw2002/s9/roshan...pdf