Effective Simulation Warm-up for a Neonatal Intensive Care Unit

Emily K. Lada Anup C. Mokashi
SAS Institute

James R. Wilson
North Carolina State University

www.ise.ncsu.edu/jwilson/informs14-simnicu.pdf

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There is no finer investment for any community than putting milk into babies.

—Winston Churchill (1943)

Outline

- Neonatal Intensive Care Unit of Duke Children's Hospital
- Overview of the Simulation Tool SimNICU
  - Objectives
  - Structure and Operation
- Problems in Warming Up SimNICU
  - Using Warm-Up Procedures for Model Verification
  - Using Warm-Up Procedures for Model Analysis
- Conclusions, Limitations, and Future Work

Neonatal Intensive Care Unit (NICU) at Duke Childrens' Hospital

- NICU has 47 "critical-care" beds and 21 "step-down" beds.
- A patient's acuity level is specified by the nurse:patient ratio.
- Gestational Age (GA) determines baseline length of stay (bLOS) and initial acuity level:
  - If GA < 29 weeks then bLOS = (37-GA)*7 days.
  - If 29 ≤ GA ≤ 33 weeks, bLOS = (35-GA)*7 days.
  - If GA > 33 weeks, then bLOS = 14 days.
  - If GA < 28 weeks, then acuity = 1:1.
  - If 28 ≤ GA ≤ 38 weeks, then acuity = 1:2.
  - If GA ≥ 39 weeks, then acuity = 1:1 or 1:2 with probability 0.5
- Patients with initial acuities 1:1–1:3 can assigned to critical-care beds; step-down beds only for 1:3 patients.

Current NICU Staffing

- Three Neonatal Fellows
- Four Attending Neonatologists
- Five Pediatric Residents
- Five Respiratory Therapists
- Nine Neonatal Nurse Practitioners
- **Over Sixty Nurses…**

Objectives of SimNICU

- Improve NICU safety and efficiency by determining appropriate staffing levels for nurses to accommodate variations in patient attributes, including acuity and length of stay.

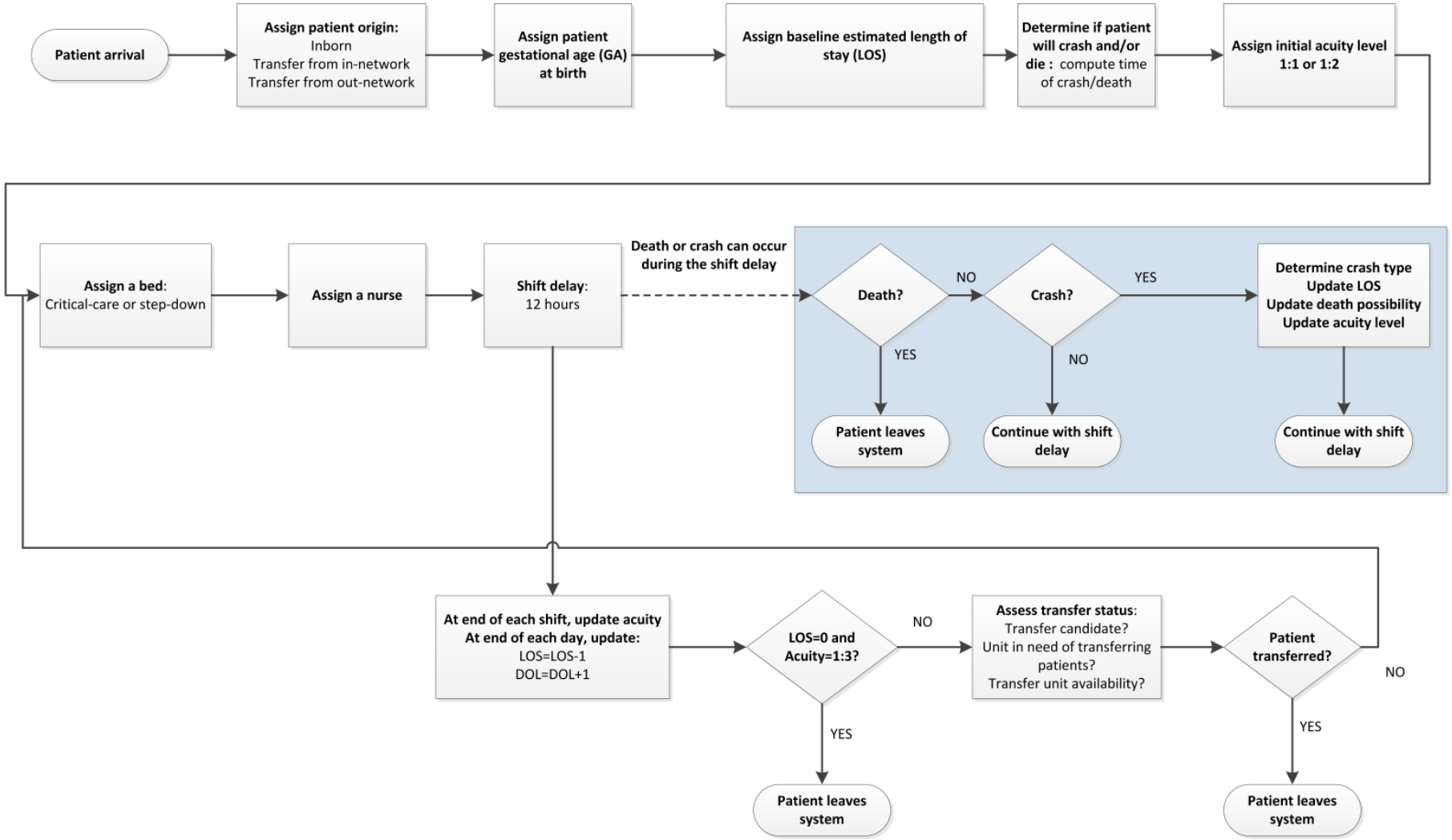
Structure and Operation of SimNICU

- Entities represent babies (Inborn, Outborn-In-Network, Outborn-Out-Network) with a randomly sampled gestational age.
- Daily arrivals are based on historical data for 2008–2013.
- Randomly sampled type and timing of various NICU-specific morbidities and the temporal affect on patient acuity.
- Nurses are assigned to 1, 2, or 3 babies, depending on acuity. Updates to (i) patient acuities and (ii) nurse and bed assignments made every 12 hours.
- Babies can be transferred from the unit if the daily census reaches a critical level.
- The model is run for a period of 1 year and the outputs are validated using historical data.

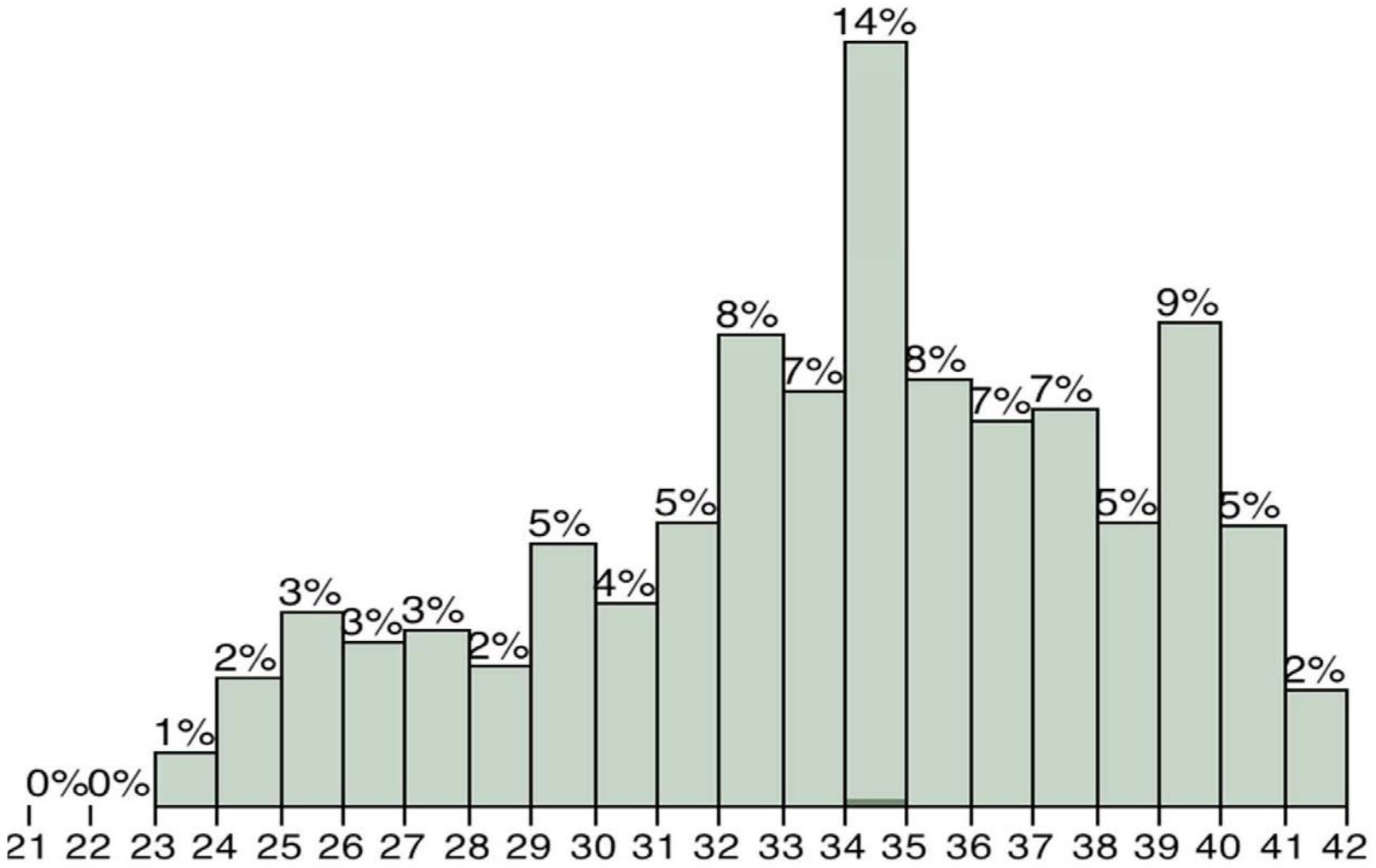
Main Outputs of SimNICU

- Number of Admissions
- Number of Deaths
- Number of Transfers
- Length of Stay
- Average Daily Census (ADC, time-averaged number of occupied beds per 24-hour period)
- Total Cost

Flow of Patients in SimNICU

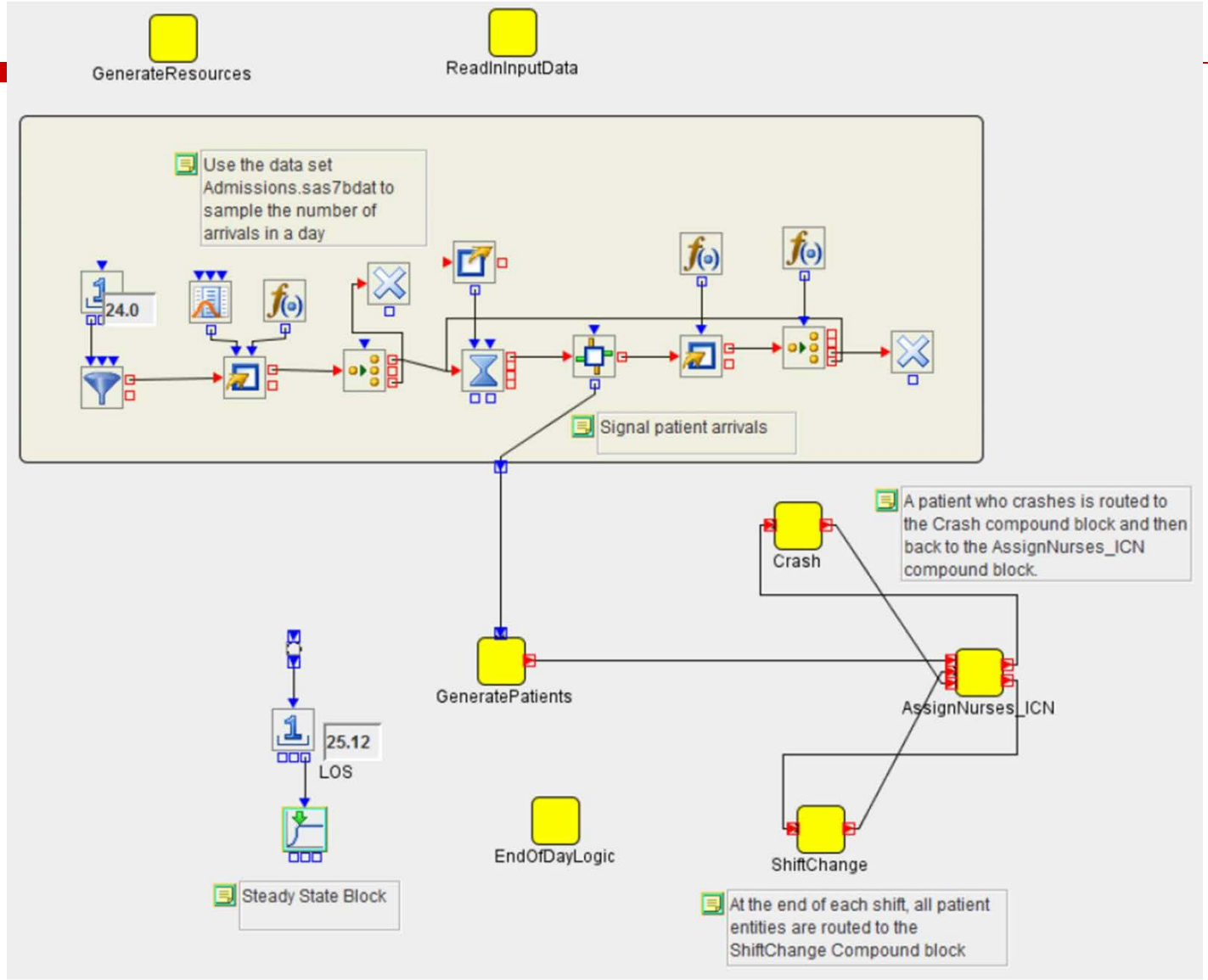


GA Distribution for Inborn Admissions

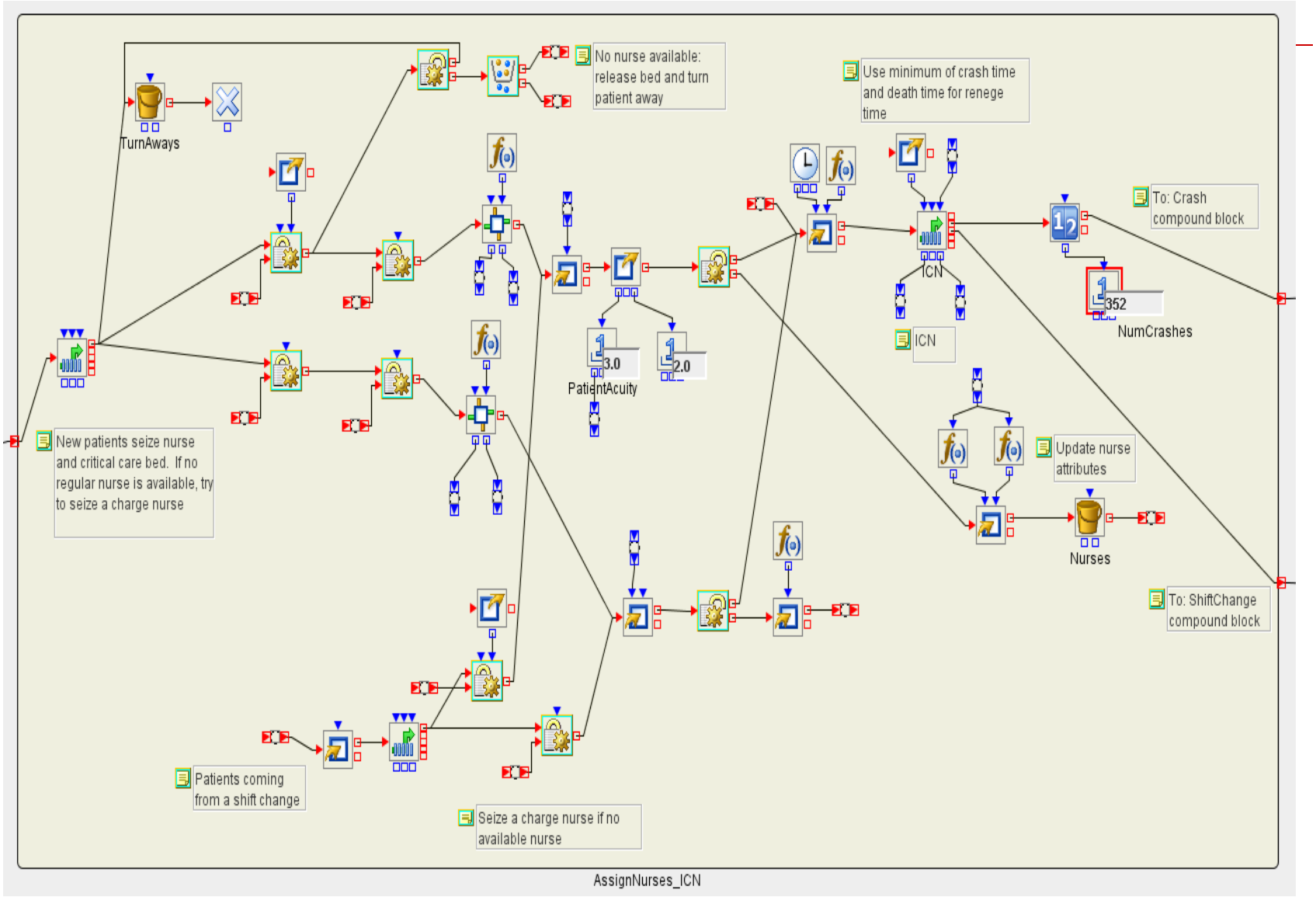


Gestational Age (Weeks) for n=3,307 Admissions

SAS Simulation Studio Model



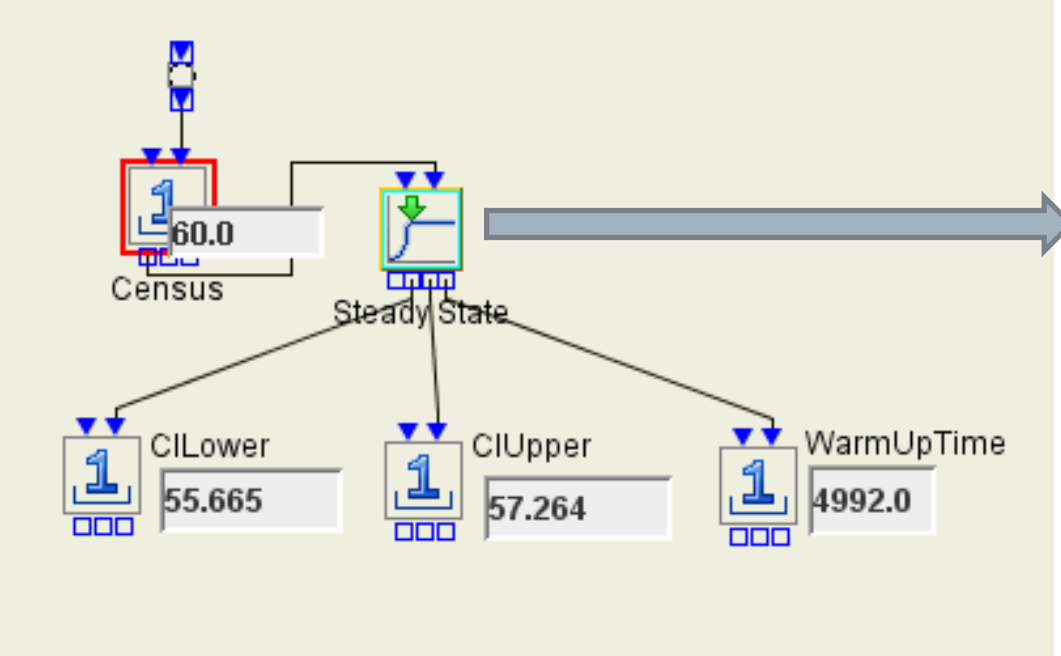
Detailed Patient Flow in SimNICU

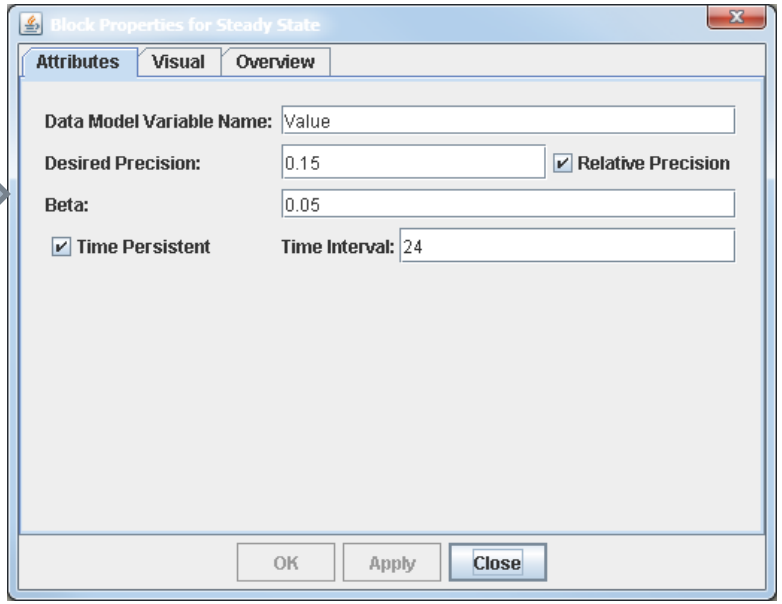


Problems in Warming Up SimNICU

- The NICU never shuts down, but it is impossible to know the starting state of the simulation for this system.
- Starting SimNICU from an empty-and-idle initial condition, we need to estimate an appropriate warm-up period and use that for a statistics-clearing time.

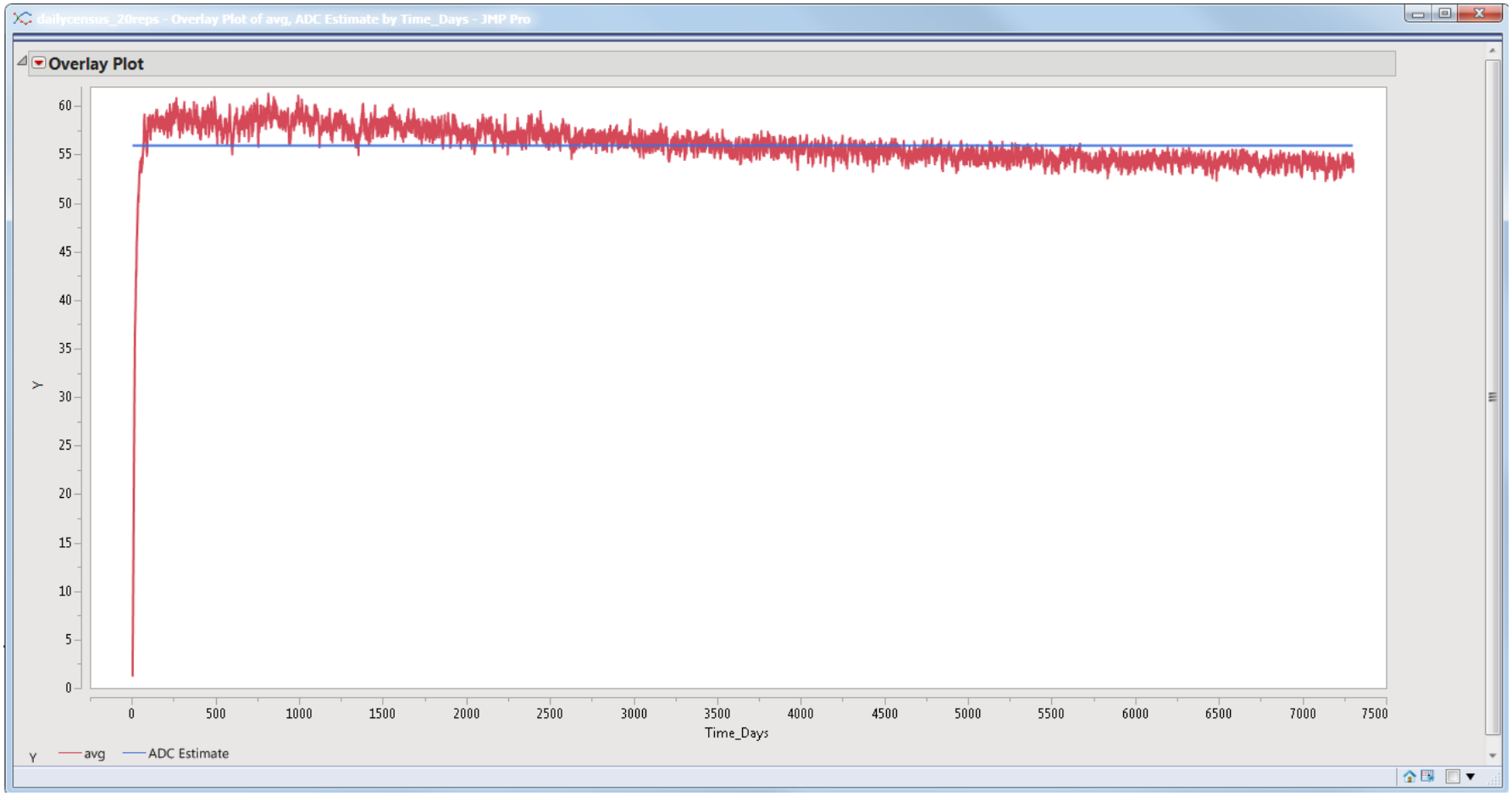
Estimating the Warm-up Period





Steady-State Block of Simulation Studio Is Based on Sbatch (Lada and Wilson 2008)

Warm-Up Problems in an Early Version of SimNICU

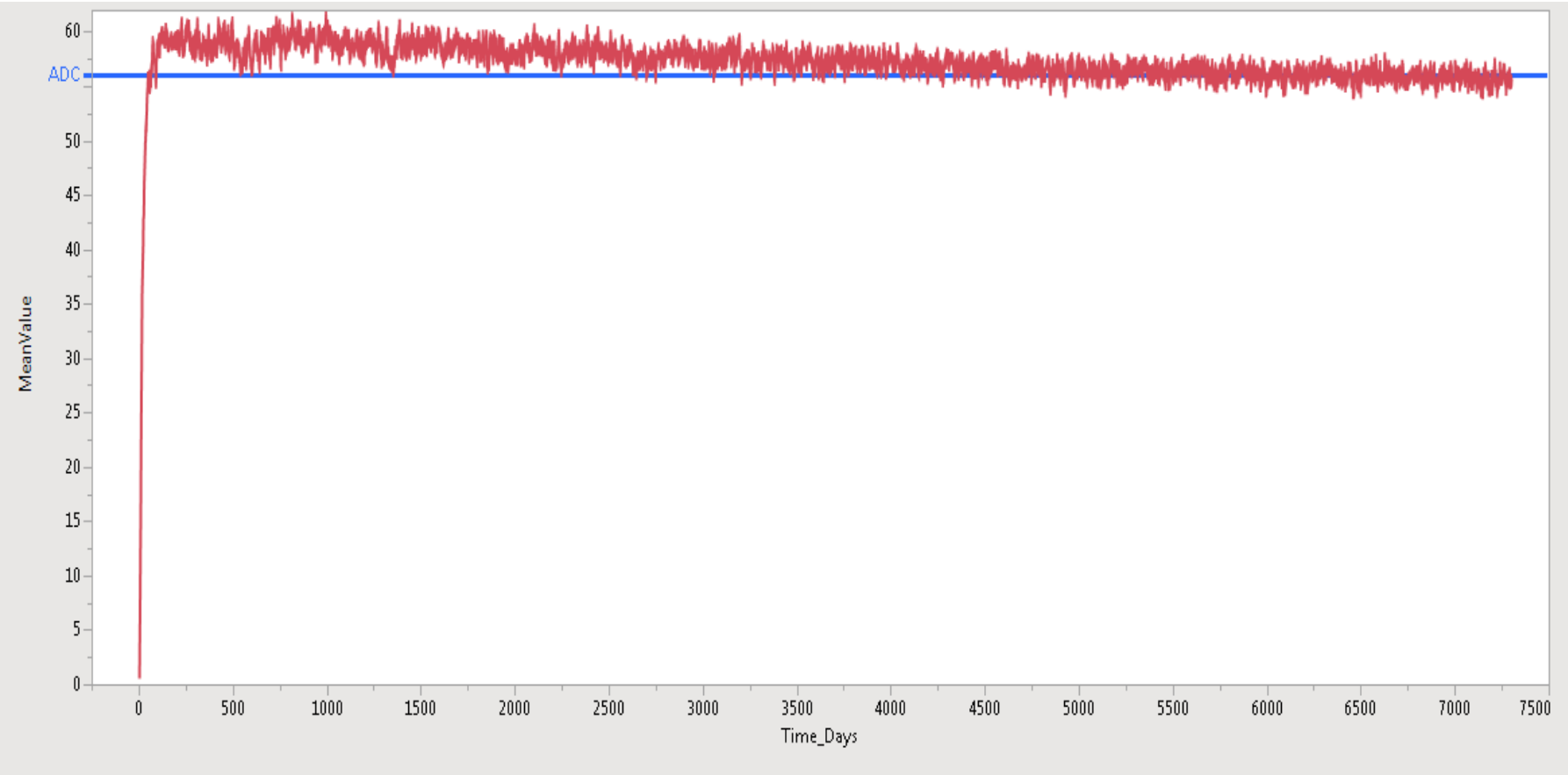


Daily census over 20 yrs averaged over 20 runs: with 24 nurses, neither Sbatch nor N-Skart could identify an appropriate warm-up period. MSER-5 delivered warm-up periods ranging from 65 days to 9.7 yrs, with mean of 5.5 yrs and std dev of 3 yrs.

Using Warm-Up Procedures in Model Verification

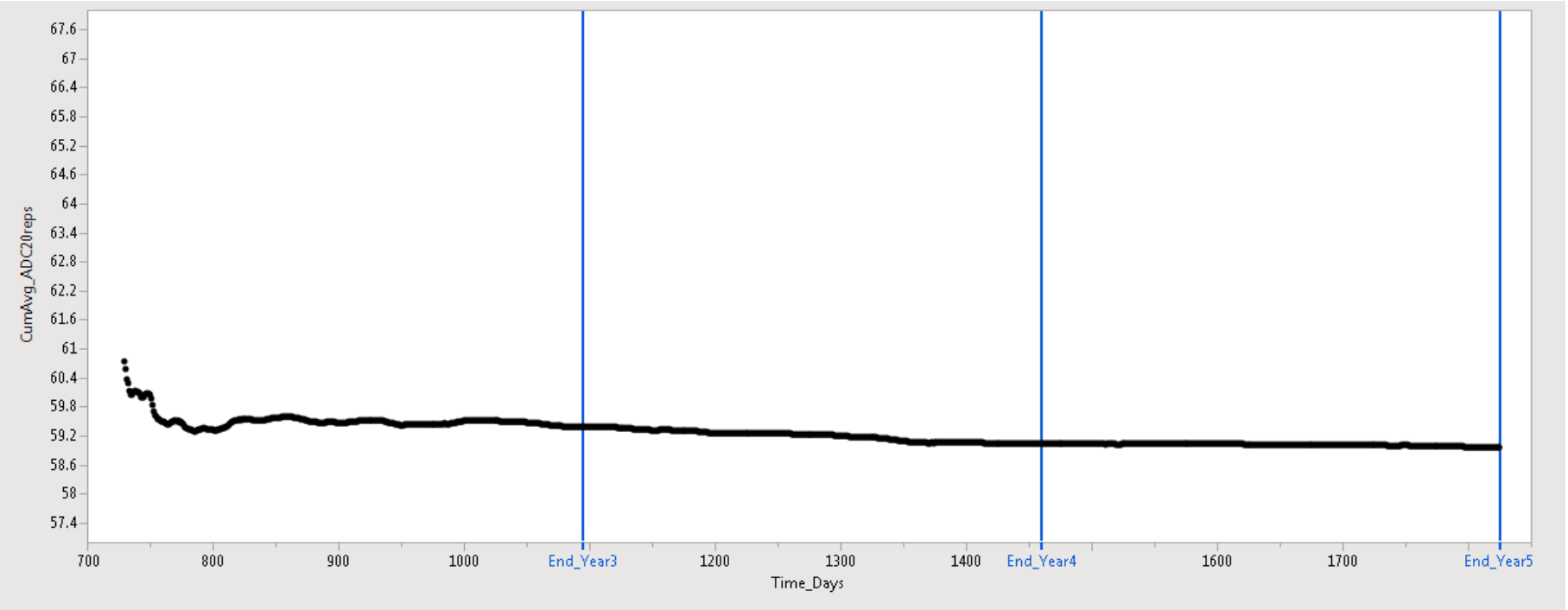
- Since the rate of new arrivals and LOS distributions were not changing over the 20-year time horizon, the average daily census should not exhibit long-term decline.
- We found the number of 1:1 babies was increasing over time because 1:1 admissions that did not crash were not being upgraded to 1:2 within 3 days.
  - This logic error reduced the availability of nurses to care for new admissions.
  - **The reduced availability of nurses to care for new admissions reduced the *effective* admission rate, causing ADC to decline slowly.**

Warm-Up Profile of Corrected Model



Daily Census for 20 yrs averaged over 20 runs: with 24 nurses, Sbatch and N-Skart identified warm-up periods ranging from 48 days to 7 mo. MSER-5 identified warm-up periods ranging from 25 days to 9.5 yrs, with mean of 2.3 yrs and std dev of 3 yrs.

Welch's Graphical Method Revisited



- Truncated sample mean averaged over 20 runs with 2-yr warm-up period and with 24 nurses

Some Recent SimNICU Results

	Model Mean (95th% CI)	Actual Data N or Mean (95th% CI)
Admissions	843 (836, 850)	792 (732, 851)
Admissions <28 Weeks	128 (126, 130)	119 (109, 129)
Average Daily Census	59 (58.8, 59.2)	57 (54, 61)
LOS (days)	26 (25, 26)	26 (25, 28)
LOS <28 Weeks (Days)	77 (76, 78)	86 (81, 91)
Deaths	35 (33, 37)	38 (34, 43)

- These results are based on 50 runs of length 3 years, with a 2-year warm-up period and with 24 nurses.

Conclusions, Limitations, and Future Work

- SimNICU yields good estimates of annual admissions, transfers, and deaths based on different staffing levels.
- Even though SimNICU is a finite-horizon simulation, it requires effective procedures for determining the length of its warm-up period; and these procedures have also proved to be effective in detecting obscure errors in the underlying model logic.
- Welch's graphical method is a critical tool for checking the warm-up periods estimated by ***any*** automated method.
- SimNICU will be used to forecast how changes in physical structure, staffing, referral patterns, or patient mix can affect the operation of Duke's NICU and other NICUs elsewhere.

QUESTIONS?