Discrete event simulation model for planning Level 2 “step-down” bed needs using NEMS

Felipe Rodrigues[1], Greg Zaric[1], David Stanford[2]

(Judy Kojlak[3], Fran Priestap[3], Claudio Martin[3])

[1] Ivey Business School @ Western University
[2] Department of Statistical and Actuarial Sciences @ Western University
[3] LHSC

Ivey International Centre for Health Innovation (IICHI)
Ontario Trillium Scholarship (OTS)
Universidade Federal do Paraná (UFPR)

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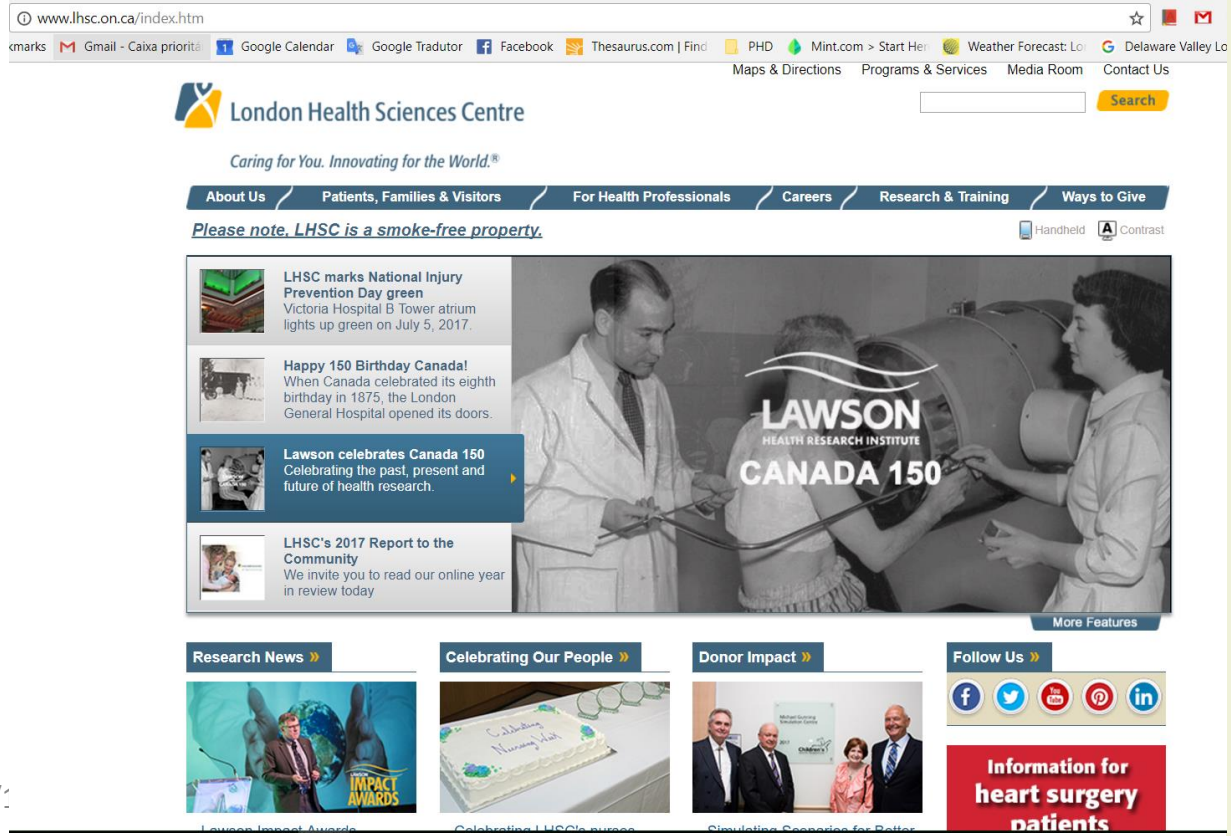
INTRODUCTION

London Health Sciences Centre

London, Ontario

Canada



PATIENT CARE 2016/2017

163,369
Emergency visits

787,709
Ambulatory visits
(excluding emergency)

52,447
Admissions

350,514
Patient days

6.4
Average length of stay (days)

9,860
Operating Room Day Surgery

17,523
Operating Room Inpatient

15,971
Operating Room Endoscopy

414
University Hospital Beds

542
Victoria Hospital Beds

107
Children's Hospital Beds

36
Newborn Bassinets

Statistics based upon data for the period April 1, 2016 to March 31, 2017

Definitions

- MSICU: Medical Surgical Intensive Care Unit
- NEMS (Miranda et al. 1997):
  - *"Nine Equivalents of nursing Manpower use Score"*
  - Therapeutic intervention index to measure nursing workload: 56 point scale

Definitions

Level of care	Bed characteristics	Patient/nurse ratio	Estimated cost $/patient-day [1]	NEMS[2]
1	Standard Ward bed: No organ support, no ventilation	3 or more to 1	$600	≤ 10
2	Step-down bed: Support single failed organ system, no ventilation	2 to 1	$2,000	11 to 25
3	Intensive care bed: Invasive ventilation and multiple organ support	1 to 1	$3,500	26 to 56

[1]Estimated cost provided by LHSC Management;
[2] Nine equivalents of nursing manpower use score (Miranda et al. [2])

LHSC – University Hospital

- Dec/13-Dec/14
  - 17,411 patients
  - 42,092 movements
- Misplacement/off-service
  - 5% to 30%
- **“step-down” status**
  - **MSICU**
    - **660 out of 864 patients**

Research questions

- What is the benefit of a "step-down" unit?
  - Patient Flow
  - Throughput
  - Length-of-stays
  - Costs
- For UH:
  - What are the UH's L2 bed needs? How efficient can they be?
- Can NEMS scores provide a useful step-down rule in estimating L2 needs?

Challenges

- No previous history of medicine L2
- Seasonality, patient heterogeneity
- Patient's health and death probability change over time
- Step-downs & bounce-backs, congestion
- Off-service
- Costs

METHODS AND MODEL

DES Model Overview

- Objectives:
  - Minimize cost
  - Minimize LoS (clinical)
  - Maximize Throughput
- Decision Variables:
  - Number of L2 Beds
  - Number of MSICU Beds

DES Model Overview

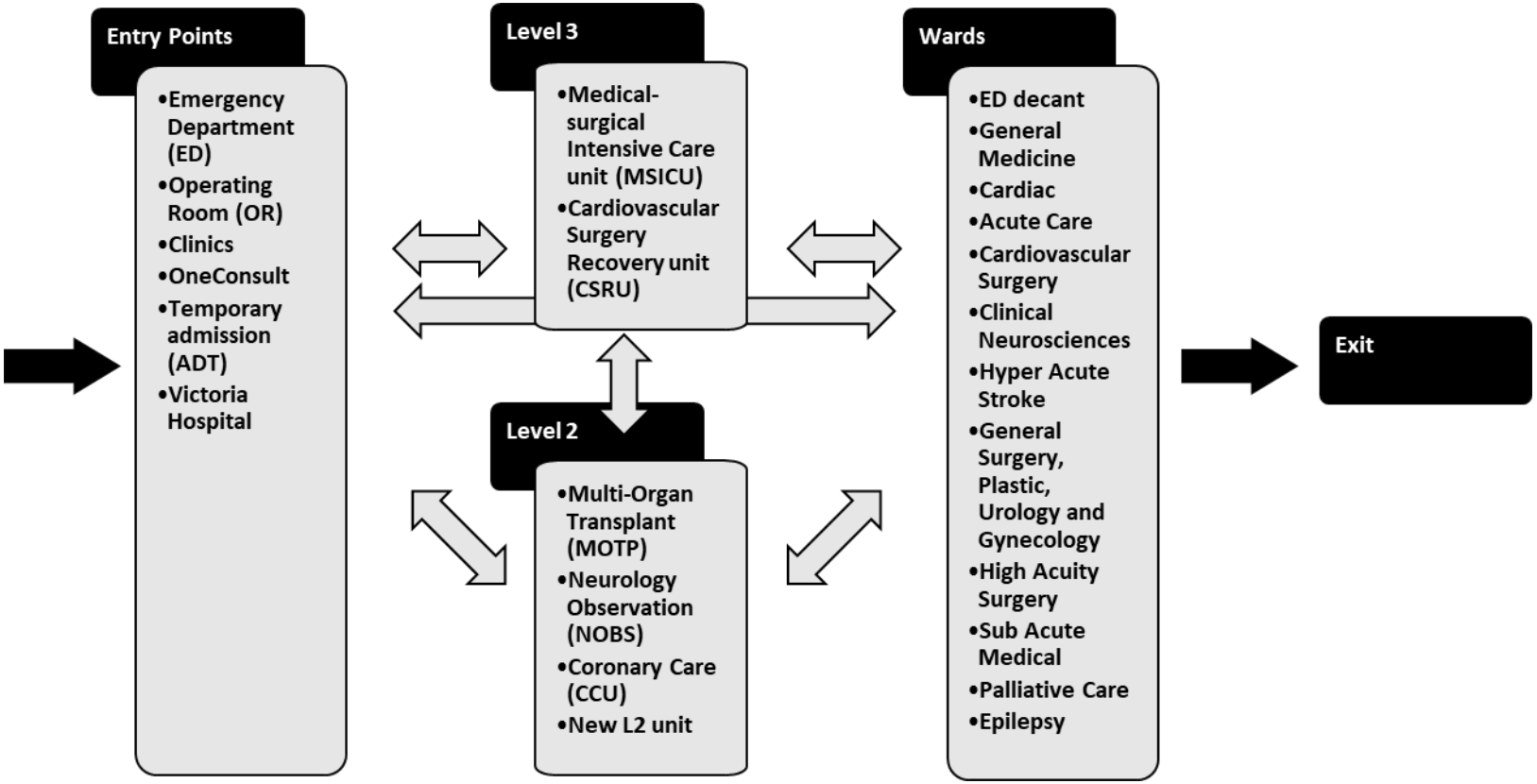
- Parameters and Constraints:
  - Arrival rates, LoS rates, death rates
  - NEMS thresholds
  - Current bed allocations
  - Flow matrix
  - Budget

Data

- Patient registry
- Patient transfer files
- Nursing workloads
- Distribution fittings: arrivals, LoS, step-downs
- Flow matrix
- Step-down rules

- N = 17,380 patients

Patient Flow



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Flow Matrix

units	type	level of care	Clinic	ED (emergency Department)	Operating Room	Victoria	10th - Epilepsy (Ward)	4th - General Medicine (Ward)	5th - Cardiac (Ward)	6th - Acute Care (Ward)	6th - Cardiac/Cardio vascular surgery (Ward)	7th - Clinical Neurosciences (Ward)	7th - Hyper Acute Stroke	8th - General Surgery, Plastic, Uro, Gyn (Ward)	8th - High Acuity Surgery	8th - Sub Acute Medical	9th - Palliative Care (Ward)	ED Decant	4th - MOTP (Transplant)	5th - CCU - Cardiac Care	7th - Neuro Obs	CSRU (cardiovascular recovery)	MSCU (medical surgery intensive care)	Discharged	Expired	Signed Out	Grand Total
Clinic	entry point	L-1 / ER / OR	0.00%	2.10%	3.20%	0.50%	0.00%	13.30%	15.20%	0.00%	14.30%	7.40%	0.80%	12.50%	0.30%	0.00%	8.50%	0.30%	11.70%	6.10%	0.30%	0.00%	0.30%	2.90%	0.00%	0.30%	100.00%
ED (emergency Department)	entry point	L-1 / ER / OR	0.00%	0.00%	4.60%	0.70%	0.00%	17.10%	6.70%	0.50%	7.60%	10.90%	1.30%	10.90%	0.10%	0.10%	9.00%	14.60%	1.20%	4.60%	1.10%	0.30%	2.50%	5.60%	0.50%	0.10%	100.00%
ONEConsult	entry point	L-1 / ER / OR	0.10%	0.10%	0.00%	0.00%	0.00%	3.60%	4.60%	0.10%	5.40%	11.00%	0.10%	5.50%	0.20%	0.00%	5.00%	0.10%	3.10%	39.30%	1.80%	2.50%	17.50%	0.00%	0.00%	0.00%	100.00%
Operating Room	entry point	L-1 / ER / OR	0.30%	0.00%	0.00%	0.00%	0.50%	0.40%	0.40%	0.00%	1.50%	7.80%	0.00%	14.50%	3.50%	0.00%	34.50%	0.00%	1.60%	0.30%	6.90%	18.70%	3.40%	5.50%	0.20%	0.00%	100.00%
U-ADT	entry point	L-1 / ER / OR	6.40%	0.10%	5.90%	0.00%	16.00%	5.60%	8.30%	0.10%	24.60%	5.80%	0.20%	7.80%	0.10%	0.10%	4.00%	0.10%	6.50%	7.10%	0.30%	0.40%	0.60%	0.00%	0.00%	0.00%	100.00%
Victoria	entry point	L-1 / ER / OR	0.40%	2.60%	0.20%	0.00%	0.20%	0.40%	3.40%	0.00%	11.70%	6.70%	0.20%	1.40%	0.00%	0.00%	2.80%	0.00%	0.60%	19.20%	1.40%	1.20%	8.10%	34.20%	5.10%	0.20%	100.00%
10th - Epilepsy (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	1.40%	0.00%	0.00%	0.00%	0.00%	0.00%	0.30%	0.60%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.60%	0.00%	0.00%	96.50%	0.00%	0.60%	100.00%
4th - General Medicine (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.10%	93.90%	4.60%	1.00%	100.00%
5th - Cardiac (Ward)	ward	L-1 / ER / OR	0.30%	0.00%	7.00%	0.30%	0.00%	1.40%	0.00%	0.20%	3.20%	0.20%	0.00%	0.40%	0.00%	0.50%	0.90%	0.00%	0.00%	3.50%	0.00%	3.20%	0.60%	76.50%	1.60%	0.20%	100.00%
6th - Acute Care (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.00%	0.00%	0.10%	0.00%	0.00%	0.00%	0.00%	0.10%	0.30%	0.30%	0.00%	0.00%	0.00%	0.00%	0.00%	95.60%	3.30%	0.10%	100.00%
6th - Cardiac/Cardio vascular surgery (Ward)	ward	L-1 / ER / OR	0.00%	0.10%	49.30%	0.40%	0.10%	3.20%	3.10%	0.30%	0.00%	0.70%	0.00%	1.50%	0.10%	0.70%	2.00%	0.10%	0.50%	6.60%	0.00%	30.50%	0.80%	0.00%	0.00%	0.00%	100.00%
7th - Clinical Neurosciences (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	8.80%	0.60%	0.30%	1.60%	0.00%	0.00%	0.10%	0.00%	0.20%	0.60%	0.00%	0.20%	2.20%	0.10%	0.10%	0.20%	4.90%	0.20%	0.80%	76.60%	2.20%	0.30%	100.00%
7th - Hyper Acute Stroke	ward	L-1 / ER / OR	0.00%	0.00%	1.40%	0.00%	0.70%	0.70%	0.00%	0.00%	0.00%	68.80%	0.00%	0.70%	0.00%	0.00%	0.70%	0.00%	0.00%	0.70%	2.20%	1.40%	1.40%	20.60%	0.00%	0.70%	100.00%
8th - General Surgery, Plastic, Uro, Gyn (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	8.50%	0.70%	0.00%	1.10%	0.20%	0.00%	0.20%	0.40%	0.00%	0.00%	1.70%	0.70%	1.80%	0.10%	0.80%	0.10%	0.00%	0.20%	1.30%	80.60%	0.90%	0.70%	100.00%
8th - High Acuity Surgery	ward	L-1 / ER / OR	0.00%	0.00%	1.60%	0.90%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	81.40%	0.00%	0.00%	0.60%	0.00%	0.60%	0.90%	0.00%	0.60%	2.80%	10.60%	0.00%	0.00%	100.00%
8th - Sub Acute Medical	ward	L-1 / ER / OR	0.00%	0.00%	2.30%	0.50%	0.00%	4.10%	0.00%	0.50%	0.00%	0.00%	0.50%	1.40%	0.00%	0.00%	3.20%	0.50%	0.00%	0.00%	0.50%	0.50%	0.00%	82.30%	3.20%	0.50%	100.00%
9th - Palliative Care (Ward)	ward	L-1 / ER / OR	0.00%	0.00%	7.20%	0.40%	0.00%	3.60%	0.10%	0.10%	0.40%	0.60%	0.00%	1.20%	0.00%	1.00%	0.00%	0.10%	0.20%	0.20%	0.10%	0.10%	0.40%	80.50%	3.60%	0.20%	100.00%
ED Decant	ward	L-1 / ER / OR	0.00%	0.00%	1.30%	0.20%	0.00%	45.70%	3.60%	4.30%	4.70%	5.00%	0.00%	9.80%	0.00%	0.50%	7.50%	0.00%	0.30%	0.00%	0.10%	0.00%	0.20%	15.60%	0.90%	0.30%	100.00%
4th - MOTP (Transplant)	intermediate unit	L-2	0.00%	0.00%	10.70%	0.20%	0.20%	13.10%	0.30%	0.70%	1.70%	0.90%	0.00%	6.10%	0.30%	0.20%	2.60%	0.00%	0.00%	0.50%	0.20%	1.60%	5.90%	52.90%	1.70%	0.20%	100.00%
5th - CCU - Cardiac Care	intermediate unit	L-2	1.30%	0.00%	7.50%	0.80%	0.00%	0.80%	20.40%	0.00%	16.30%	0.60%	0.00%	0.20%	0.10%	0.00%	0.30%	0.00%	0.20%	0.00%	0.10%	4.10%	1.70%	43.20%	2.00%	0.40%	100.00%
7th - Neuro Obs	intermediate unit	L-2	0.00%	0.10%	5.80%	0.10%	0.40%	0.30%	0.00%	0.10%	0.00%	71.50%	0.70%	0.00%	0.00%	0.00%	0.40%	0.00%	0.10%	0.10%	0.00%	0.80%	3.80%	15.70%	0.10%	0.00%	100.00%
CSRU (cardiovascular recovery)	intensive care	L-3	0.00%	0.00%	4.40%	0.10%	0.00%	0.60%	0.00%	0.10%	82.70%	0.50%	0.00%	0.10%	0.20%	0.00%	0.10%	0.00%	1.70%	1.60%	0.10%	0.00%	4.10%	0.70%	3.00%	0.00%	100.00%
MSCU (medical surgery intensive care)	intensive care	L-3	0.00%	0.00%	8.60%	0.90%	0.00%	16.50%	1.70%	0.10%	0.70%	7.00%	0.30%	6.90%	2.90%	0.00%	2.30%	0.10%	8.10%	3.50%	6.80%	2.00%	0.00%	9.40%	22.00%	0.20%	100.00%
Grand total			0.40%	0.10%	5.00%	0.30%	0.90%	6.70%	3.00%	0.30%	7.30%	6.10%	0.30%	6.40%	0.80%	0.20%	8.00%	3.00%	1.30%	3.00%	1.80%	3.80%	2.20%	37.00%	1.90%	0.20%	100.00%

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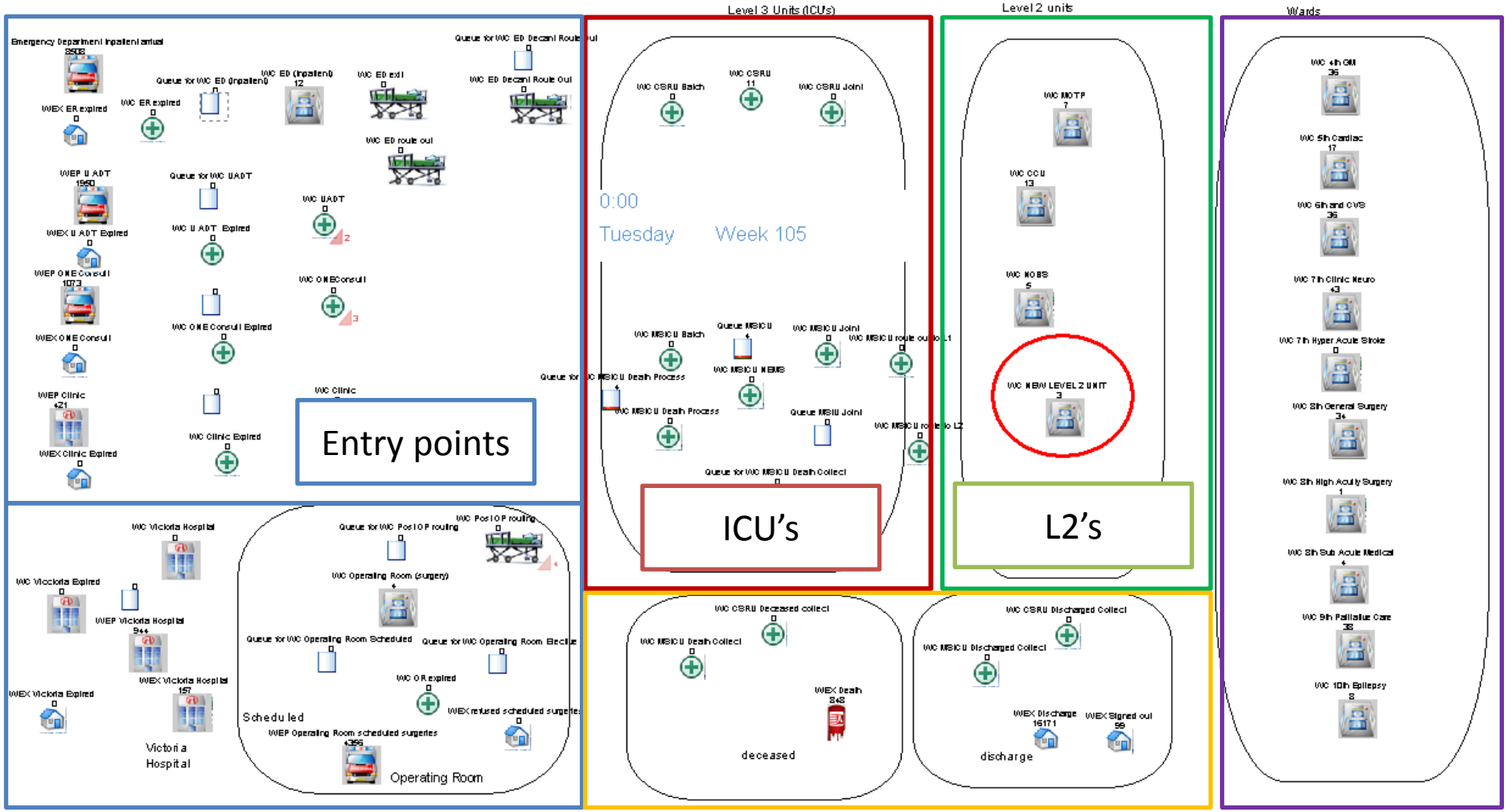
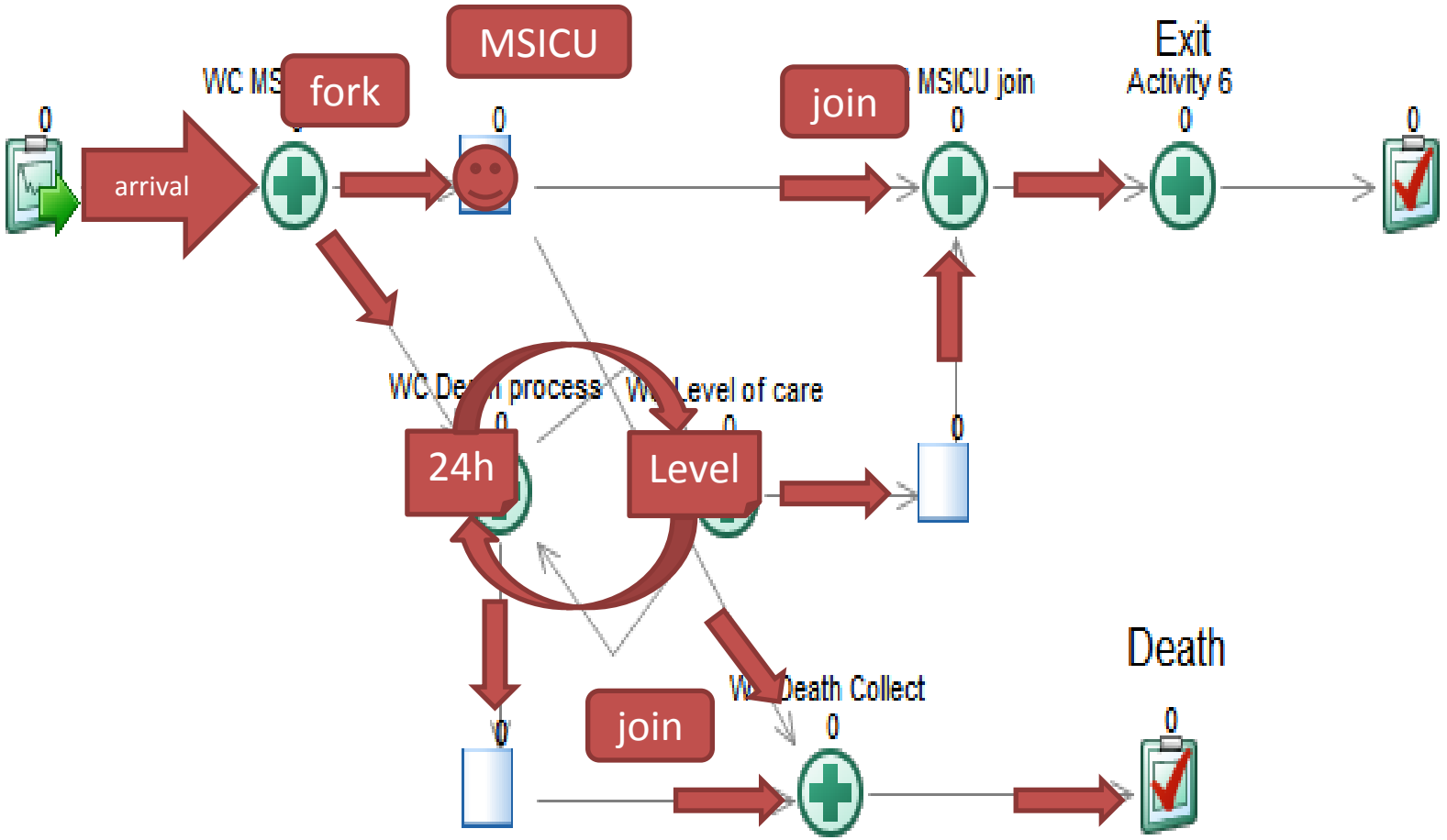
Model



Simulation model –Level of care and death process



Scenarios

1. New capacity:

   Up to 20 beds at L2 Unit

2. Re-allocation of existing capacity

   25 beds allocated between MSICU vs L2 bed mix

3. New capacity with re-allocation

   30 beds allocated between MSICU vs L2 bed mix

MODEL VALIDATION

Results – Baseline Scenario

Indicator	-95% confidence limit	Simulation Average	95% confidence limit	Empirical data	Difference
Throughput (patients/year)	17,128.05	17,194.00	17,159.95	17,380.00	-1.07%
Average overall LOS (days/stay)	6.84	6.87	6.90	6.90 (CIHI [7])	-0.40%
Cost of hospital stay	$6,347.36	$6,345.41	$6,343.48	$6,123.00 (CIHI [7])	3.63%
Total operational cost	$108,717,845	$109,103,000	$109,488,155	$106,417,740 (LHSC [24])	2.52%
MSICU Average LOS (hours)	162.12	164.24*	166.36	159.6*	2.91%
MSICU Std Dev of LOS (hours)	174.13	177.96	181.80	201.8	-11.81%
MSICU Long stays (≥504 hours)	5.53%	5.26%	4.90%	5%	-0.27%

*P value and statistical significance:The two-tailed P value equals 0.5884

By conventional criteria, this difference is considered to be not statistically significant.

The mean of simulation minus raw input data equals 4.6400

Confidence interval: 95% confidence interval of this difference: From -12.2025 to 21.4825

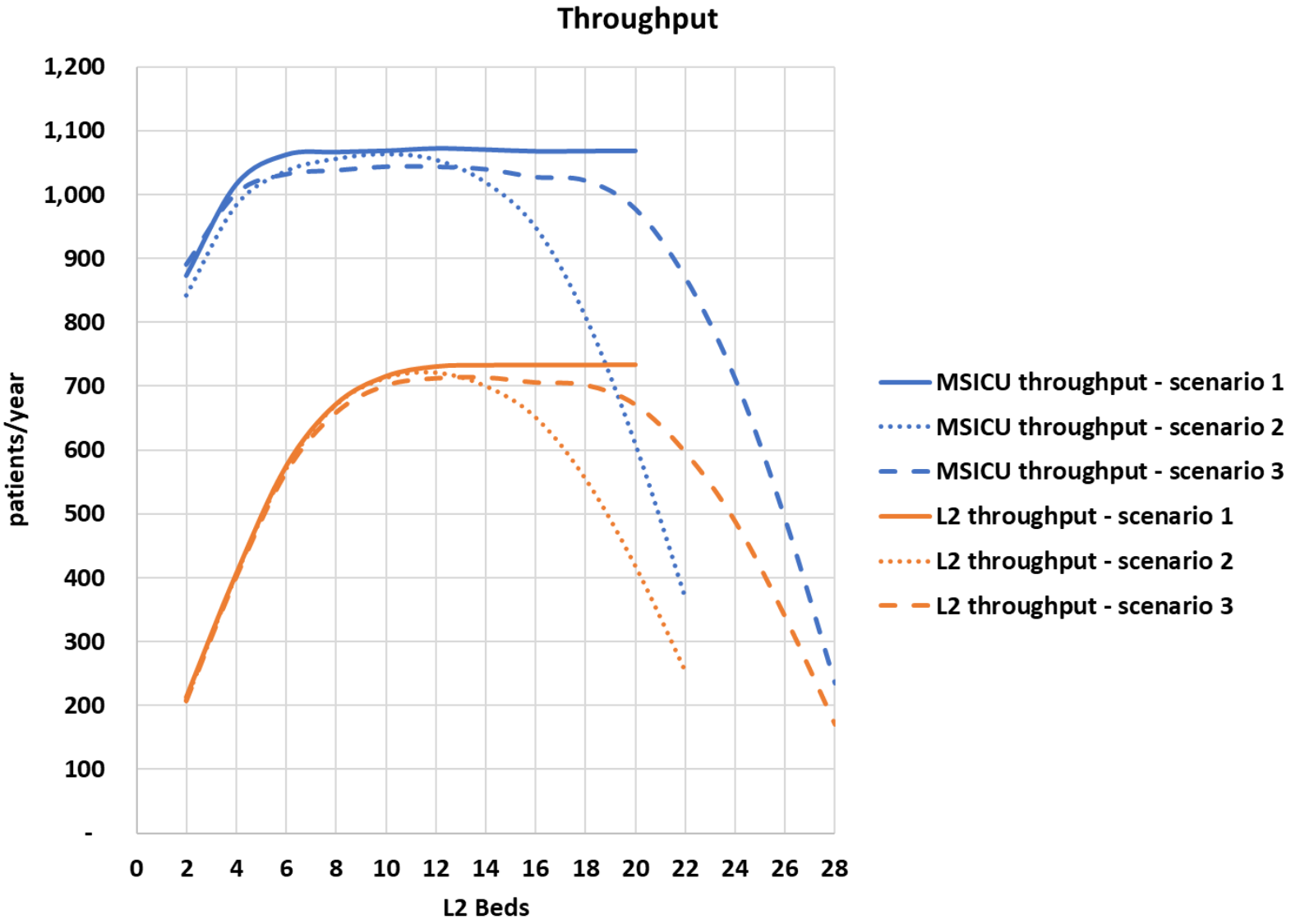
Intermediate values used in calculations: t = 0.5413 df = 1963 standard error of difference = 8.572

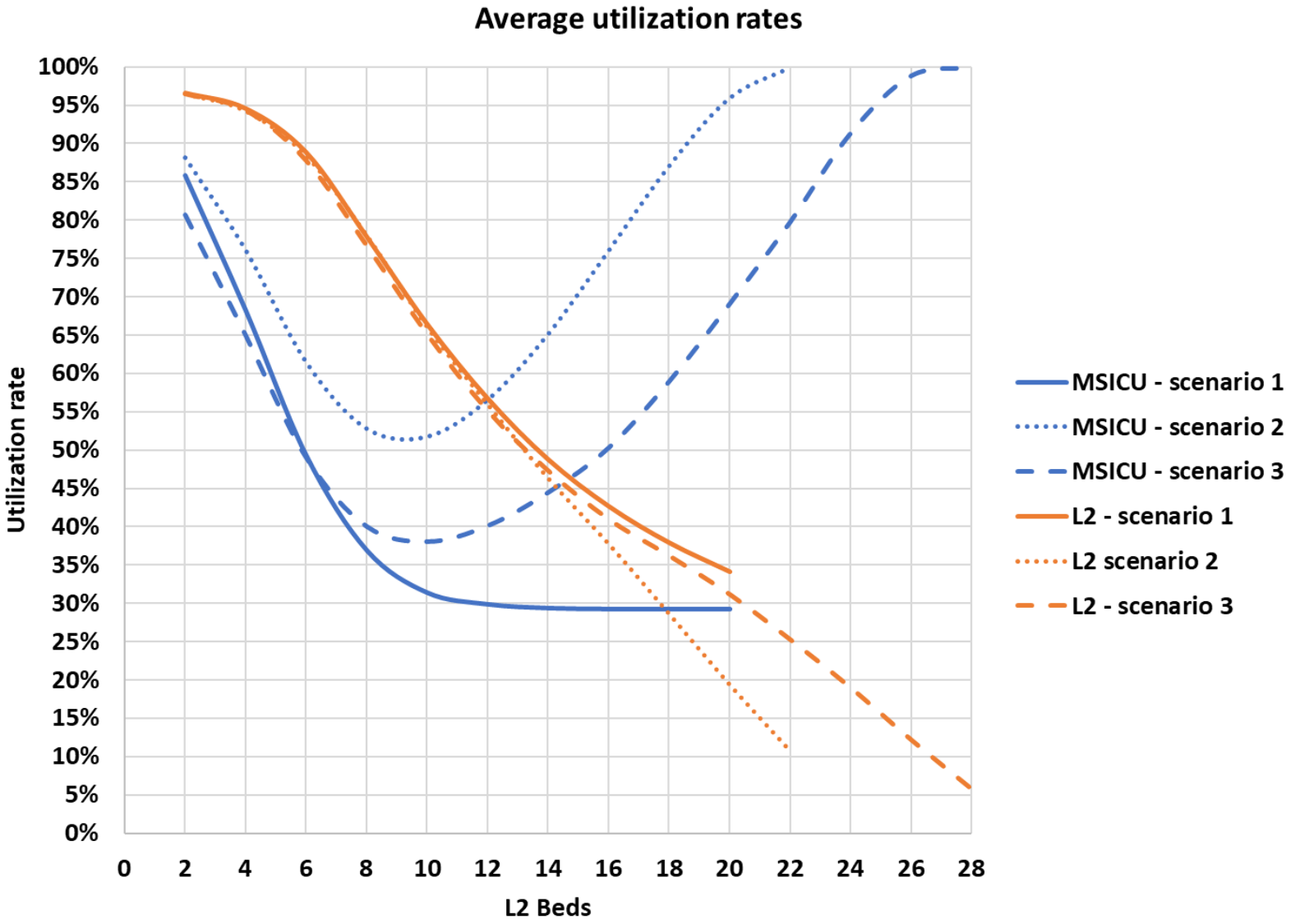
SCENARIO ANALYSIS

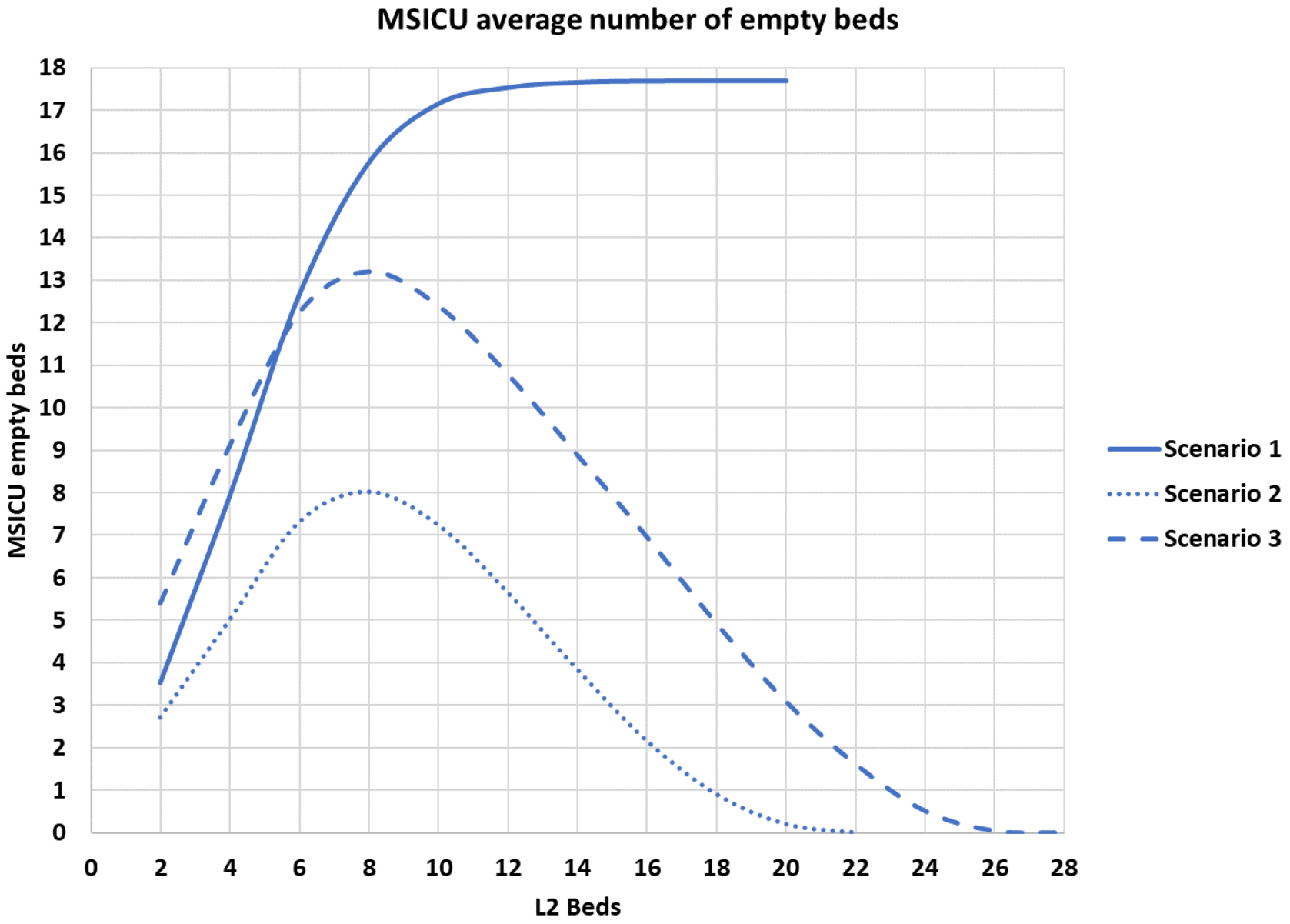
Off-service impact

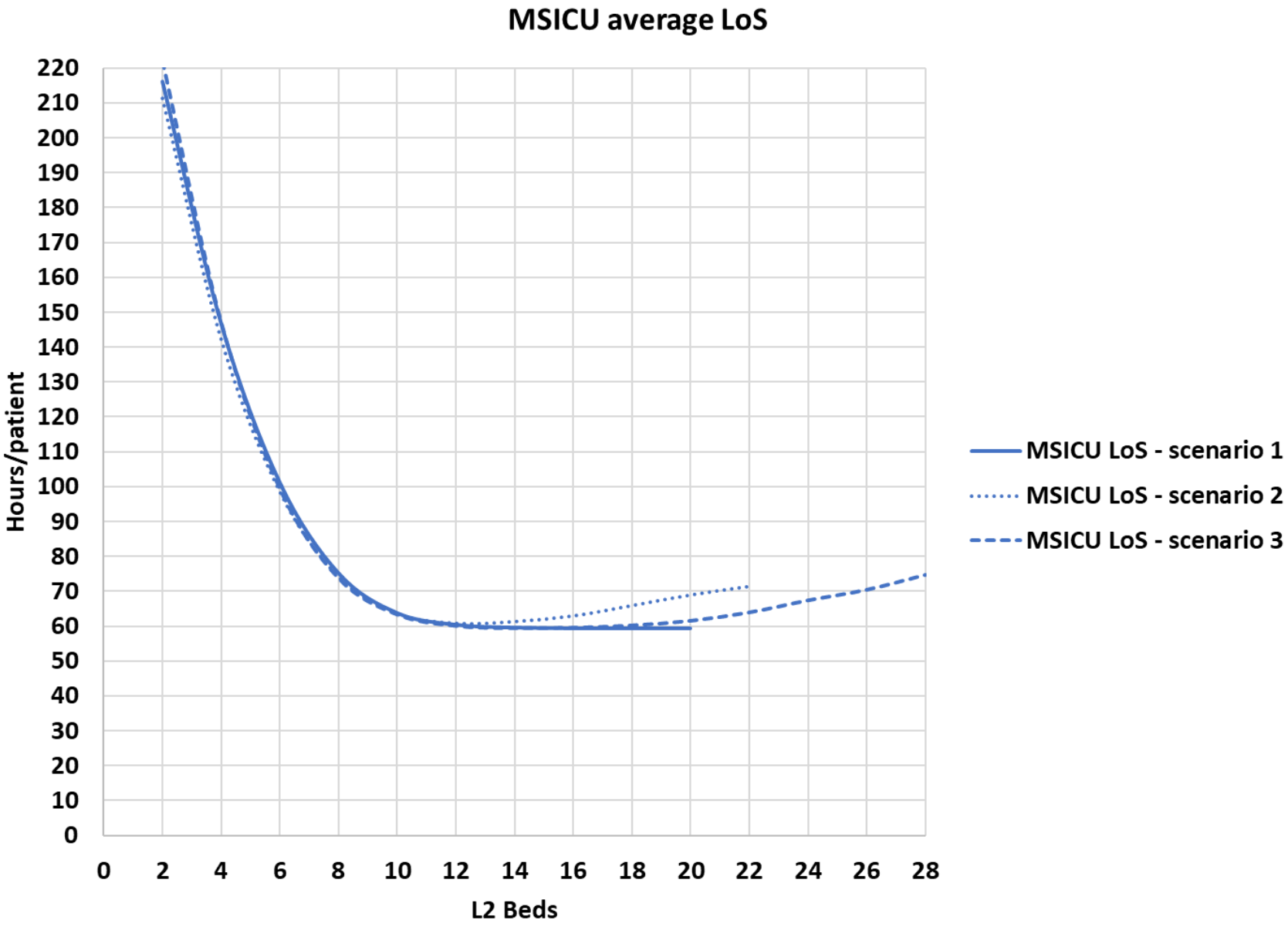
Unit	Baseline	Scenario 1 (new capacity)	Scenario 2 (reallocation)	Scenario 3 (new + reallocation)
Existing L3 units (CSRU and MSICU)	~620	~110	~150	~140
Existing L2 units (MOTP, CCU, NOBS)	~570	~220	~200	~210

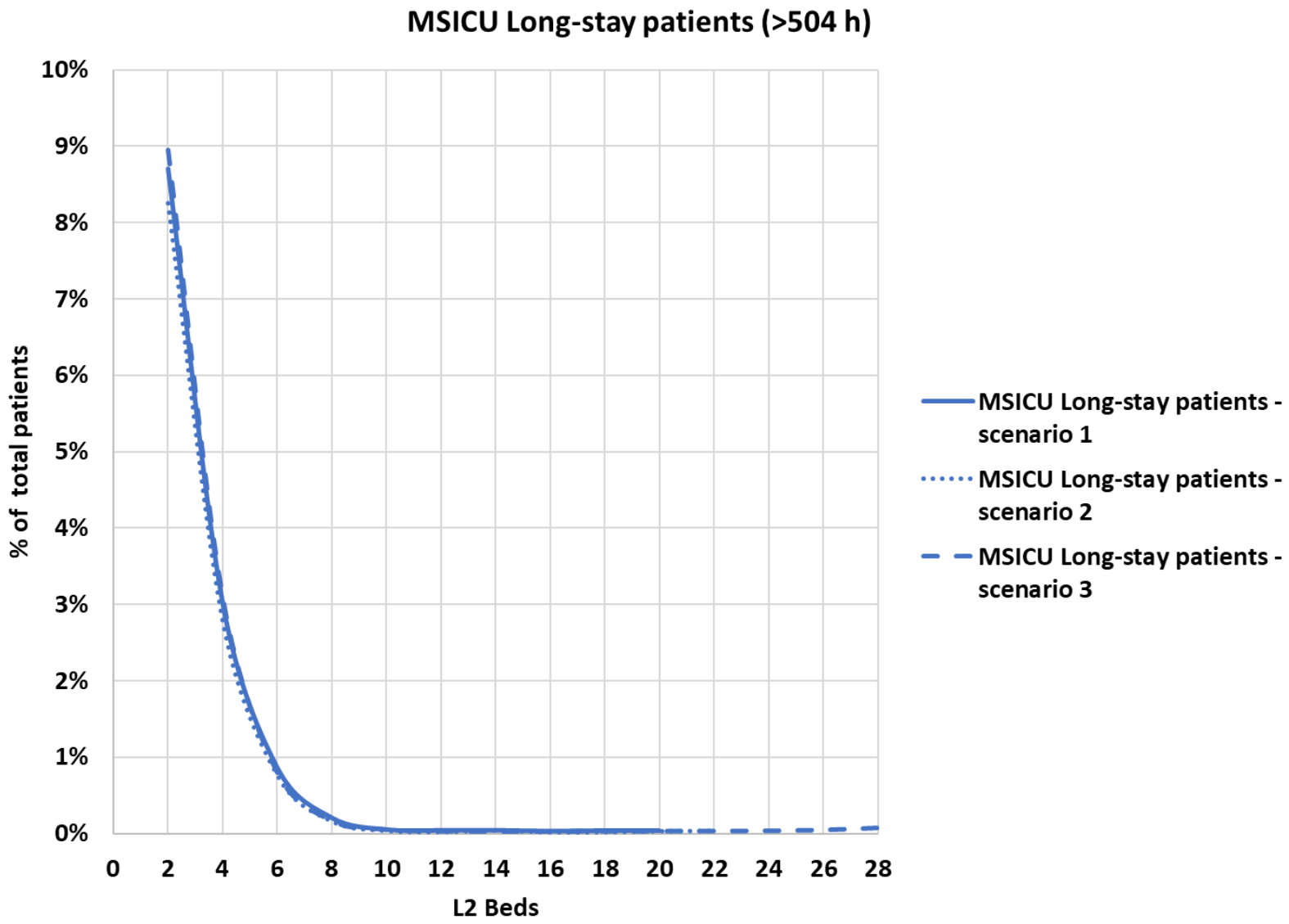
*(patients/year)

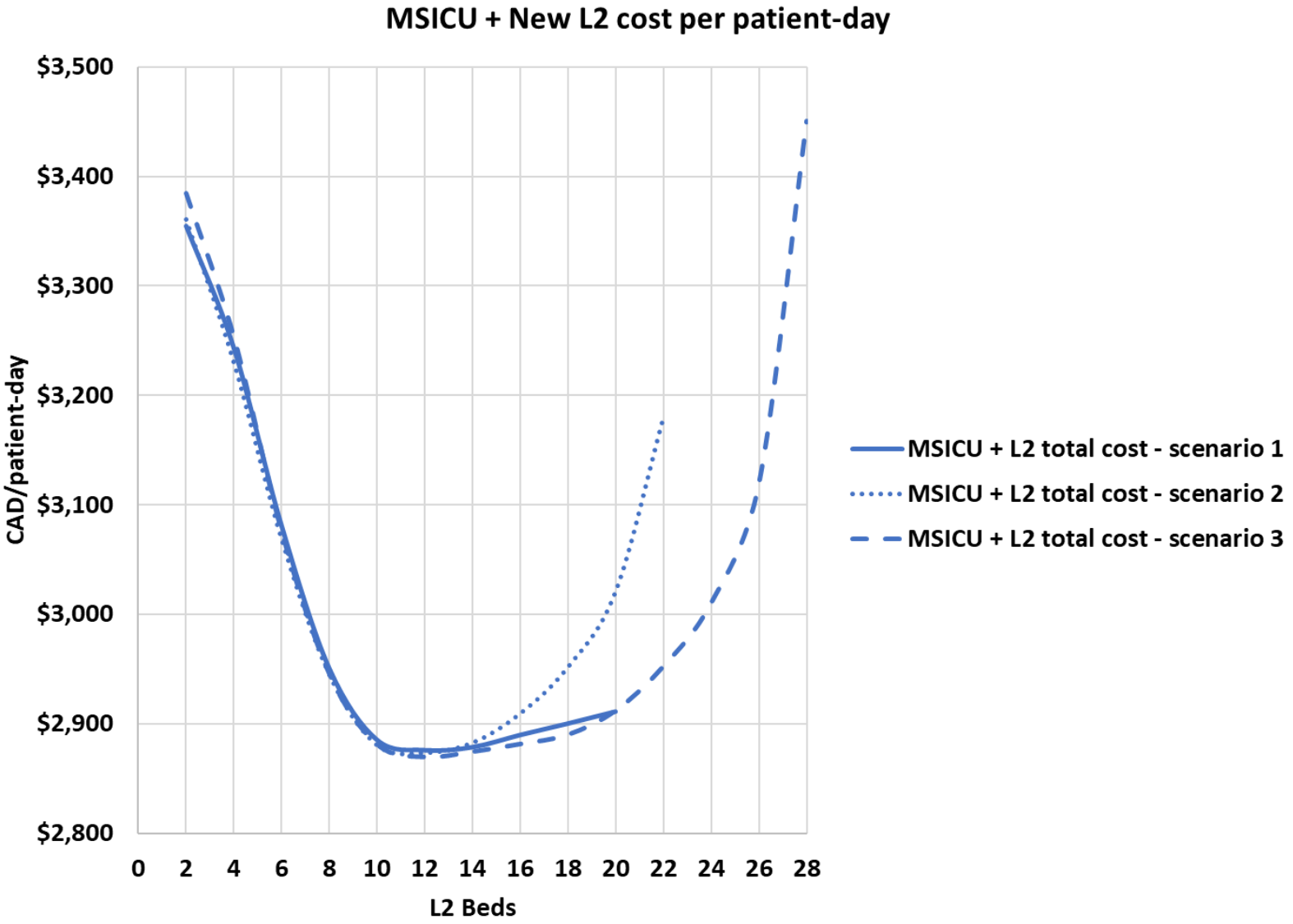

Throughput
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
-
patients/year
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
MSICU throughput - scenario 1
MSICU throughput - scenario 2
MSICU throughput - scenario 3
L2 throughput - scenario 1
L2 throughput - scenario 2
L2 throughput - scenario 3


Average utilization rates
Utilization rate
100%
95%
90%
85%
80%
75%
70%
65%
60%
55%
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
MSICU - scenario 1
MSICU - scenario 2
MSICU - scenario 3
L2 - scenario 1
L2 scenario 2
L2 - scenario 3


MSICU average number of empty beds
MSICU empty beds
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
Scenario 1
Scenario 2
Scenario 3


MSICU average LoS
Hours/patient
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
MSICU LoS - scenario 1
MSICU LoS - scenario 2
MSICU LoS - scenario 3


MSICU Long-stay patients (>504 h)
10%
9%
8%
7%
6%
5%
4%
3%
2%
1%
0%
% of total patients
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
MSICU Long-stay patients - scenario 1
MSICU Long-stay patients - scenario 2
MSICU Long-stay patients - scenario 3

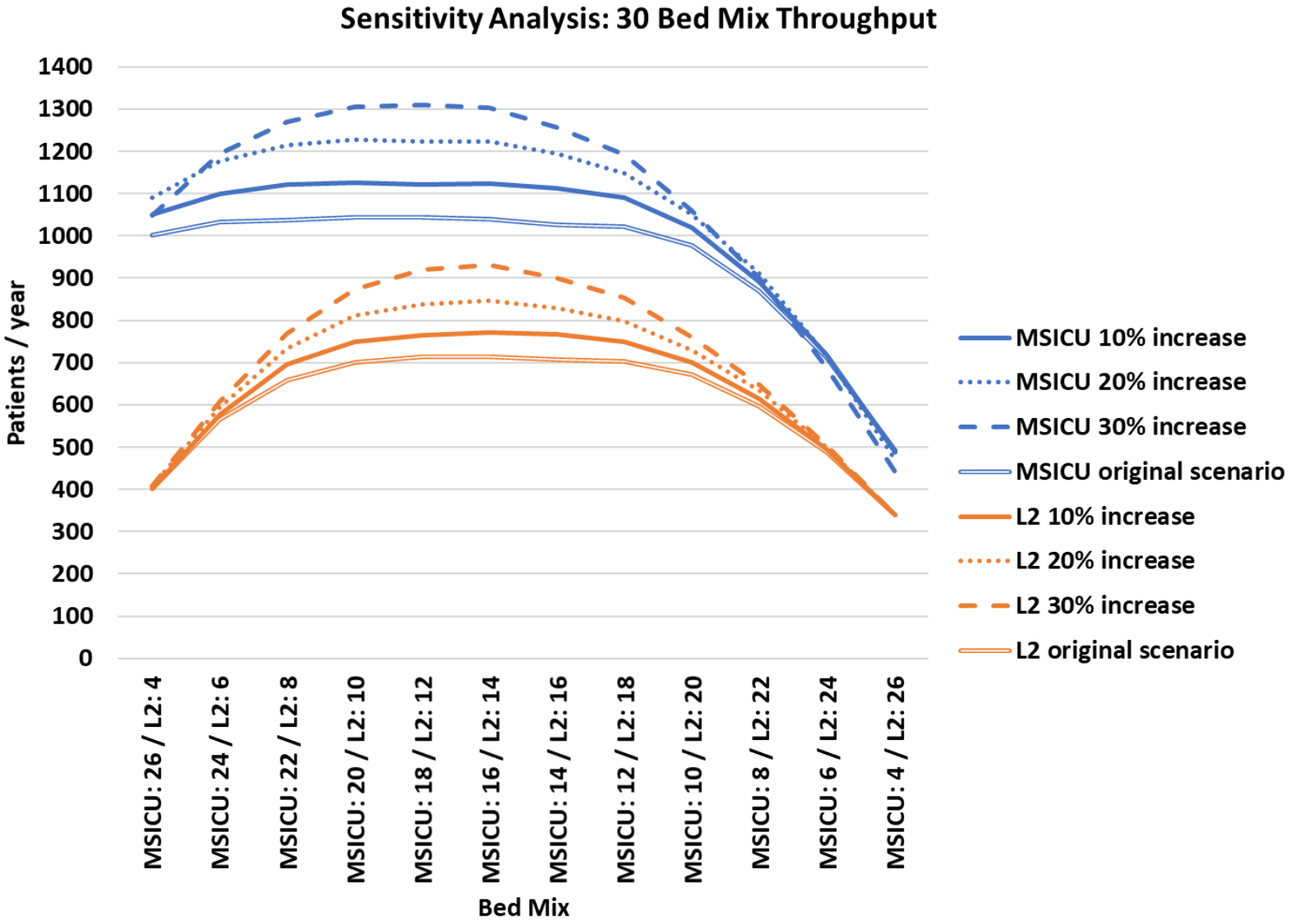

MSICU + New L2 cost per patient-day
$3,500
$3,400
$3,300
$3,200
$3,100
$3,000
$2,900
$2,800
CAD/patient-day
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
L2 Beds
MSICU + L2 total cost - scenario 1
MSICU + L2 total cost - scenario 2
MSICU + L2 total cost - scenario 3

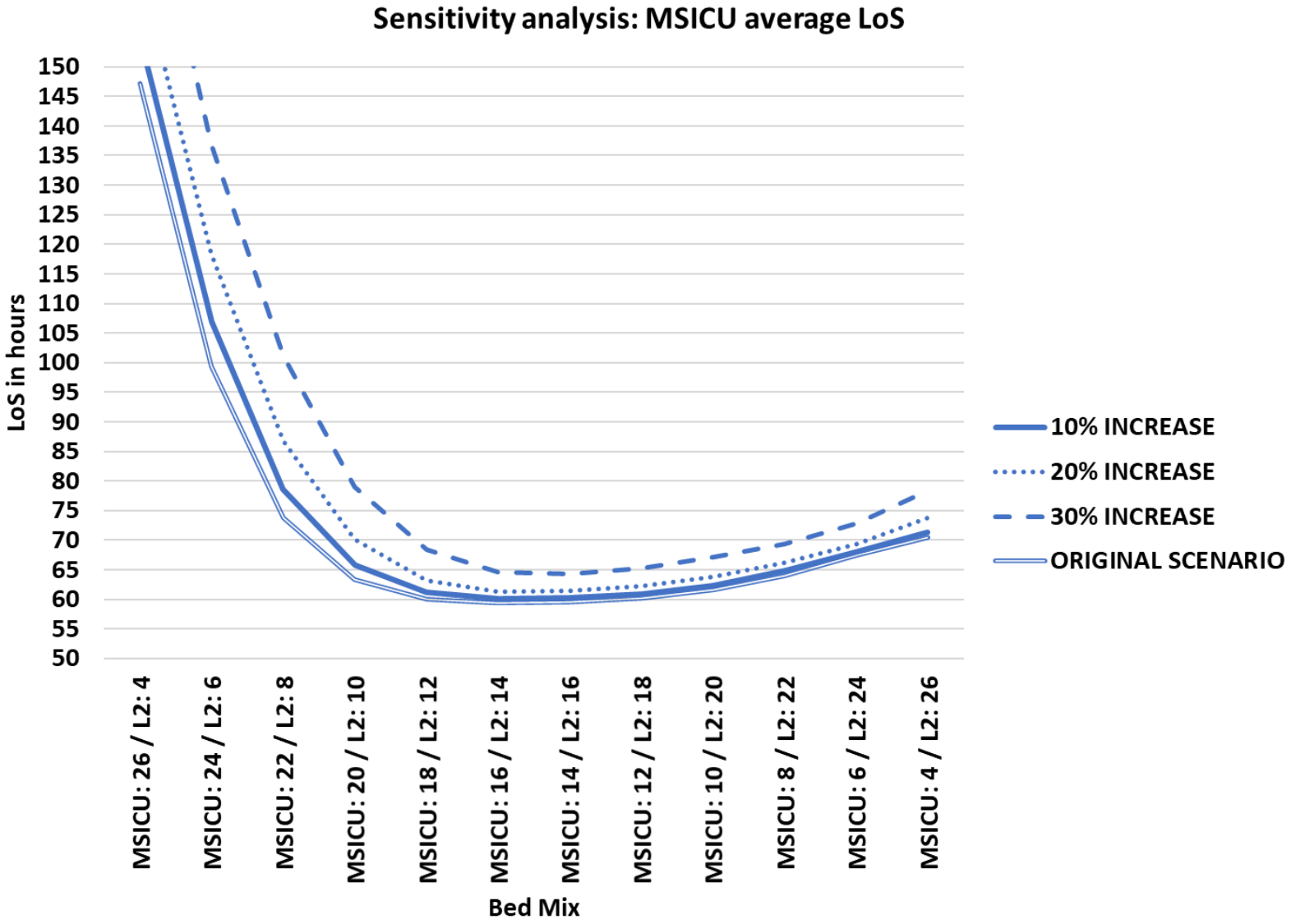
SENSITIVITY ANALYSIS

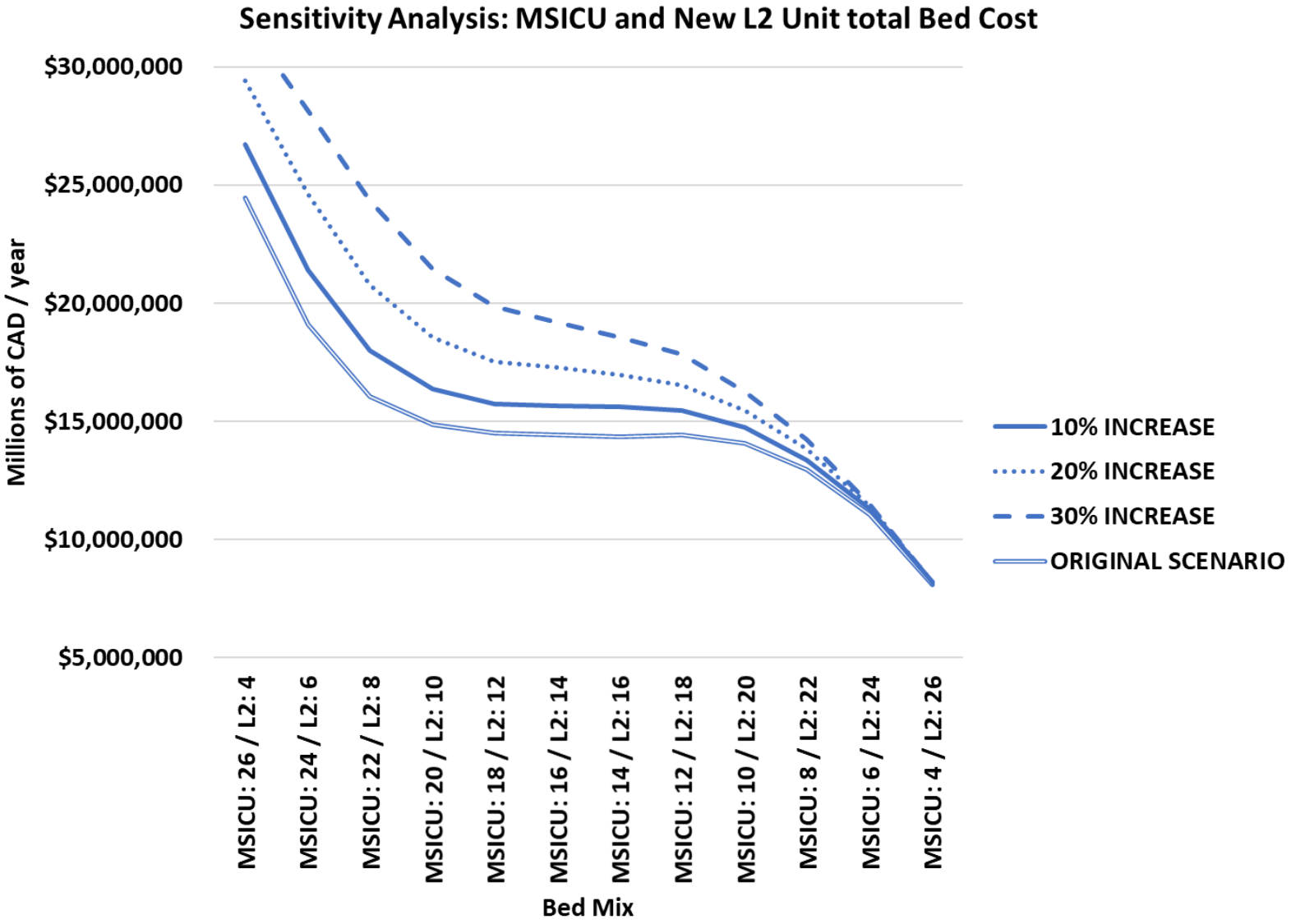
1st Scenario (@ 12 L2 Beds)

Scenario	Wait for Disposition wait (h)	std (h)	≤5 min	ED Decant LOS (h)	std (LoS)	≤1 hour
Baseline	0.12	4.99	99%	1.27	7.95	90%
25 MSICU and 12 *L2*	0.22	2.57	98%	2.07	6.33	84%
5% increase	0.3	2.57	97%	2.08	6.35	82%
10% increase	1.13	6.34	94%	3.01	7.56	75%
20% increase	2.09	7.88	87%	3.22	7.36	69%
30% increase	26.67	50.1	55%	5.26	8.96	52%

Scenario	Queue for WC OR wait (h)	std (h)	≤1 hour	Total LOS LOS	std (h)
Baseline	0.43	1.26	87%	164.93	212.83
25 MSICU and 12 *L2*	0.35	1.03	93%	162.69	196.77
5% increase	0.35	1.03	88%	163.69	194.67
10% increase	0.75	1.69	79%	164.83	194.2
20% increase	1.01	1.98	74%	165.2	194.3
30% increase	1.28	2.24	69%	173.25	189.65


Sensitivity Analysis: 30 Bed Mix Throughput
Patients / year
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
MSICU: 26 / L2: 4
MSICU: 24 / L2: 6
MSICU: 22 / L2: 8
MSICU: 20 / L2: 10
MSICU: 18 / L2: 12
MSICU: 16 / L2: 14
MSICU: 14 / L2: 16
MSICU: 12 / L2: 18
MSICU: 10 / L2: 20
MSICU: 8 / L2: 22
MSICU: 6 / L2: 24
MSICU: 4 / L2: 26
Bed Mix
MSICU 10% increase
MSICU 20% increase
MSICU 30% increase
MSICU original scenario
L2 10% increase
L2 20% increase
L2 30% increase
L2 original scenario


Sensitivity analysis: MSICU average LoS
LoS in hours
150
145
140
135
130
125
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
MSICU: 26 / L2: 4
MSICU: 24 / L2: 6
MSICU: 22 / L2: 8
MSICU: 20 / L2: 10
MSICU: 18 / L2: 12
MSICU: 16 / L2: 14
MSICU: 14 / L2: 16
MSICU: 12 / L2: 18
MSICU: 10 / L2: 20
MSICU: 8 / L2: 22
MSICU: 6 / L2: 24
MSICU: 4 / L2: 26
Bed Mix
10% INCREASE
20% INCREASE
30% INCREASE
ORIGINAL SCENARIO


Sensitivity Analysis: MSICU and New L2 Unit total Bed Cost
$30,000,000
$25,000,000
$20,000,000
$15,000,000
$10,000,000
$5,000,000
Millions of CAD / year
MSICU: 26 / L2: 4
MSICU: 24 / L2: 6
MSICU: 22 / L2: 8
MSICU: 20 / L2: 10
MSICU: 18 / L2: 12
MSICU: 16 / L2: 14
MSICU: 14 / L2: 16
MSICU: 12 / L2: 18
MSICU: 10 / L2: 20
MSICU: 8 / L2: 22
MSICU: 6 / L2: 24
MSICU: 4 / L2: 26
Bed Mix
10% INCREASE
20% INCREASE
30% INCREASE
ORIGINAL SCENARIO

Summary

Indicator	Baseline	Scenario 1	Scenario 2	Scenario 3
MSICU capacity (beds)	25	25	13	18
L2 Capacity (beds)	0	12	12	12
Total Capacity (beds)	25	37	25	30
Mean (beds)	19.1	14.4	14.32	14.29
Median (beds)	19	14	14	14
Mode (beds)	19	14	13	15
Max (beds)	25	29	24	27
Std. dev (beds)	3.28	4.02	3.32	4.33
Average utilization	76.40%	38.92%	57.28%	47.63%
Max utilization	100%	78.38%	96.00%	90.00%
Cumulative frequency below 75%	21	≈17	≈16	≈17
Cumulative frequency below 95%	25	≈25	≈20	≈21
LOS in MSICU (h)	164.24	60.37	60.66	60.06
Cost CAD $/patient-day	$3,477.44	$2,876.21	$2,873.83	$2,869.46
Total Cost MSICU+L2 CAD $/year	$24,019,830.00	$14,909,503.75	$14,760,363.22	$14,503,103.34

CONCLUSIONS AND EXTENSIONS

Conclusions

- L2 beds has positive impact in MSICU patient flow
  - reduces occupancy, Length-of-stays, off-service and Costs
- Added capacity: diminishing benefits
- Converting MSICU beds into L2 beds:
  - Can have a positive impact under certain conditions
  - Best combination was added capacity with reallocation
- NEMS scores provide a useful step-down rule in estimating L2 needs

Next steps

- New simulations:
  - Victoria Hospital
  - Dedicated long-stay beds
- MSICU LoS Forecasting model incorporating:
  - NEMS measurements
- Analytical model incorporating:
  - Bounce-backs
  - off-service
  - NEMS measurements

Picture: Piotrek Angiel
Mount Assiniboine, AB 2015