Using Data Collected from a Commercial Sensor System to Inform Mathematical Models of Healthcare Associated Infections

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Abstract

Background: Hospital acquired infections are commonly spread through the movement of healthcare professionals (HCP). Computational simulations provide a powerful tool for understanding how HCP behavior contributes to these infections, but how well they reflect the real world rests on a number of critical parameters. Our goal is to provide accurate, fine-grained estimates of real HCP movement and interaction parameters suitable for simulating the potential spread of pathogens over different types of inpatient facilities.

Methods: We have obtained a 44 million element de-identified commercial dataset compiled from over 27,000 HCPs assorted into 30+ job types and collected over 27 months from over 20 facilities of varying size using a proprietary electronic sensor system. Each observation records an HCP visiting one of 12,000 rooms (38% being patient rooms), and consists of the entry and exit timestamps, hand hygiene behavior, and, for many rooms, their (x,y) geometric coordinates within the facility. From these data, we can reconstruct the behavior – including their location and hand-hygiene adherence – of each instrumented HCP across multiple shifts.

Results: Distributions describing various aspects of HCP behavior (e.g., arrival rates and dwell times) have been derived by HCP job function, department or unit assignment, type of shift (day vs night), time of day, size and staffing of facility. In a similar fashion, we have constructed HCP cross table transition probabilities by job type, room type, department type, unit type and facility type. These distributions can be used to generate reasonable HCP movement and behavior patterns in a simulation environment. Distributions of dwell time are for the most part heavy tailed, but vary by type of job and facility: dwell times over all facilities, job types and room types averaged about 339 seconds (std dev 495 seconds), with a mean of maximums by job type of around 37,168 seconds. However, these distributions differ within job type but across facilities (nurses in one facility averaged 397 seconds, but 277 seconds in another) and within facility but across job type (physicians averaged 292 seconds, while nurses averaged 397 seconds and physical therapists averaged 861 seconds).

Conclusion: Our results provide a unique resource for disease modelers who wish to build meaningful simulations of the transmission of hospital acquired infections. The scale and diversity of the data give us the unique capability to provide, with confidence, distinct parameter sets for different types and sizes of healthcare facilities across a wide range of situations.

Introduction

The premise of the MInD program is that mathematical models and computational simulation studies can promote understanding of disease diffusion, help predict outbreaks and their evolution, and explore the effectiveness of various interventions. The key to success is access to useful model parameters that accurately reflect the context under study. Parameters are hard to derive from first principles, so instead, modelers resort to estimating parameters from observational data. But these estimates are hard to obtain, especially as the granularity of the model under construction increases; finer-grained models require a greater number of parameters, which are concomitantly harder to estimate because of the added complexity of data collection at the fine-scale. Moreover, these parameters tend to vary more by context, such as the type of facility or mix of patients.

Data

In 2018, we were approached by a commercial hand-hygiene sensor company with an interest in licensing some of our group's technology. Because of the complexity of commercial arrangements, we agreed instead to license the technology not for money, but in exchange for 27 months of de-identified data from their proprietary electronic sensor system:

- 44,144,156 observations of 27,467 healthcare workers
- 36 facilities, 498 units, 1,069 departments and 5,628 rooms
- 293 job designations, remapped to 32 job types

Table 1: Summary statistics of the data over facilities

	mean	std	min	25%	median	75%	max
Observations	1,261,262	1,570,202	29	159,085	642,239	1,660,480	5,835,636
HCPs	789	711	1	260	652	1,053	2,562
Departments	27	22	1	9	20	40	104
Units	15	10	1	7	13	24	45
Rooms	202	134	1	90	222	273	489
Days	436	318	4	119	496	684	926

Results

Figure 1: Radar chart of facilities over six components (number of floors, units, departments, employees, jobs, and patient rooms). Facilities with large area can be viewed as 'large' hospitals.

F = Floors
U = Units
D = Departments
E = Employees
J = Jobs
P = Patient rooms

Temporal Distribution: Dwell times (duration of a visit to the patient room in seconds) and arrival rates (patient room visit count per day by a HCP) are computed over job types, shifts, and facilities.

Table 2: Dwell Time of HCPs in Patient Rooms

Job	Overall			Day Shift			Night Shift		
	median	mean	std	median	mean	std	median	mean	std
Nursing	216	338	447	215	336	439	217	341	459
Physical Therapy	272	437	473	273	437	459	203	457	1101
Respiratory Therapy	218	312	329	219	314	317	216	309	344
Social Work	205	356	498	205	342	425	222	679	1307
Occupational Therapy	357	578	617	358	576	600	203	908	1711
Physician	223	348	563	223	340	462	218	396	934
Nursing Assistant	198	333	586	196	326	561	201	343	624
Case Manager	190	318	525	190	311	478	195	389	844
Transporter	156	214	364	158	211	324	148	225	492
Housekeeping	251	384	444	250	380	428	253	399	506
Phlebotomist	268	335	351	271	348	373	267	326	333
Administration	157	291	601	158	283	534	151	322	808
Food Service	111	162	324	111	159	227	96	502	2359
Mid-level Provider	243	396	847	248	397	871	218	390	707
Speech Therapy	378	583	610	382	587	595	231	398	1139
Quality Staff	182	311	441	179	294	415	249	415	588
Clerical	168	292	571	164	275	504	176	321	670
Pharmacy	191	307	656	192	302	611	185	326	833
Spiritual Care/Chaplain	218	363	502	222	364	489	199	358	569
Laboratory Staff	264	322	347	273	340	460	258	309	231
Nursing Management	173	289	482	172	282	429	176	322	660
Dietitian	173	277	513	173	273	414	234	1396	5123
Mental Health	302	476	484	306	478	472	174	381	801
Paramedics	183	320	443	187	348	397	179	323	520
Nurse Educators	238	413	514	251	434	512	193	305	511
Surgical Tech	201	336	675	216	367	693	171	265	625
IT	166	285	389	165	279	365	168	296	438
Radiology Tech	222	435	620	289	680	846	202	233	149
Volunteer/Interpreter	187	353	484	187	353	476	140	350	906
Resident Physicians	182	311	405	211	321	420	191	325	523
Patient Representative	198	307	443	199	290	365	207	333	531
Facilities/Maintenance	213	346	526	218	361	529	200	309	516

Table 3: Arrival Rates of HCPs in Patient Rooms

Job	Overall			Day Shift			Night Shift		
	median	mean	std	median	mean	std	median	mean	std
Nursing	15	15	2	17	17	2	13	13	1
Physical Therapy	12	13	2	13	13	2	2	5	8
Respiratory Therapy	15	15	3	17	18	3	12	13	2
Social Work	5	6	2	5	6	3	1	3	4
Occupational Therapy	11	11	2	11	12	2	1	3	6
Physician	6	6	1	7	7	1	4	4	1
Nursing Assistant	17	18	2	20	20	3	14	14	2
Case Manager	7	7	3	6	7	3	5	7	8
Transporter	7	7	2	8	8	2	5	5	1
Housekeeping	11	11	1	12	13	2	6	7	1
Phlebotomist	8	8	3	7	8	3	9	9	4
Administration	6	6	2	6	6	2	5	5	2
Food Service	10	10	2	10	10	2	1	2	1
Mid-level Provider	9	9	2	10	10	2	6	5	2
Speech Therapy	8	8	2	8	8	2	4	6	5
Quality Staff	3	3	2	3	3	3	3	6	6
Clerical	11	10	3	11	11	4	10	10	3
Pharmacy	4	5	2	4	5	2	4	4	2
Spiritual Care/Chaplain	4	4	1	5	5	2	3	4	3
Laboratory Staff	8	8	2	7	8	2	8	9	2
Nursing Management	5	6	3	6	6	4	3	4	5
Dietitian	4	5	2	4	5	2	1	3	3
Mental Health	9	9	4	9	9	3	3	3	3
Paramedics	19	20	6	24	25	11	14	15	7
Nurse Educators	8	8	3	8	9	3	5	5	4
Surgical Tech	7	7	4	7	8	5	5	5	4
IT	2	3	4	2	4	4	5	6	4
Radiology Tech	6	7	3	5	6	3	8	8	3
Volunteer/Interpreter	5	6	3	5	6	3	4	5	2
Resident Physicians	8	8	2	9	9	3	6	7	3
Patient Representative	6	7	4	6	8	5	3	4	3
Facilities/Maintenance	7	7	1	8	8	2	6	6	1

Results (continued)

Table 4: Median Dwell Time of HCPs in Patient Rooms by Facility

Table 5: Median Arrival Rates of HCPs in Patient Rooms by Facility

Spatial Distribution: Inter-room travel distance is computed from consecutive patient room visits of HCPs. The scale of unit measurement for distance was different across facilities and was unknown to us. To deal with differences in distance scale by facility, we normalized distances by the median patient room sizes for each facility.

Table 6: Inter-Room Distance Traveled by HCPs

Job	Overall						
	mean	std	min	25%	median	75%	max
Nursing	3.5	3.5	0.3	1.4	2.5	4.3	79.0
Physical Therapy	8.5	8.5	0.3	2.3	5.3	11.8	67.5
Respiratory Therapy	5.0	4.5	0.3	1.9	3.8	6.8	73.6
Social Work	6.6	7.0	0.3	1.9	4.1	8.6	49.3
Occupational Therapy	8.4	8.7	0.3	2.2	5.1	11.5	64.7
Physician	6.6	7.5	0.3	1.9	4.1	8.4	80.3
Nursing Assistant	3.8	3.9	0.3	1.5	2.6	4.6	78.8
Case Manager	5.2	5.5	0.3	1.8	3.6	6.5	75.1
Transporter	14.6	10.4	0.3	5.4	13.5	21.6	70.4
Housekeeping	4.7	5.8	0.3	1.4	2.7	5.4	79.5
Phlebotomist	7.5	8.3	0.3	1.9	3.9	10.6	68.3
Administration	4.9	6.6	0.3	1.4	2.5	5.2	69.3
Food Service	6.5	7.1	0.3	1.9	3.8	8.4	64.1
Mid-level Provider	4.4	4.5	0.3	1.6	3.1	5.6	72.1
Speech Therapy	9.9	9.5	0.3	2.9	6.7	13.8	68.5
Quality Staff	6.1	7.1	0.3	1.9	3.6	7.6	50.2
Clerical	3.3	4.1	0.3	1.4	2.2	3.9	80.7
Pharmacy	8.1	8.6	0.3	2.2	4.7	11.8	66.0
Spiritual Care/Chaplain	7.6	7.7	0.3	1.8	4.7	11.0	42.0
Laboratory Staff	4.6	4.9	0.3	1.5	3.0	5.5	50.1
Nursing Management	8.3	8.5	0.3	2.4	5.0	11.6	63.4
Dietitian	6.0	6.1	0.3	1.9	4.8	8.5	48.2
Mental Health	2.0	2.4	0.3	1.0	1.7	2.3	45.2
Paramedics	5.2	6.0	0.3	1.5	3.0	6.2	47.5
Nurse Educators	5.5	5.6	0.3	1.5	3.6	8.1	46.1
Surgical Tech	9.3	8.8	0.4	2.5	4.2	7.2	12.8
IT	9.3	8.8	0.5	2.4	7.2	12.8	58.2
Radiology Tech	9.0	9.5	0.3	1.4	4.1	12.4	45.5
Volunteer/Interpreter	5.0	5.6	0.5	1.5	3.2	6.1	64.1
Resident Physicians	6.5	6.8	0.4	1.7	3.6	7.8	67.8
Patient Representative	2.7	3.2	0.4	1.0	2.0	3.7	38.6
Facilities/Maintenance	6.3	7.7	0.3	1.5	2.9	7.2	64.4

Table 7: Median Inter-Room Distance Traveled by HCPs by Facility

HCP Trajectory

Almost half (6024) of the 12081 locations in the data set include their spatial characteristics as polygons in the (x, y) coordinate plane. These polygons are used to compute distances between pairs of rooms in each facility, e.g. length of dotted arrows in Figure 2.
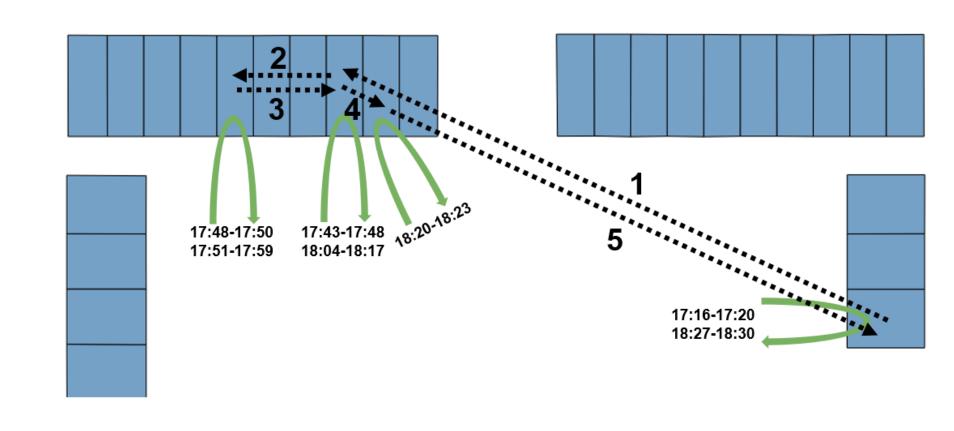

Figure 2: Trajectory of a Nurse. Solid arrows denote entry-exit event of the nurse and dotted arrows denote the trajectory of the nurse. HCPs show tendency to visit nearby rooms consecutively.

Discussion

The temporal distributions of HCPs are different among job types. The collection of 44 million entry-exit events of HCPs show that therapists (speech: 583s±610 or occupational: 578s±617) stay longer at patient rooms compared to nurses (338s±447) or physicians (348s±563). Dwell times of HCPs are generally longer during night shifts compared to day shifts. Mean dwell times are longer than median dwell times regardless of job types and shifts, which implies right-skewed distribution.

Arrival rates in individual-level show that paramedics visit patient rooms the most frequently (20±6 / day), followed by nursing assistants (18±2 / day), nurses (15±2 / day), and respiratory therapists (15±3 / day). In general, HCPs visit patient rooms more frequently during day shifts, except for phlebotomists, quality staff, laboratory staff, IT, and radiology tech.

The spatial distribution of HCPs also differs across job types. Inter-room distance travel by paramedic is the shortest (2.0±2.4), followed by patient representatives (2.7±3.2). Inter-room distance traveled by nurses (3.5±3.5) or nursing assistants (3.8±3.9) is relatively shorter than other job types because they tend to visit nearby rooms as they do patient rounds. Therapists (speech therapy: 9.9±9.5, physical therapy: 8.5±8.5) tend to walk longer distances compared to other jobs; perhaps their patients are not likely to be in proximity. As expected, transporters (14.6±10.4) travel much longer than other job types. Note that these values are not in standard measurement, e.g., inches, feet, nor yards, so it could only be used for comparing distance traveled across job types.

Conclusion

From the 44 million de-identified visits from over 27,000 HCPs across 37 facilities, we computed temporal and spatial distributions of HCPs across their job types. HCP behaviors (dwell time, arrival rates, and distance traveled) vary across different job types within the same facility and differ within the same job type across facilities. Our results provide parameters for modeling communities to build simulations from these HCP behaviors.

Limitations and Future Studies

The dataset contains HCP visits only, which lacks patient information, which is crucial for building a disease simulator. However, we may estimate whether the patient was in the patient room or not by using arrival rates and dwell times of housekeepers. Consecutive short visits to a room or a long-duration visit of a housekeeper may denote a "deep-clean" event. We plan to look up for these cleaning events to use as a proxy for determining if a patient is at a room or not.

We have not discussed hand hygiene parameters, which is another critical element of disease modeling. Every entry-exit event of a HCP to a room has an identifier of hand hygiene. We plan to utilize these indicators to compute hand hygiene compliance rates of HCPs across job types.

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