TEAM 15

Output Analysis

Hospital Infection Model

Contents

How does the distribution of resources affect a hospital given certain conditions?

Setting The Stage

For our output analysis, we analysed the data by individually toggling the value for **number of beds per ward** OR **number of healthcare workers** while keeping the other variables constant.

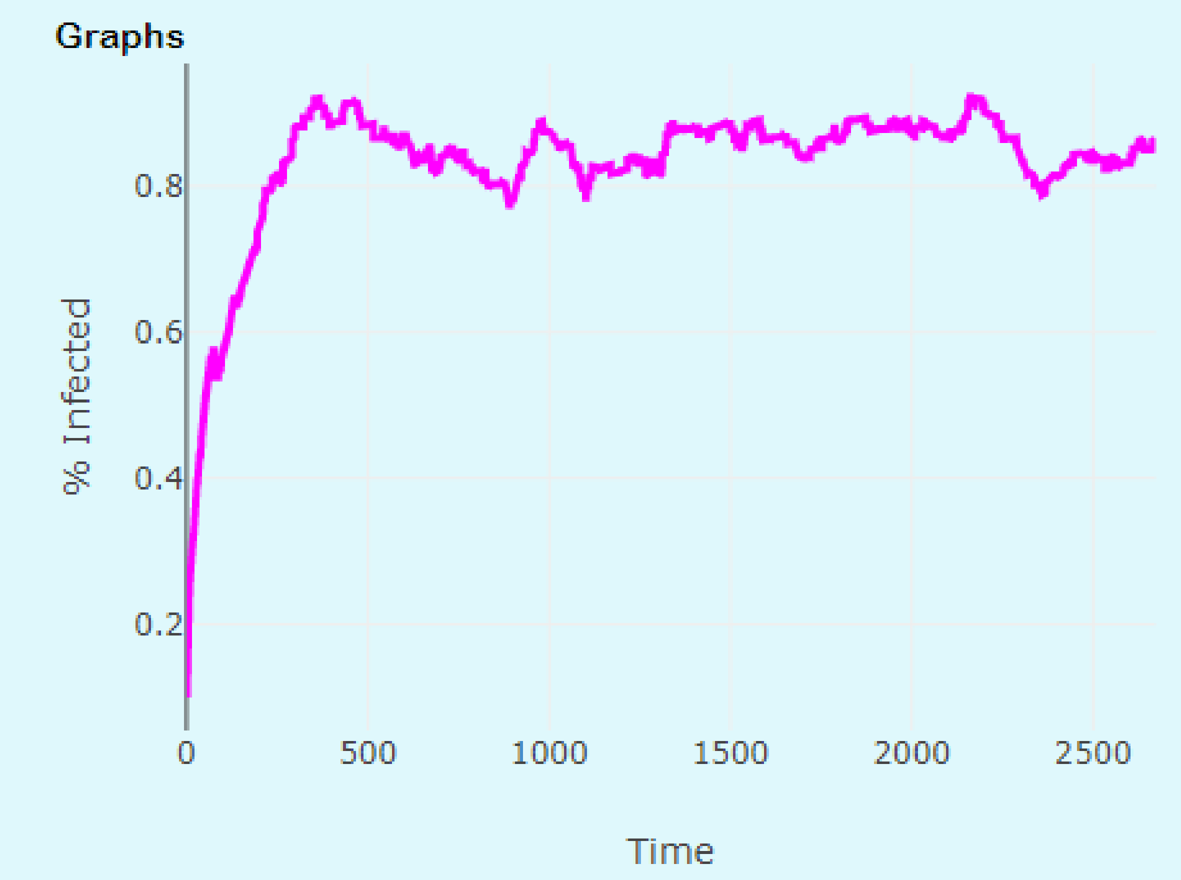
Measures of system performance that can be estimated using our simulation are:

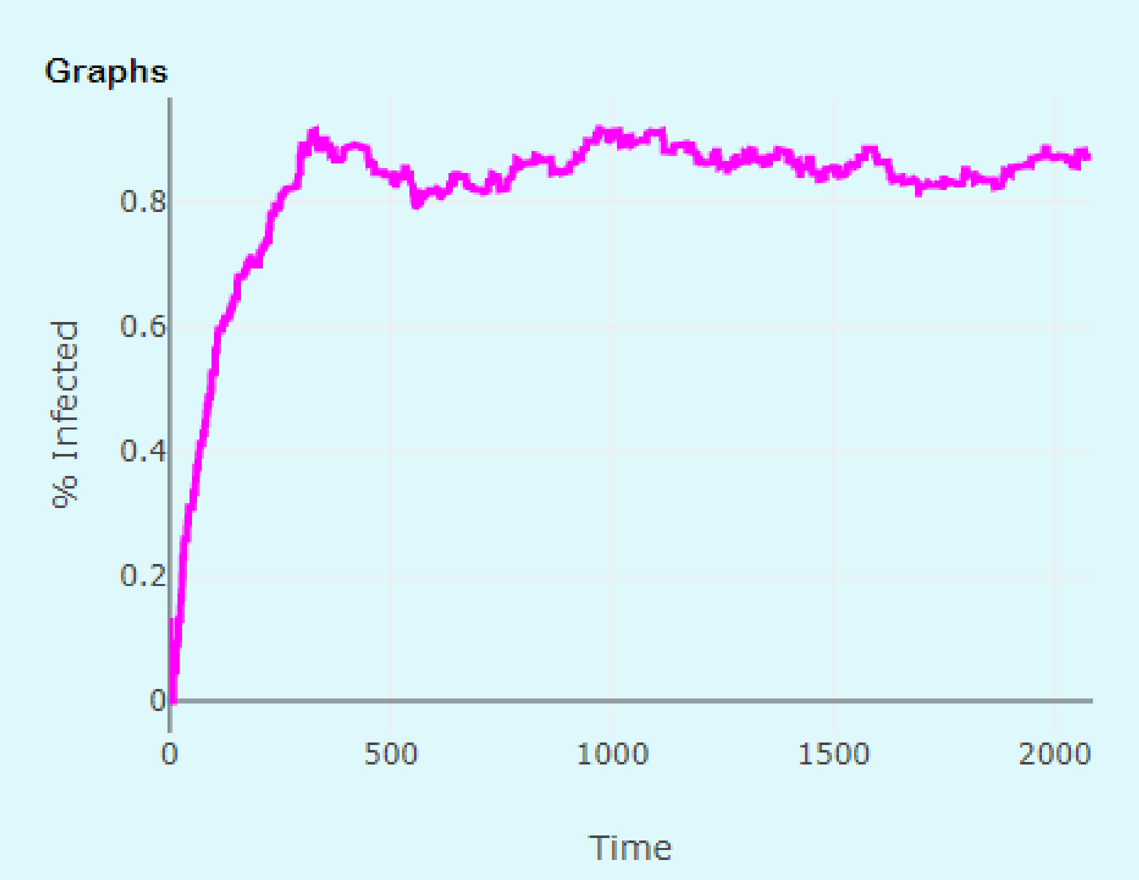
1. Promptness & availability of treatment for infected and warded patients
   - **Standards of measure:** % of turned away patients (refers to patients turned away from standard wards), cumulative number of patients turned away from standard wards, cumulative number of patients turned away from isolation wards, cumulative number of deaths.

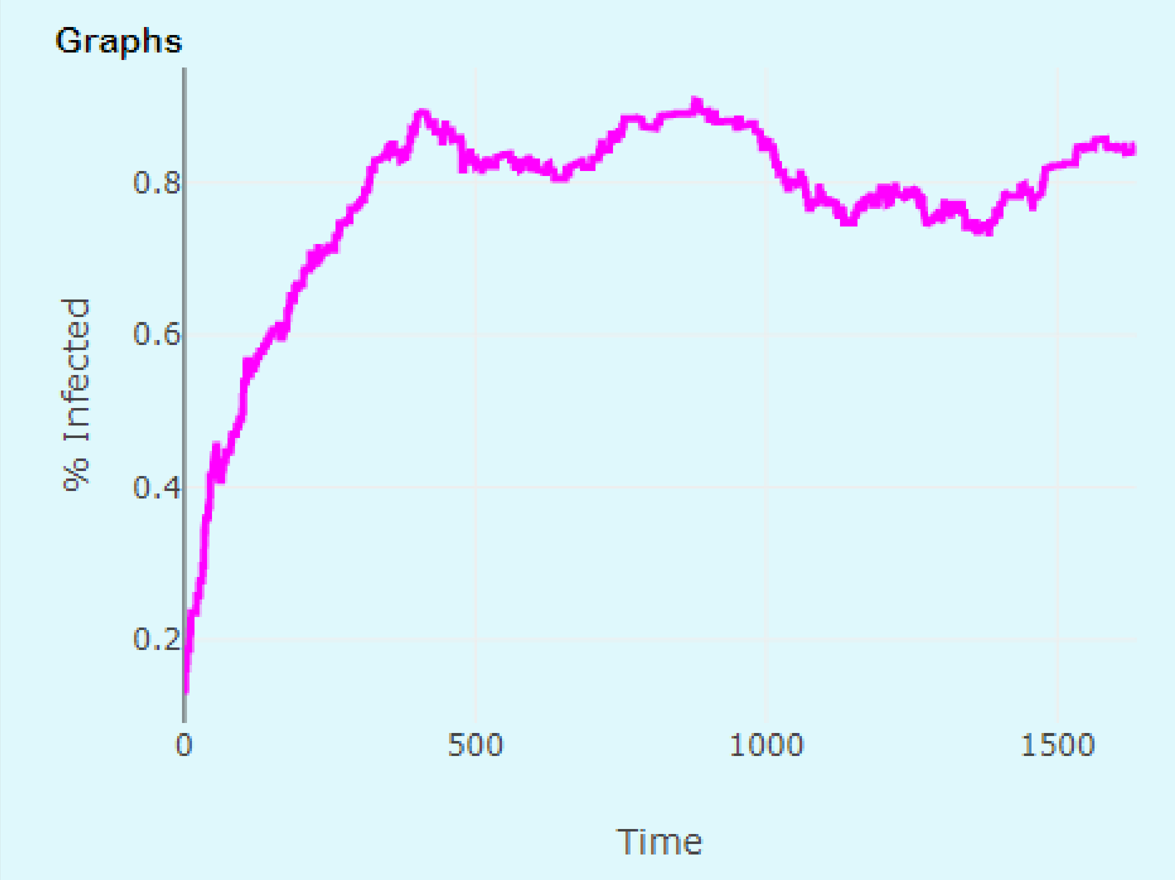
2. Spread of infection (infection can refer to any disease)
   - **Standard of measure:** % of infected (proportion of agents in the current population who are infected; tracked at each time step)

Data Analysis

Determining Burn-In Period and Simulation Length







At first, we ran multiple simulations using different values of number of beds and number of healthcare workers respectively to determine the burn-in period. We then took 0 - 499 as the burn-in period since the graph for each run stabilized at around the 500 mark. Finally, we decided to set the limit for each simulation run at approximately 4000 time units so as to make it least 5 times the burn-in period for ample data collection.

Collecting The Data

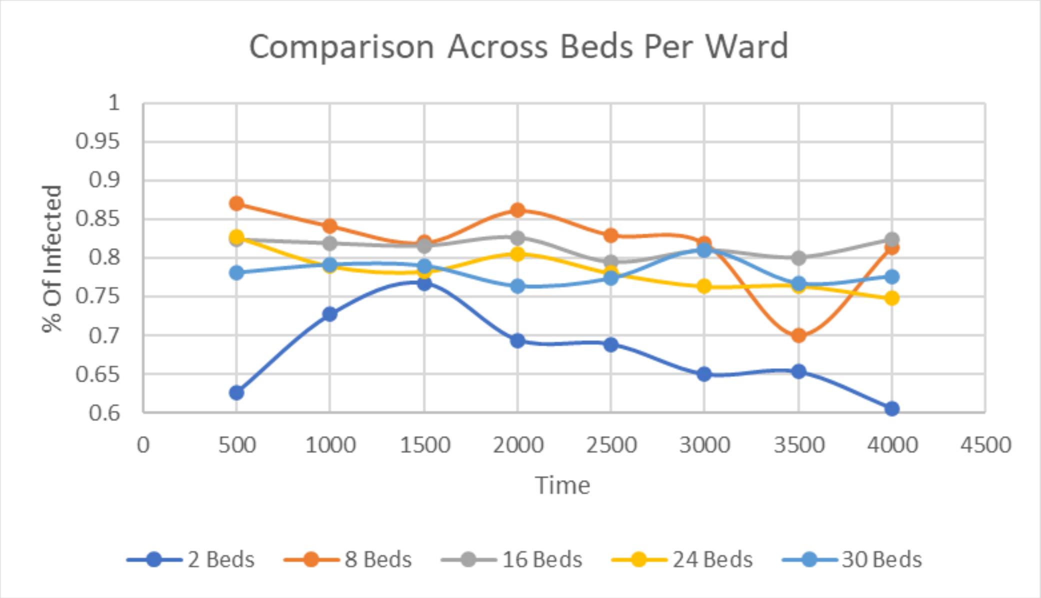
All other variables default	# of healthcare workers = 30	# of beds = 2									
Time Units	% of infected (Run 1)	% turned away (Run 1)	% of infected (Run 2)	% turned away (Run 2)	% of infected (Run 3)	% turned away (Run 3)	% of infected (Run 4)	% turned away (Run 4)	% of infected (Run 5)	% turned away (Run 5)	Avg % of infected	Avg % turned away
500	0.72	0.7228	0.5778	0.8349	0.5962	0.7283	0.6122	0.7303	0.6279	0.8041	0.62682	0.76408
1000	0.8305	0.7604	0.551	0.8605	0.8085	0.88221	0.7083	0.8191	0.7358	0.796	0.72682	0.823642
1500	0.8	0.8209	0.6596	0.8754	0.7347	0.8479	0.8	0.8721	0.84	0.8322	0.76686	0.8497
2000	0.6522	0.8654	0.68	0.8779	0.6818	0.8809	0.6667	0.8772	0.7885	0.8457	0.69384	0.86942
2500	0.6393	0.8755	0.6818	0.9002	0.6042	0.8838	0.7292	0.8938	0.7872	0.8672	0.68834	0.8841
3000	0.6047	0.8834	0.6739	0.9021	0.5349	0.8984	0.7234	0.9009	0.7115	0.8647	0.64968	0.8899
3500	0.4	0.8997	0.5652	0.9059	0.5869	0.8983	0.8298	0.9058	0.8824	0.8803	0.65286	0.898
4000	0.5111	0.8935	0.6604	0.9013	0.525	0.9066	0.7292	0.9105	0.6047	0.8951	0.60608	0.9014
Total acquired infections	155		157		152		161		156		156.2	
# of patients turned away from standard ward	724		771		756		743		754		749.6	
# of patients turned away from isolation ward	120		134		126		132		133		129	
# of deaths	14		7		10		7		9		9.4	

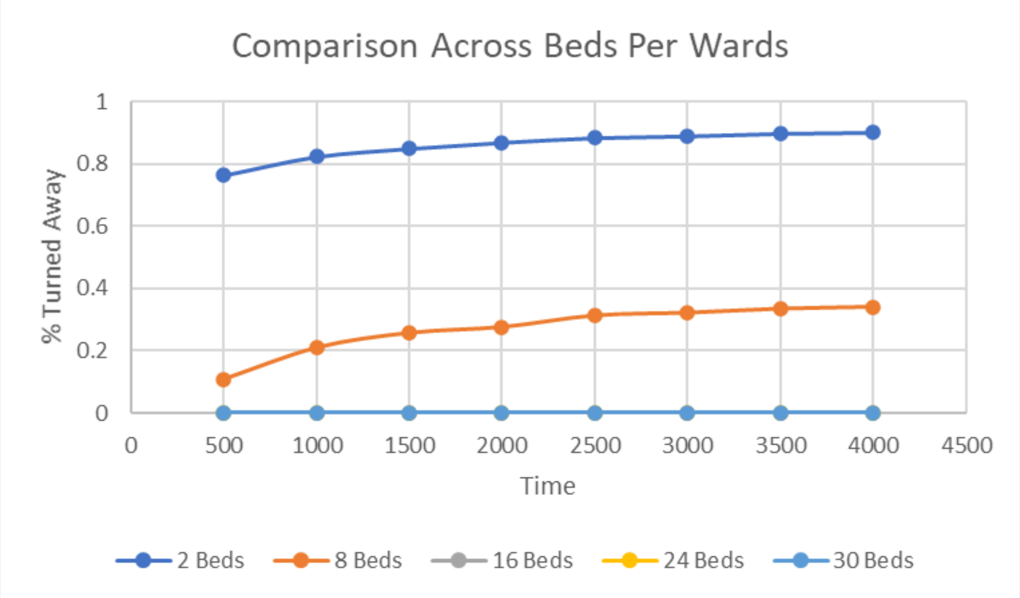
The picture above is an example of how we recorded and collected data for our analysis.

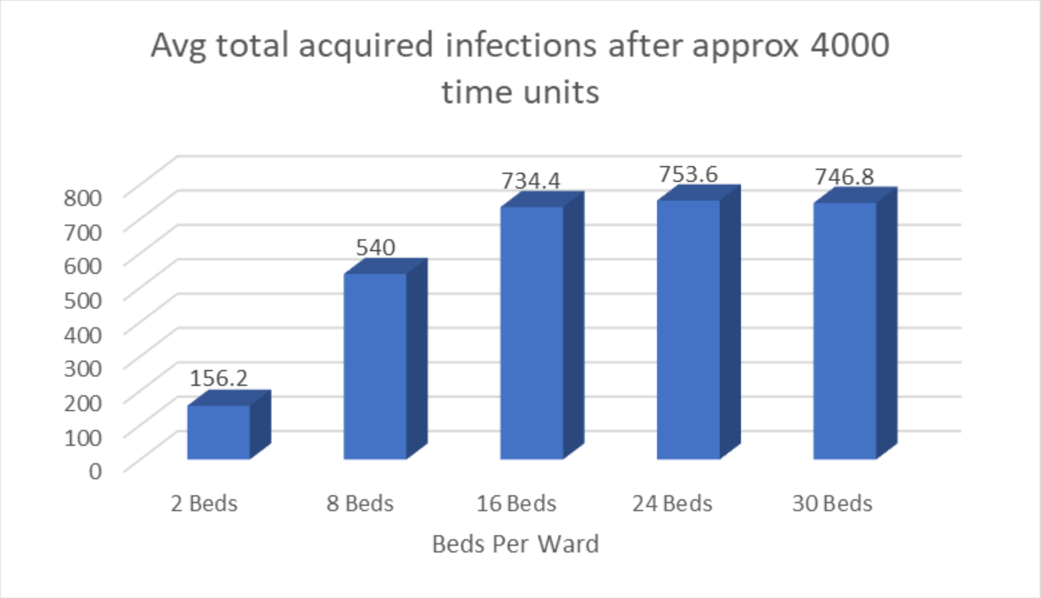
1. We set the number of beds per ward to 2 while keeping all other variables and values constant.
2. Five simulation runs were run with these set parameters, recording the data for % of infected and % turned away at every 500 time unit interval.
3. For each run, we also recorded cumulative data corresponding to the total acquired infections, number of patients turned away from standard ward, number of patients turned away from isolation ward, and number of deaths.
4. The last two columns on the far right calculate the average output in order to give us the expected output for the value setting. We used this expected output to compare across the different value settings.

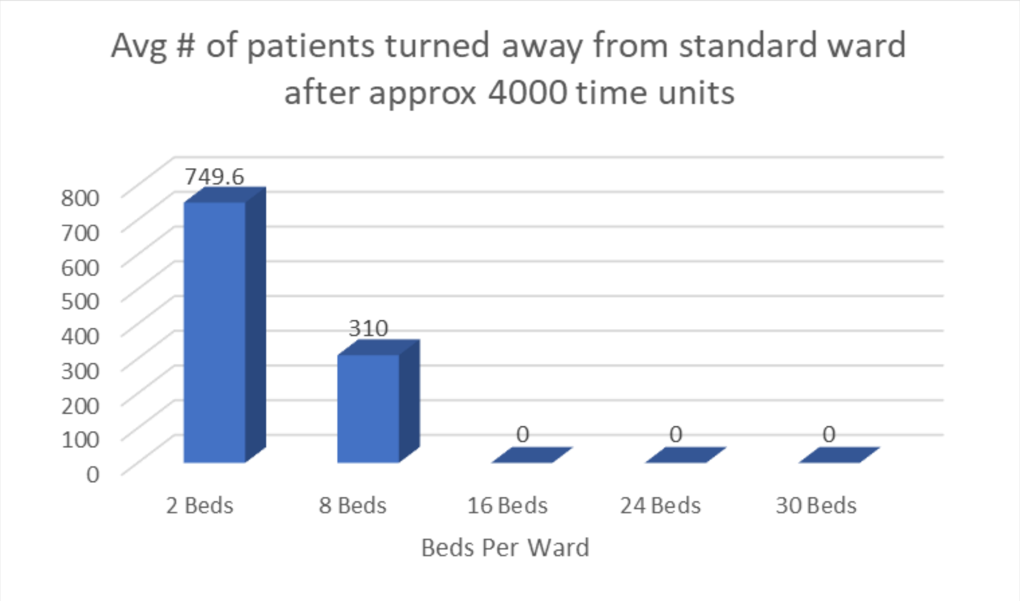
Changing **only one variable at a time** with the other variable set to default, we then repeated this process for number of beds = 8, 16, 24, 30 and number of healthcare workers = 10, 20, 30, 50, 100. The graphs generated will be in the following slide.

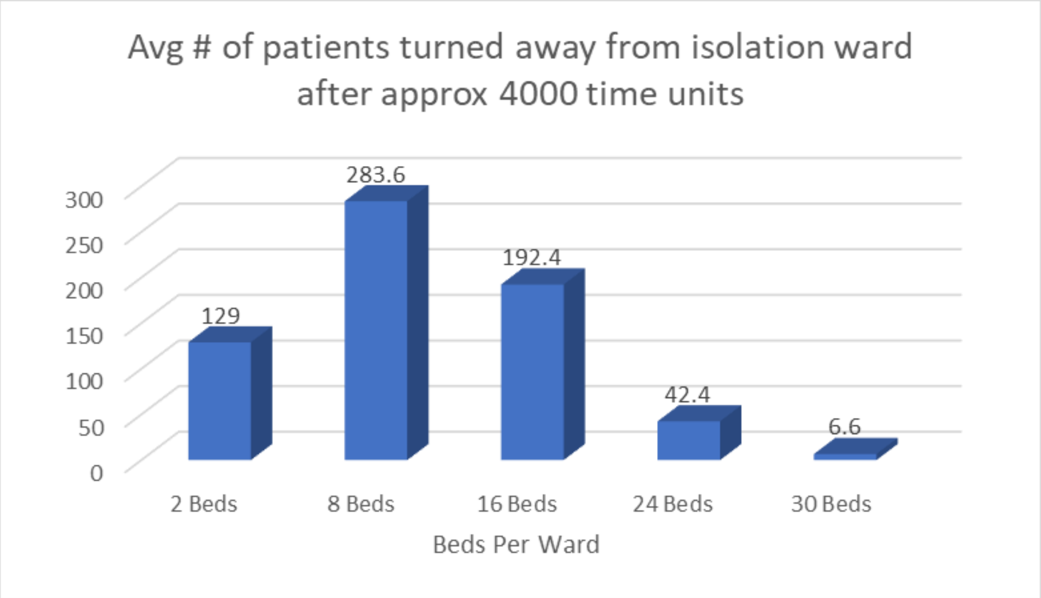
Number of Beds Per Ward

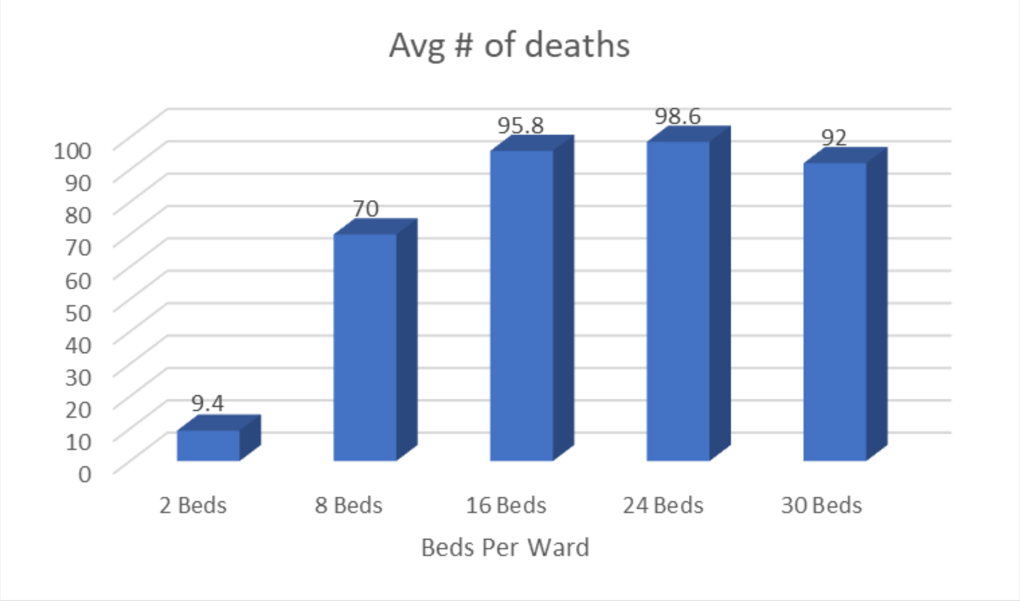








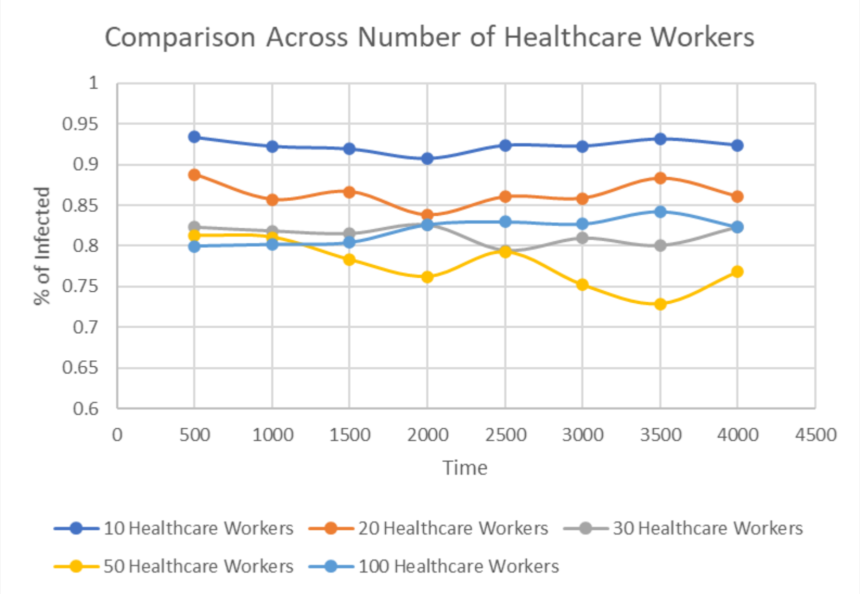


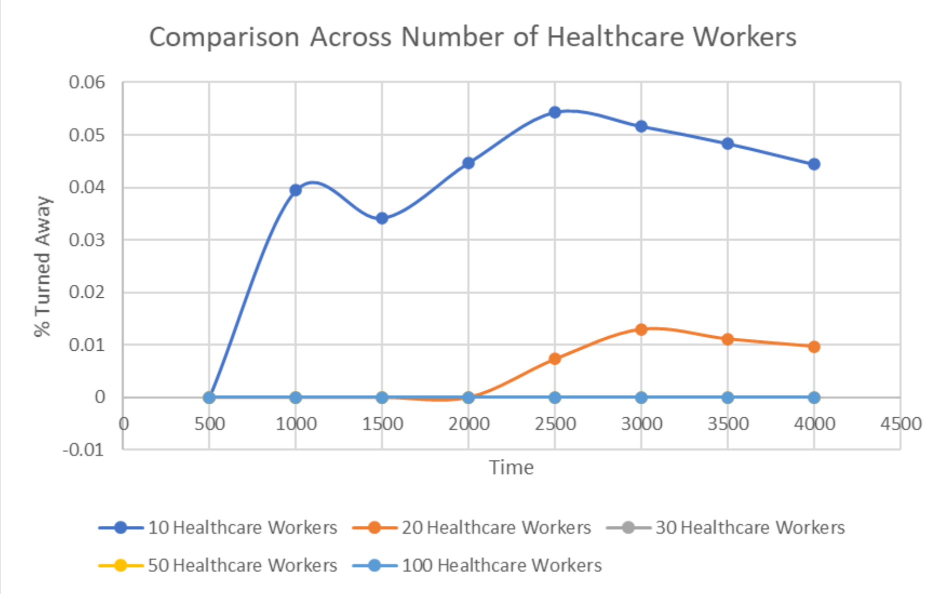


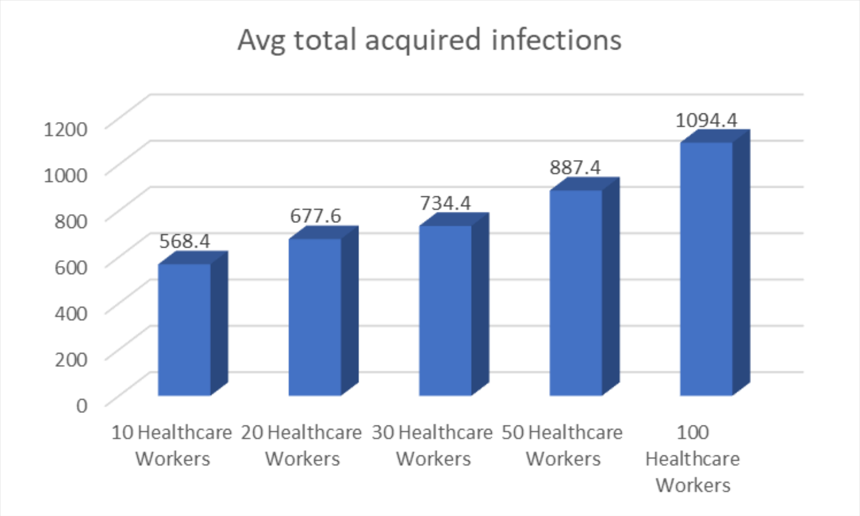
These graphs reflect the averaged values for each of the bed value settings, assuming all other variables are kept at default values. From the data, we can see that while having the minimum of 2 beds per ward has really good results on paper (lower % of infected, lower average total acquired infections, lower average number of patients turned away from isolation ward, and lower average number of deaths), this can be attributed to the fact that the very limited capacity leads to many prospective patients being turned away due to full occupancy, and as such there are less agents in the system for infection spread. Notice (from the graphs) that having 2 beds per ward has an extremely high average number of patients being turned away from the standard wards. This aligns with our reasoning that many patients are being turned away from even entering the system, even prospective infected patients.

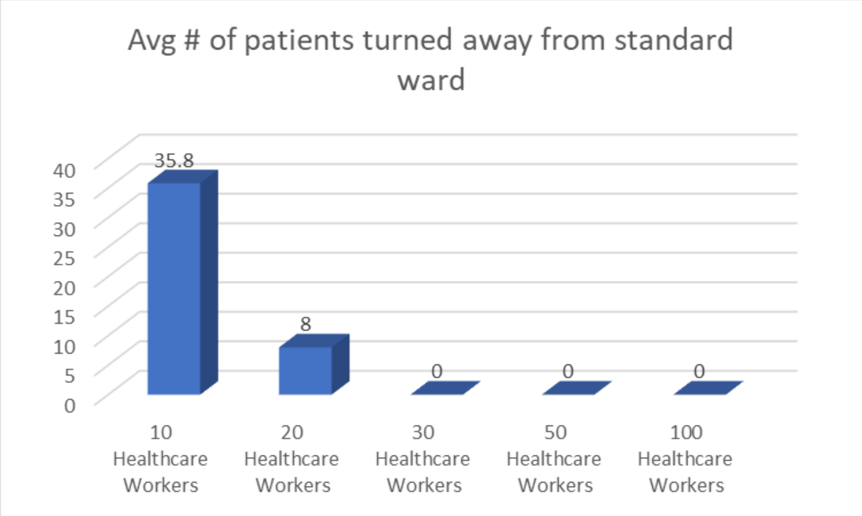
From the graphs, we can also see that there is little benefit to having more than 16 beds per ward since the difference in % of infected and number of deaths is very minimal and there is no difference at all regarding the number of patients being turned away from the standard ward. The only benefit to having more beds is having fewer people being turned away from the isolation ward.

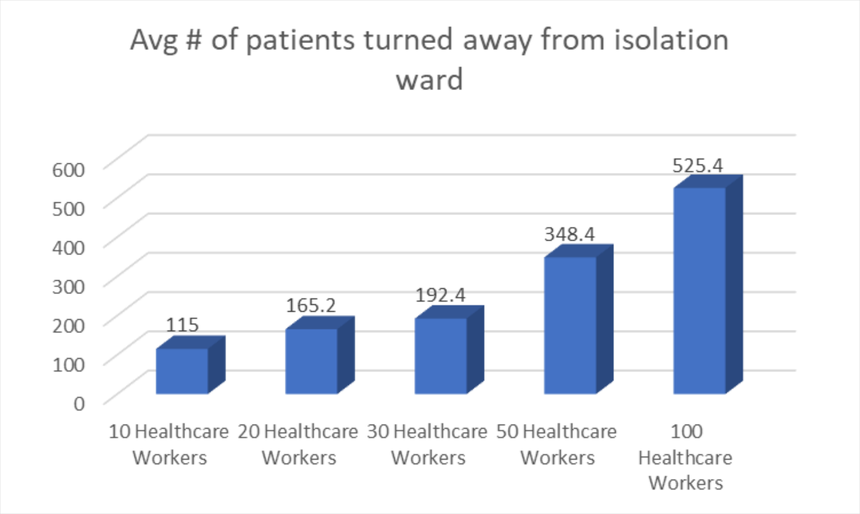
Number of Healthcare Workers

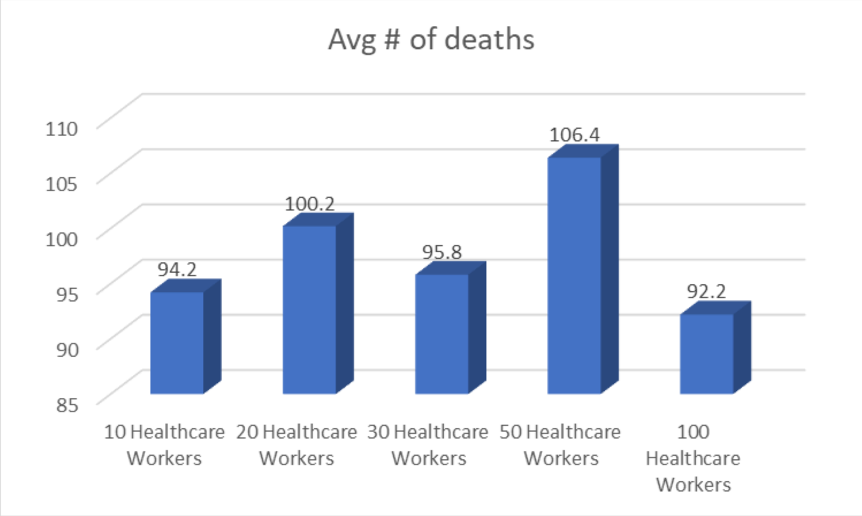












These graphs reflect the averaged values for each of the healthcare workers settings assuming all other variables are kept at default values. From the data, we can see that there doesn't seem to be much difference in % of infected between each value setting, although having too few healthcare workers seem to contribute to a slightly higher % of patients turned away from the standard wards.

From the graphs, we can also see that there is not really much benefit to having more than 30 healthcare workers in the system. Actually, having more healthcare workers contributes to higher average total acquired infections and higher average number of patients turned away from isolation wards. This could be due to the fact that since healthcare workers can themselves be infected and infect others, having more of them in the system increases the number of susceptible agents for infection spread, thus contributing to the overall spread of infection within the system.

Discussion of Results

Number of Beds:

The results of the analysis were not very surprising since we anticipated that having too few beds would lead to a bottleneck in the system and severely limit the ability of the hospital to cater to incoming patients. Having more beds definitely provided more benefits, but at a certain point, the cost of having those extra beds did not contribute much to the overall effectiveness of the system. This observation was in line with our initial idea that there had to be a somewhat optimal number of beds for each setting (assuming that there were no limits in the financial budget. However, we had no initial estimate of the optimal number, so the model helped us to identify an estimate of the optimal number of beds for the default system.

Number of Healthcare Workers:

Surprisingly, the number of healthcare workers in the system did not have much of an impact as we initially thought. The ramifications of having the least number of healthcare workers in the system were less than having the least number of beds. However, we also postulated that having too many healthcare workers in the system would lead to a higher number of infected since they themselves would serve carriers and vectors for the infection. Our results seem to agree with this hypothesis since having more workers in the system contributed to a higher number of overall infections. If we were able to construct a more complex model to capture the effect of administering patient care on patients' recovery rate, we might have observed a greater impact on the system when changing the number of healthcare workers.

Disclaimer

The mentioned insights and following recommendations are based off the assumption that the system has the default values for all other (non-resource related) adjustable parameters:

- Arrival rate of patients = 0.5
- Infection rate of patients = 0.5
    - This is the toggled "infection rate"
- Infection rate of healthcare workers = 0.1 x (Infection rate of patients)
    - 0.1 is always multiplied to the set infection rate for healthcare workers, as our model assumes the hygiene protocols and PPE help protect healthcare workers from infection, and hence they would have a lower infection rate
- Distance of transmission = 2
- Infection diagnosis rate = 0.7
- Infection recovery rate = 0.5

Recommendations

Expected % of Infected (16 Beds, 20 Workers)	0.864
Expected % Turned Away (16 Beds, 20 Workers)	0.005
Total acquired infections	677.600
# of patients turned away from standard ward	8.000
# of patients turned away from isolation ward	165.200
# of deaths	100.200
Expected % of Infected (24 beds, 20 Workers)	0.838
Expected % Turned Away (24 beds, 20 Workers)	0.000
Total acquired infections	703.2
# of patients turned away from standard ward	0
# of patients turned away from isolation ward	52.4
# of deaths	102.4
Expected % of Infected (16 Beds, 30 Workers)	0.814
Expected % Turned Away (16 Beds, 30 Workers)	0.000
Total acquired infections	734.400
# of patients turned away from standard ward	0.000
# of patients turned away from isolation ward	192.400
# of deaths	95.800
Expected % of Infected (24 Beds, 30 Workers)	0.783
Expected % Turned Away (24 Beds, 30 Workers)	0.000
Total acquired infections	753.600
# of patients turned away from standard ward	0.000
# of patients turned away from isolation ward	42.400
# of deaths	98.600
Expected % of Infected (30 Beds, 30 Workers)	0.782
Expected % Turned Away (30 Beds, 30 Workers)	0.000
Total acquired infections	746.800
# of patients turned away from standard ward	0.000
# of patients turned away from isolation ward	6.600
# of deaths	92.000

Default Values

Cheapest

Most Costly

From the information derived from our testing, we have come up with certain recommendations for setups that yield the best results.

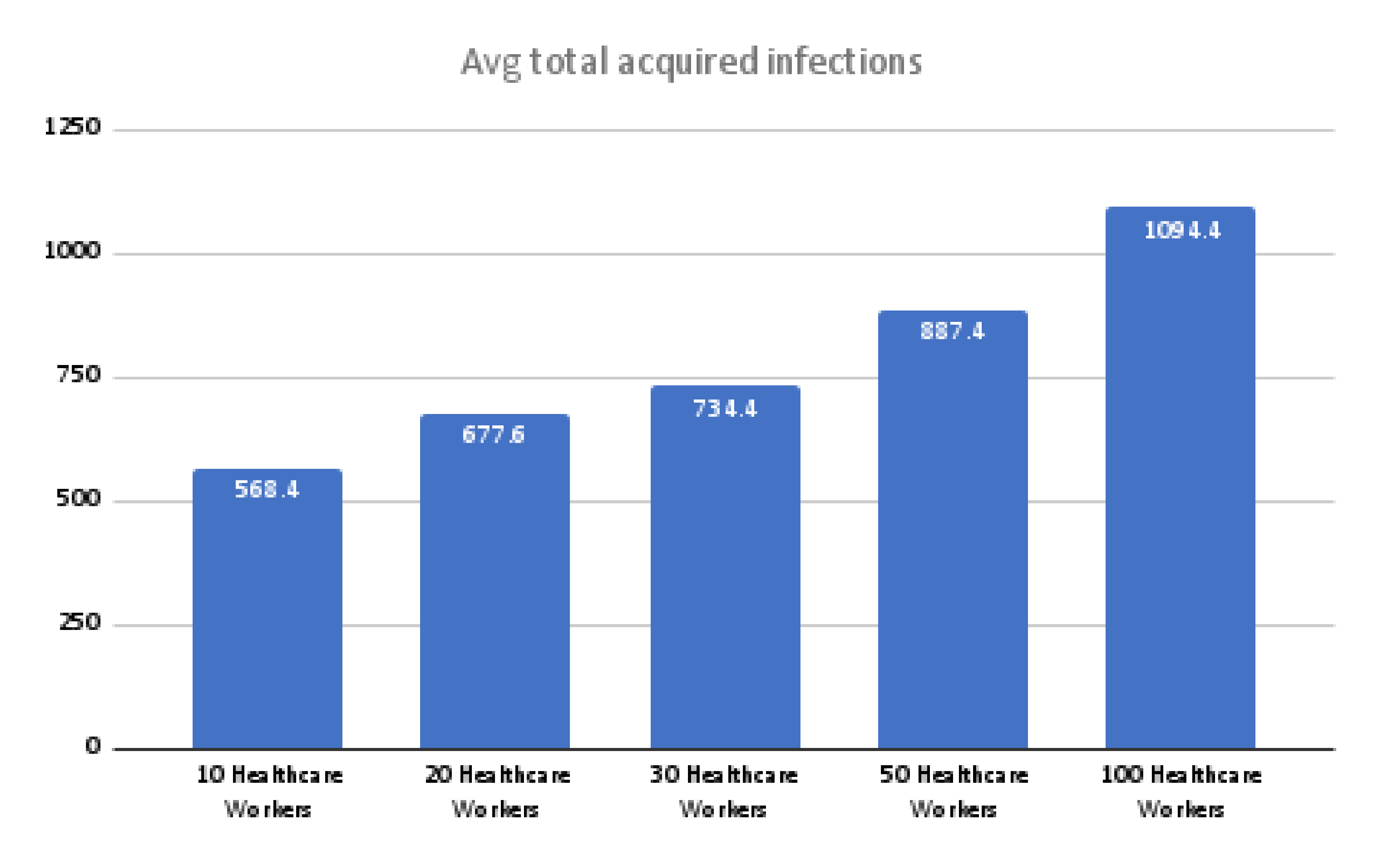
We assumed the cost of having more healthcare workers to be more than having more beds since purchasing beds is usually a one-time payment and healthcare workers have regular salaries.

*Only the resources (no. of beds and workers) were toggled. All other parameters were set to the default.

Lessons Learnt

Initial state of healthcare workers

As seen from our output analysis, when the number of healthcare workers in the system at one time increases, the average number of acquired infections also increases. This could be attributed to the higher number of healthcare workers having an initial state of being infected already, since the initial state of each worker is governed by a fixed probability in the code.



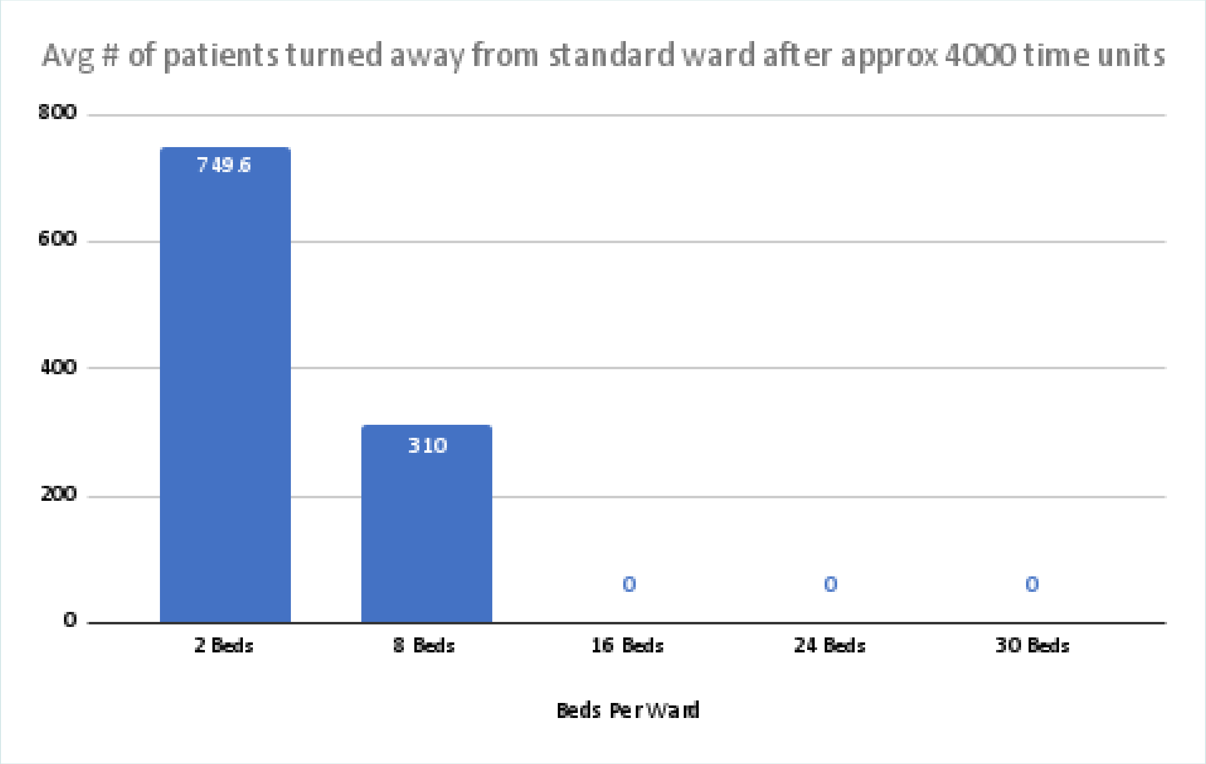
Initial state of healthcare workers

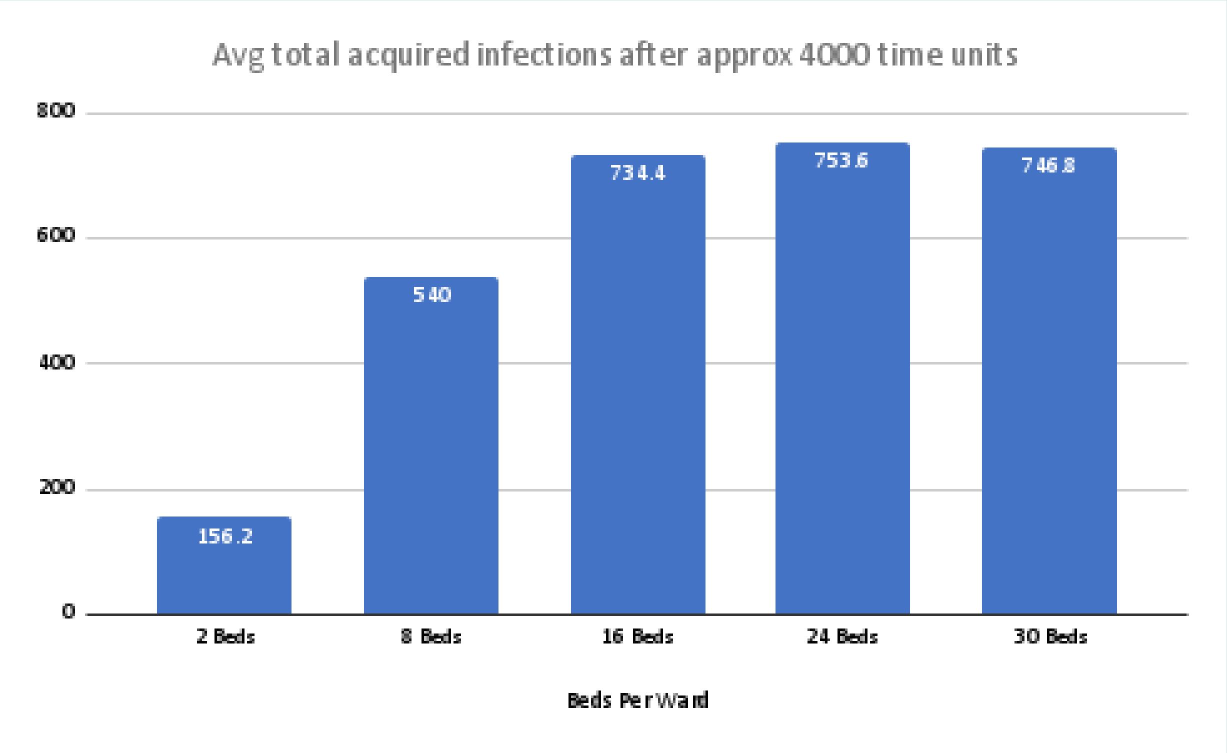
Suggestion: Initialise all healthcare workers to be of healthy state as opposed to having a mix of both healthy and undiagnosed state healthcare workers at the start of the simulation.

Explanation: In this way, the spread of infection will solely be from patients initially and the relationship between the number of healthcare workers and number of acquired infections can be better analysed.

Resource Allocation

There is an inverse relationship between the percentage of patients turned away at standard wards and the percentage of patients infected in relation to the number of beds per ward (capacity).





When the number of beds per ward is lower, it causes a higher percentage of patients being turned away at the standard wards and in turn a lower percentage of patients infected; Vice versa when the number of beds per ward is higher.

Resource Allocation

As such, hospital managements need to decide on their priorities and limits in terms of controlling the percentage of patients being turned away and the percentage of patients being infected. Then, they are able to allocate resources (i.e. beds, healthcare workers) more efficiently to suit their goals.
Their cost of resources also have to be taken into account.

Possible Future Modifications

For a more complex model...

- Incorporate doctors with specialisations to have a few assigned patients as only some patients require the attention of these doctors.
- Incorporate the effect of administering patient care and treatment on the recovery rates of patients.
- Separate healthcare workers into 2 separate agents - nurses and doctors - since they are likely to have different interactions and movements throughout the day.
- Incorporate visitors into the system and implement visiting hours to better simulate the spread of infection since visitors would move around the hospitals as well.
- Patients can be being diagnosed with the infection only when they interact with a doctor.
- Other methods for infection spread can be included such as through contact.

These would make the simulation more realistic in terms of healthcare workers' movements and infection spread and diagnosis.

END OF OUTPUT ANALYSIS