# Appendix A

**Hospital model supporting material**

***Key differences between flows under routine and MCI models***

This difference can be described with reference to admissions, state-dependent care, and service requirements as described next.

**Admissions**:In the U.S., patients cannot be turned away from the ED under routine situations. However, in a MCI, hospitals reject approximately 50% of the green “walking-wounded” patients. This rejection of patients is replicated through a direct exit point after triage. Many hospitals also have plans to cancel approximately 90% of scheduled, elective surgeries. This is captured in the model through a reduction in OR demand and by eliminating a portion of pre-op patients from patient flows.

Non-medical areas, such as cafeterias and corridors, can be used in a MCI to expand the capacity (e.g. number of beds) of a facility and improve physical space for formation of queues in the ED and IGWs. A maximum 25% increase in number of beds is presumed in the model for IGW and ED beds. These changes are reflected in the model by increasing resources (beds), maximum queue lengths (adding non-medical areas) and service rates (efficiency). Moreover, in practice, some hospitals have the ability to convert their ED rooms to ORs if included in the original architectural design. In these cases, the capability of a hospital to accept trauma patients in the ED is not limited to the number of ED trauma rooms (typically one or two). This is considered in the model by reducing the number of ED beds and increasing the number of trauma beds for medium ISS MCI patients and medium ESI routine patients.

**State-dependent care**: Patients in higher acuity care areas may be transferred to lower acuity care areas or to other health care facilities 2. In the model, the care paths are reconfigured to support these alternative options that present themselves as the state of the system evolves, thus alleviating undesirable waiting time. Consider the case where a patient is assigned to the SICU after an operation. If the SICU is full at the time the patient is released from surgery, the patient can be sent to the stepdown unit instead.

**Patient-care service requirements**: Nurses may perform tasks ordinarily performed by physicians, e.g. a registered nurse might be required to diagnose or treat an equivalent ESI-4 patient where an ED physician would traditionally perform this job. Also, higher patient-to-nurse ratios (e.g. 8-10 to 1 instead of 5-6 to 1) may be permitted than under routine circumstances. This is modeled with increased number of staff and longer shifts than will ordinarily be required. Lastly, despite the potential for increased 30-day returns for patients, average patient length-of-stay will be reduced through lower standards of care, where early discharge from critical care units and inpatient wards is permitted. An increase in early discharge of approximately 30% of inpatients from IGWs is considered reasonable in an MCI following reverse triage protocols used to determine which patients can be discharged. This is modeled with a 25% to 30% decrease in Length of Stay (LoS) of patients in IGWs and lower acuity critical care units.

***Model outputs***

Over 50 queues from the model runs were monitored to evaluate hospital performance. Tables A1 and A2 list the queues and exit points that were monitored, respectively. Performance measures are average and maximum waiting time and number of people waiting in the queue, and queue length was gathered from each run.

Table A1 Monitored queues

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Emergency department | | | |  | | Diagnosis | | |
| *Registration* | | *ED treatments/procedures* | |  | | *Laboratory* | | |
| Registration nurse | | ED physician for first visit | |  | | Laboratory equipment | | |
|  | | ED physician for final diagnosis | |  | | Laboratory technician | | |
| *ED bed/room* | | ED physician to perform procedure | |  | | Laboratory specialist | | |
| ESI-4 & 5-patients | | Technician to take patient tests | |  | |  | | |
| ESI-2 & -3 patients | | Nurse to draw blood, etc. | |  | | | *Imaging* | |
| ESI-1 & 2- patients | | Technician/nurse to monitor | |  | | | X-Ray Equipment | |
|  | |  | |  | | | CT-Scan Equipment | |
| ED Trauma Rooms | | *ED Exit queues- blockage in ED* | |  | | | MRI Equipment | |
| ED trauma bed | | ED to inpatient wards | |  | |
| ED Trauma team | | ED to ICU | |  | |
|  | | ED to OR | |  | |
|  | | Trauma to IGW | |  | |
|  | | Trauma to Post-op | |  | |
|  | | Direct ICU | |  | |
| Operation theatres | | | | | | | | | |
| *Pre-op* | *OR* | | *Post-op* | | | | | | |
| Bed | Bed | | *PACU* | | *SICU* | | | *Stepdown* | |
| Specialist | Specialist | | Bed | | Bed | | | Bed | |
|  |  | | Physician | | Physician | | | Physician | |
| *Pre-op exit queue* | *OR exit queue* | | Nurse | | Nurse | | | Nurse | |
| Pre-op to OR | OR to PACU | | *Post-op exit* | | | | | | |
|  | OR to SICU | | *PACU* | | *SICU* | | | *Stepdown* | |
|  | OR to Stepdown | | PACU to IGW | | SICU to IGW | | | Stepdown to IGW | |
|  |  | | PACU to SICU | | SICU to Stepdown | | |  | |
|  |  | | PACU to Stepdown | |  | | |  | |

Table A2 Output categories in terms of number of patients transferred or who expire

|  |  |
| --- | --- |
| ***Transfers*** | ***Mortalities*** |
| # ESI-4 & -5 who LWBS | # mortalities while waiting to initiate critical service |
| # ESI-3 transferred out from ED main treatment area  # transferred from treatment area before ED bed assignment | During transfer from ED to ICU |
| Before entering ICU |
| Between Trauma and SICU |
| # transferred before entry to hospital and diverted elsewhere | In Trauma |
| In Pre-op |
| # re-scheduled elective surgeries | Average mortality rates for critical units |
| OR |
| SICU |

# Appendix B

**Additional analysis on OR and IGW capacity expansion**

An alternative approach to adding capacity to the OR or IGWs would be to cancel elective surgeries (MO1). Results of numerical experiments in which MO1 modifications were added to the ASC4 and MO2 combination suggest an additional 98% decrease in pre-op waiting times and 76% decrease in OR waiting times, 47% increase of medium ESI patient throughput in the ED, while simultaneously eliminating a blockage in the IGWs. Thus, the combined effects are super-additive.

For example, results from Table 3 indicate that alone, MO5 did not lead to significant improvements. Pairing MO5 with MO2, however, led to a decrease in hospital transfers by 79% and ED transfers by 13%. However, the combined MO2-MO5 strategy also resulted in blocking of the operation theatres, creating an unstable situation involving 40-hour wait times for the ORs and a 7-fold increase in patient deaths in pre-op. This combination also produced a sharp rise in average waiting times (from 4 to 8 hours) for IGW beds. To test this hypothesis, 50 staffed beds (an increase by 25% in number of beds) were added to the representative hospital. With this addition, the blockage in the operational theatres dissolved and waiting times for IGW beds dropped to below an acceptable threshold. Many additional combinations can be tested using this framework.