MSM of Surgical Flow Explains Lognormal Distribution of Surgical Time and Occurrence of Large Delay

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Background

Improving operating room management is a constant issue for modern large hospital systems who have to deal with the reality of day to day clinical activity characterized by poor prediction of surgical time and significant percentage of add-on cases due to emergencies.

Surgical flow in a large multi-disciplinary operating room (OR) suite is a very complex phenomena. In a typical large OR suite (Figure 2.), the number of staff and patient involved during the daily activity is about several hundred. The environment is stressful and demanding: team work quality and coordination have a profound impact on the optimum management of resources. We envision that a system approach to model this complexity can get us a better understanding of the root cause of delays and poor efficiency.

Objectives

We hypothesize that the following three key ingredients will provide the level of accuracy needed to improve OR management:

1. Construction of a multi-scale model that links all key elements of the complex surgical infrastructure and processes in the surgical flow.
2. Real time updates of the model with ad hoc sensors of tasks/stages.
3. Careful analysis of patient population factors and staff behavior.

As opposed to many other industrial sectors such as air civil aviation or nuclear energy that have mastered the topic of industry organization, and achieved remarkable reliability and consistency in their procedure flow, progress in surgical flow management has been very slow. We believe that human factor is at the center of the difficulty of OR suite management and should be incorporated in the model if all possible.

Scale

Our scale's representation (Fig. 1) gives an idea of the complexity of the communications. Each layer includes the smaller layers.

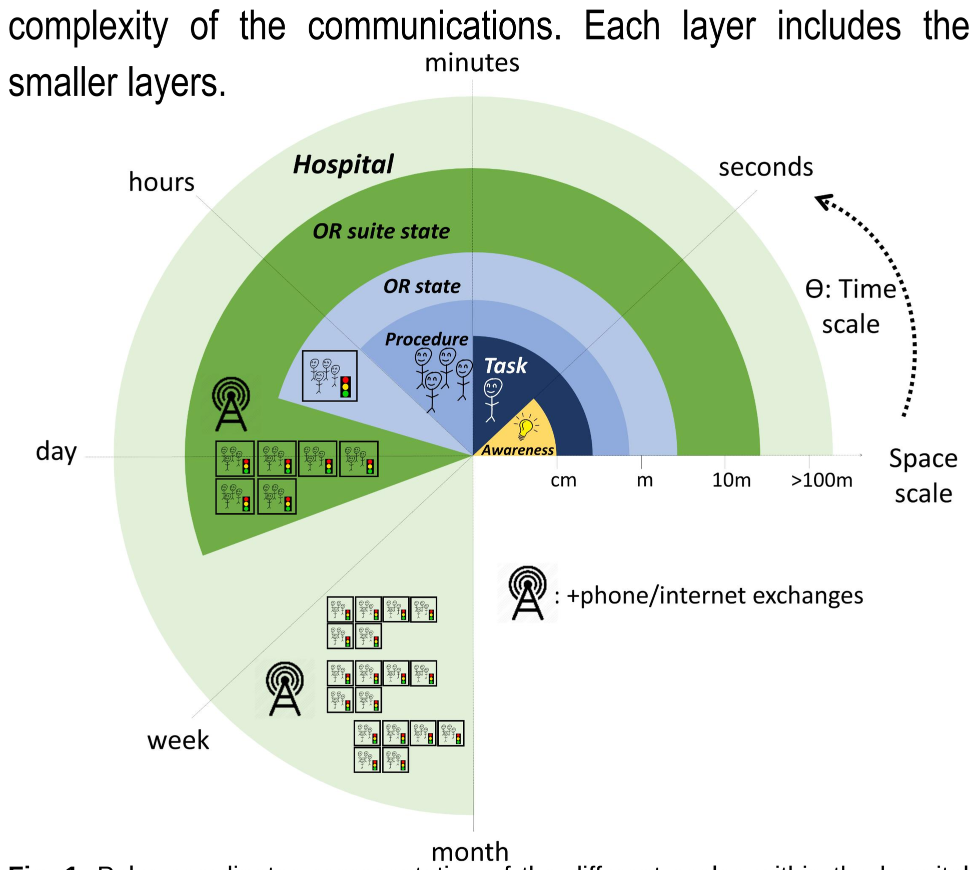

Fig. 1. Polar coordinates representation of the different scales within the hospital, concerning the organization of the surgical suite. The angle represents the time scale of the communications, the distance from the center represents the actual distance in the physical world within the hospital. We include also the communications through phone/internet/hospital system.

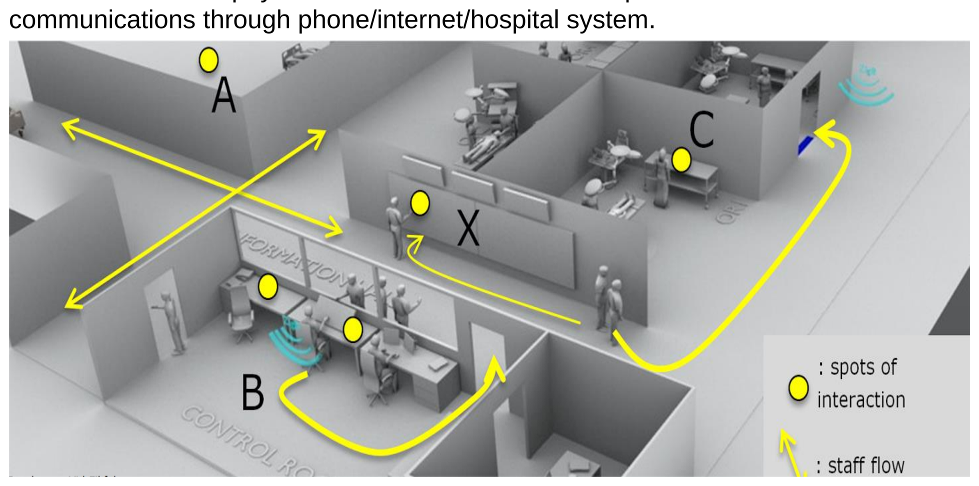

Fig. 2. 3D reconstruction of the Dunn surgical suite of the Houston Methodist Hospital. With more than 20 ORs in service, this surgical suite flow is one of the biggest and staff workload is very high.

Data Acquisition

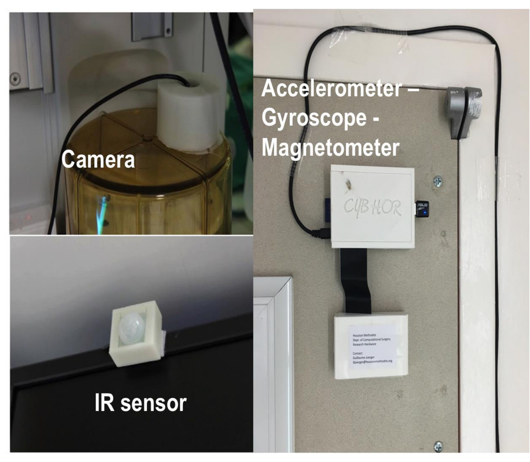

Figure 3. Sensors of the smartOR system, installed in 5 ORs of Dunn surgical suite of the Houston Methodist Hospital. They target and automatically record events in the OR, not people.

Figure 4. Organizational whiteboard within the surgical suite. This whiteboard holds the patient flow and staff coordination.

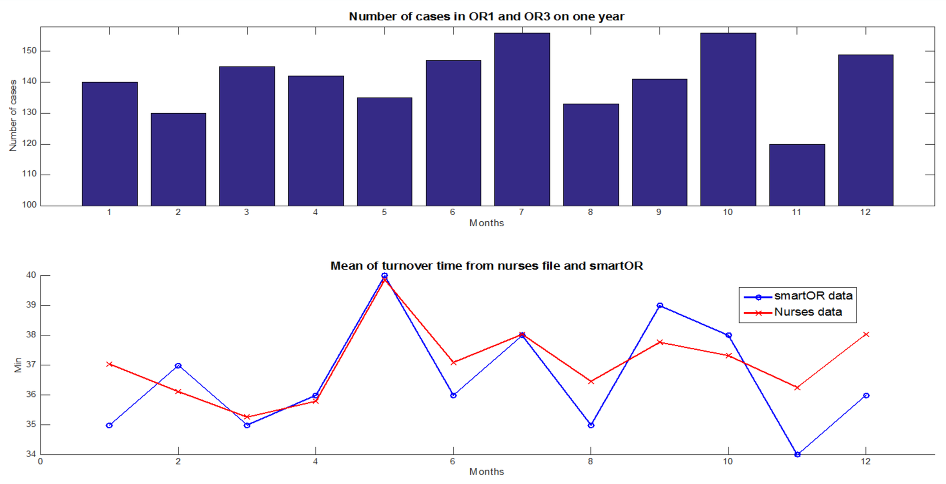

Figure 5. Top: number of cases in OR1 and OR3 on one year. Linking with the bottom graph on which we see the mean delays between the automatic data captured by smartOR and the manual input data by nurses along the year.

Model and Simulation

We construct a multiscale agent-based model of surgical flow (Fig. 6, 7, 8) that integrates our non-invasive human friendly sensor technique to monitor surgical flow in a large OR suite. This model is built upon extensive clinical experiences and observations.

The data acquisition was done on an extensive period of time of more than a year and provided an accurate time distribution of OR state for a thousand procedures. Staff decision on OR suite management and rescheduling was observed and analyzed with a campaign of photography of the whiteboard (Fig. 4) that centralizes all the activity and list all the cases scheduled that day. Non-linear fitting of our multiscale agent system to the data set produced by our distributed array of sensors set up at key points of the ORs (Fig. 3) helped us to reveal a number of mechanisms that leads to delays and inefficiencies (Fig. 5). We were able to classify the relative impact of human factors and of the limitation of shared resources that were entered in our model on surgical flow efficiency and delays (Fig. 5, 10, 11).

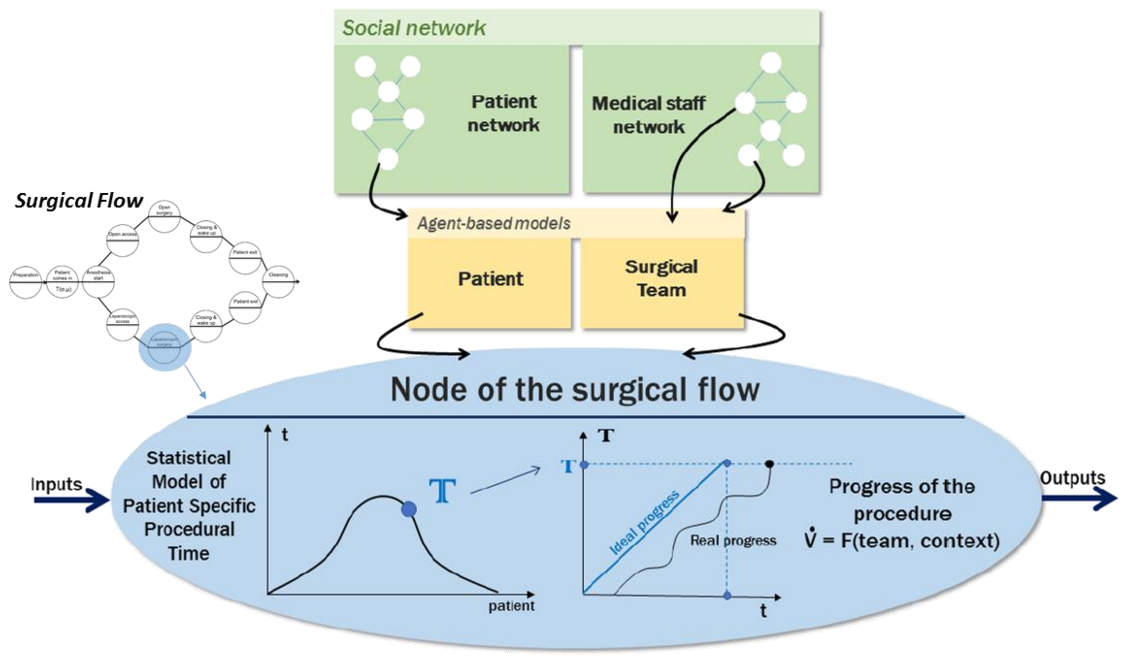

Fig. 7. Representation of a node of the surgical flow, and its integration within the whole model.

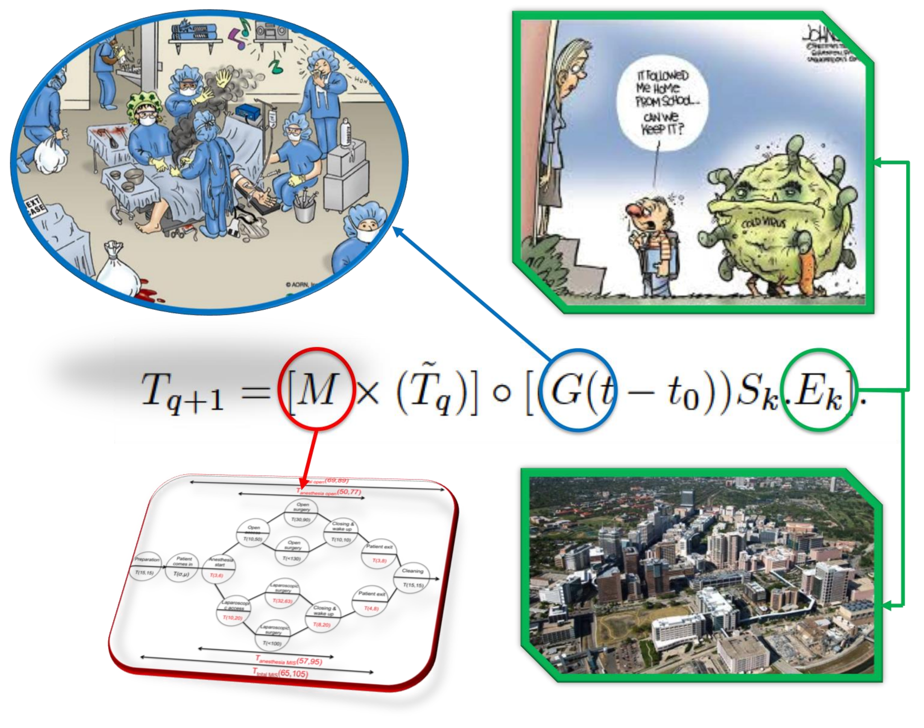

Fig. 6. Representation of the modelization of a task.

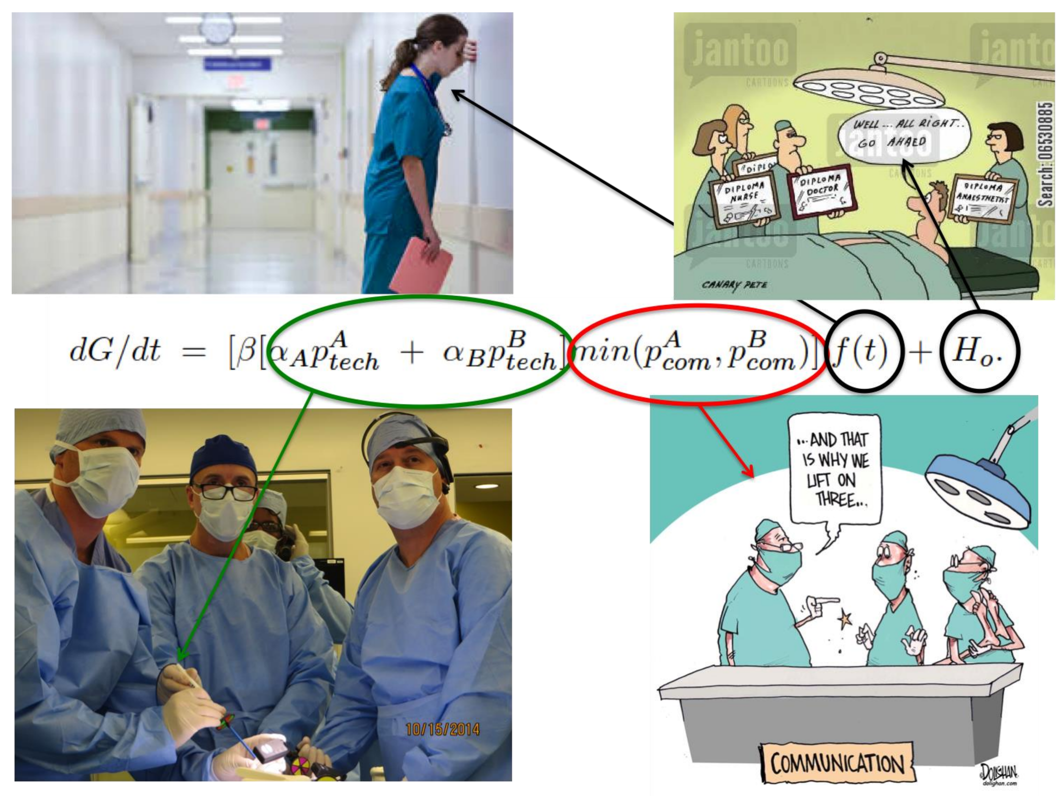

Fig. 8. Representation of the modelization of human factors.

Credibility of the model: work in progress

Our data set includes very short surgeries such as cholecystectomy or appendectomy as well as much longer one such as organ transplantation. We are currently refining our surgical flow chart by including more specific description of each surgery types and use multivariate statistical analysis and classifiers to study our population sample.

Fig. 9. Curves stands for the normal distribution of procedural time: Clinical data in red. **Model** in black

Interrogating the model

- *How shortage of personnel, that is shared between ORs, affects overall performances?*

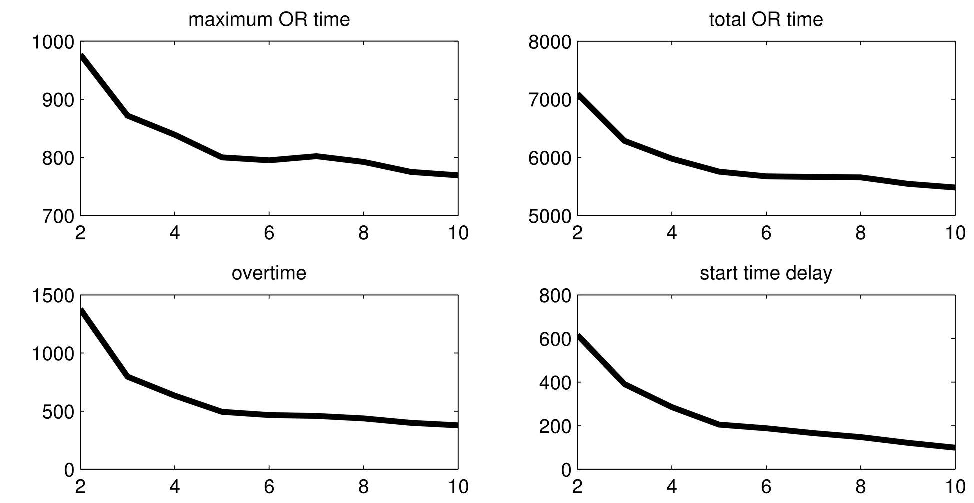

Fig. 10. Impact of the number of anesthesiologists on outcome. We run the simulation with 10 ORs and considered a variation from 2 to 10 anesthesiologists. Total time on vertical axis is expressed in minute. Interpretation of such curves indicates that a 1:2 ratio of anesthesiologists to ORs is close to optimal.

- *How distribution of staff's skills impacts performances?*

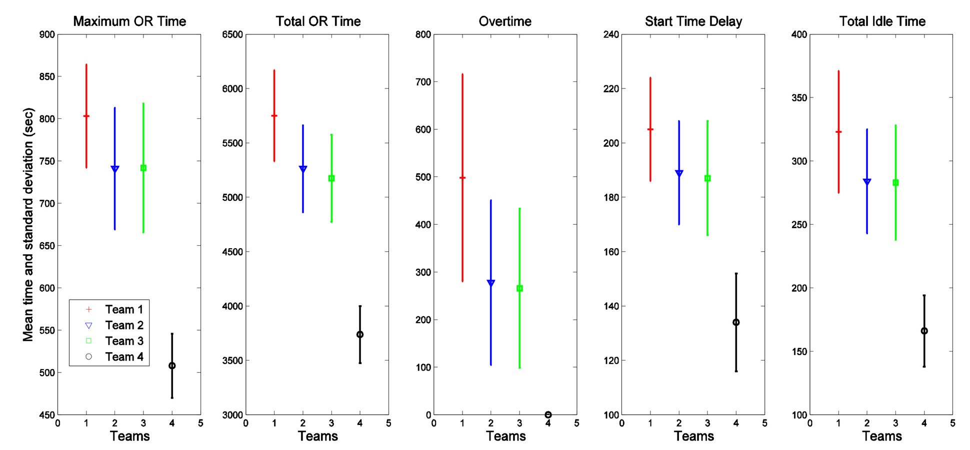

Fig. 11. Improving team performance as opposed to specific staff individual skills is the best way to significantly make progress.

- *Does the size of the OR suite matters?*

The general answer is that large OR suite allows better sharing of resources and have more flexibility in scheduling. We observed that large OR suites accrue less surgery overtime compared to smaller OR suites due to add-on cases that are typically in the range of 10-20 % of the daily OR suite capacity.

Conclusion

Our main new findings:

1. Team training is a key to increase the overall efficiency.
2. Inertia effect due to delay in OR awareness had the most negative impact on large OR suite.

The future of complex surgical flow management relies on a cyber-physical infrastructures that monitor accurately events and uses real time simulation with multiscale model similar to ours in order to assist the management process and fully utilizes the resources of the OR suite without increasing the stress on personal.

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