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An exact approach for relating recovering surgical patient workload to the master surgical schedule

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Outline

- Motivation / Background
- The Master Surgical Schedule (MSS)
- Model: Ward workload as a function of the MSS
- Application

Motivation / Background
> Problem Description

Netherlands Cancer Institute - Antoni van Leeuwenhoek Hospital

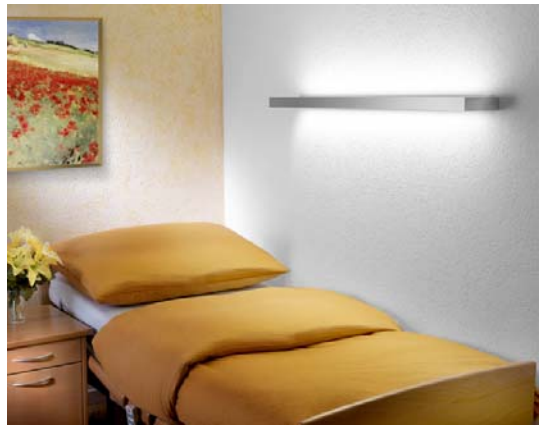
- 550 scientists and scientific support personnel
- 53 medical specialists,
- 180 beds,
- Out-patient clinics receive 24,000 new patients each year,
- 5 operating rooms
- 9 irradiation units.

- OR 6 to open.

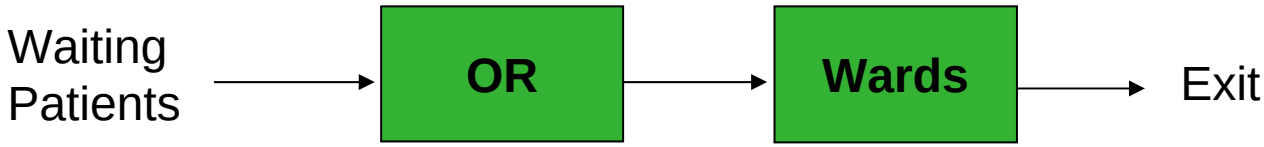
Motivation / Background
> The OR-Ward Relationship

OR 6 opened in 2009

- How will this impact the rest of the hospital, particularly the Wards?
  - Occupancy Rate
  - Admission rates / Discharge rates
  - Frequency of treatments



Motivation / Background
> The OR-Ward Relationship



- **Upstream of the OR:** Sufficient patient buffer to prevent ‘starving’
- **In the OR:** Physician schedules, equipment...
- **Downstream of the OR:** Our Focus

Motivation / Background
> The OR-Ward Relationship

Patient Flow (day of surgery)

- **Morning of Surgery:** Patient is admitted to the ward
- **Time of Surgery:** Patient has anesthesia, surgery, PACU
- **After Surgery:** Patient admitted to Ward and recover for LOS
- **After Recovery:** Patient is discharged home

The Master Surgical Schedule

- Surgical department activity is dictated by the MSS.
  - What specialties get what OR blocks? (Not patient specific)
  - Typically cyclical
  - Organizes the OR: Accounts for potential resource conflicts within the OR, e.g. physician schedules, equipment, etc.
- Dictates the arrival pattern of recovering Surgical Patients to the wards

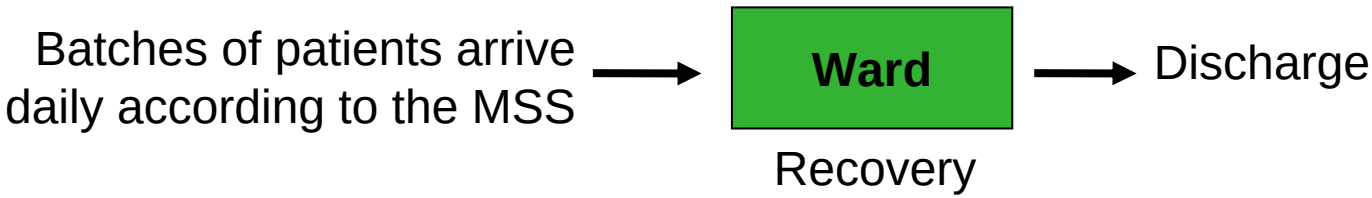
The Master Surgical Schedule

	Mon	Tue	Wed	Thu	Fri
OR1	Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VRP)
OR2	KNO	CHI (RUT)	Urologie (hbs)	RT	Urologie (MND)
OR3	KNO	Plas Chi	KNO	KNO	Plas Chi
OR4	CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne
OR5	RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urologie (P&B)
OR6	Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor/rur)

Goal: Directly derive ward workload metrics from the MSS

Model: Ward workload as a function of the MSS

Conceptual Model Scheme

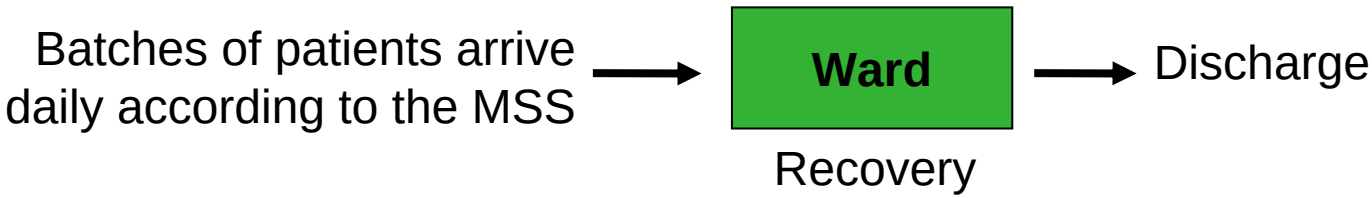


Assumptions

- No cancelations due to lack of ward space (extra nurses will be called in)
  - Acceptable Risk of “calling in a nurse” is ~10%
- Time scales is days.
- Count patients on the day of admission, not on the day of discharge

Model: Ward workload as a function of the MSS

Conceptual Model Scheme

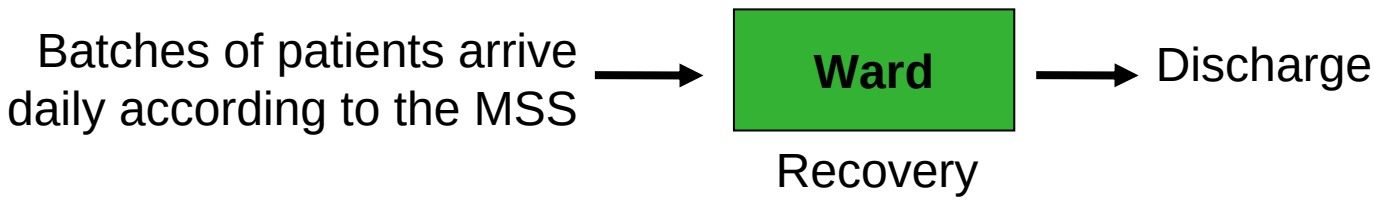


Metrics

1) Recovering Patients in the Hospital
2) Ward occupancy
3) Rates of admissions and discharges
4) Patients in recovery day *n*

Model: Ward workload as a function of the MSS

Conceptual Model Scheme



Data

- For each surgical specialty
  - Empirical Distributions of Cases/Block (batch size)
  - Empirical Distribution of Length of Stay (LOS)

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

Recovering patients in the hospital on the day of surgery (*t=0*)

- Consider the influence of a single specialty in isolation
  - Let *c(x)* be a random variable for the number of completed surgeries
  - *c(x)* also describes the batch size of admissions to the ward
  - Finally *c(x)* represents the number of recovering patients in the hospital on the day of surgery (*t=0*)

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

Recovering patients in the hospital on the days after surgery (*t>0*)

- Each day *t* a patient has two options: “Stay” or “Be discharged”
  - Let *d(t)* be the probability a patient who is in the hospital on day *t,* is discharged on day *t*

$$h_t(x) = \sum_{k=x}^{C} h_{t-1}(k) \binom{k}{x} (d(t))^{k-x} (1 - d(t))^{x}$$

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

Recovering patients in the hospital on the days after surgery (*t>0*)

- Let $h_t(x)$ be the probability of x patients on day t, then

$$h_t(x) = \begin{cases} c(x) & \text{when } t = 0 \\ \sum_{k=x}^{C} \binom{k}{x} (d(t))^{k-x} (1 - d(t))^{x} h_{t-1}(k) & \text{otherwise.} \end{cases}$$

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

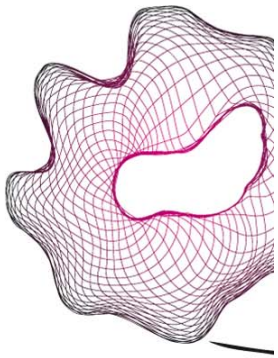
Recovering patients in the hospital (all specialties)

- Consider a given MSS in isolation

	Mon	Tue	Wed	Thu	Fri
OR1	Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VRP)
OR2	KNO	CHI (RUT)	Urologie (hbs)	RT	Urologie (MND)
OR3	KNO	Plas Chi	KNO	KNO	Plas Chi
OR4	CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne
OR5	RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urologie (P&B)
OR6	Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor/rur)

- Each block generates patients for the ward. The number of patients is distributed according to $h_t(x)$.
- Since patients do not interfere with each other during recovery, the aggregate number of patients can be computed with discrete convolutions

$$C(x) = \sum_{k=0}^{\tau} A(k)B(x-k)$$



Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

Recovering patients in the hospital (all specialties)

- Let $H_{t'}(x)$ be the probability of x patients on day t' for all specialties
  - $t'=1$ is the first day of the MSS cycle

$$H_{t'}(x) = h_n^{block\ 1} * h_n^{block\ 2} * h_n^{block\ 3} * \dots$$

- Where:

  $*$ indicates a discrete convolution

  $\boldsymbol{n}$ is a function of t' and the weekday the block falls on (this ensures the arrival of patients are offset to reflect the day of surgery)

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

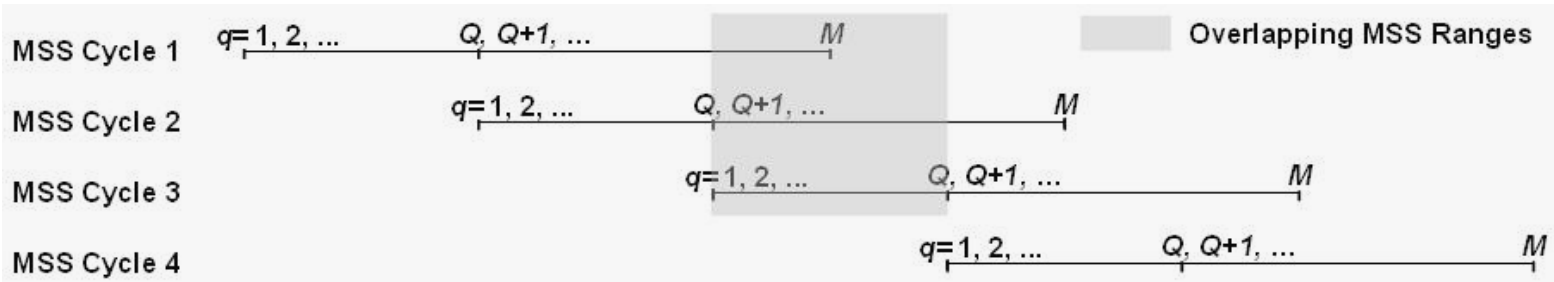
Recovering patients in the hospital (all specialties, recurring MSS)

	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
OR1	Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VRP)			Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VRP)			Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VR
OR2	KNO	CHI (RUT)	Urologie (hbs)	RT	Urologie (MND)			KNO	CHI (RUT)	Urologie (hbs)	RT	Urologie (MND)			KNO	CHI (RUT)	Urologie (hbs)	RT	Urolog (MND
OR3	KNO	Plas Chi	KNO	KNO	Plas Chi			KNO	Plas Chi	KNO	KNO	Plas Chi			KNO	Plas Chi	KNO	KNO	Plas C
OR4	CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne			CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne			CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne
OR5	RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urologie (P&B)			RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urologie (P&B)			RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urolog (P&B
OR6	Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor/rur)			Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor/rur)			Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor

- With recurring MSS, patients from different MSS cycles will overlap
- MSS is cyclic, i.e. the MSS does not change from week to week

Model: Ward workload as a function of the MSS
> Metric 1: Recovering Patients in the Hospital

Recovering patients in the hospital (all specialties, recurring MSS)



- Let $\mathbf{H}_q(x)$ be the 'steady state' distribution for the number of patients recovering in the hospital on any day *q* of the MSS

$$\mathbf{H}_q(x) = H_q * H_{q+Q} * H_{q+2Q} * \ldots * H_{q+\lceil M/Q \rceil Q}$$

Model: Ward workload as a function of the MSS
> Metric 2: Ward occupancy

	Mon	Tue	Wed	Thu	Fri
OR1	Chi (KLM)	CHI (VWL)	CHI (vwl/rur) HIPEC	Chi (nie)	Chi (VRP)
OR2	KNO	CHI (RUT)	Urologie (hbs)	RT	Urologie (MND)
OR3	KNO	Plas Chi	KNO	KNO	Plas Chi
OR4	CHI (COR)	Gyne	Chi Mamma	Plas Chi	Gyne
OR5	RT	CHI (SND/WOS)	RT (vwl/rur)	Urologie (pel/bex)	Urologie (P&B)
OR6	Urologie (P&B)	CHI (VWL)	Gyne	Chi (ODB)	Chi (Cor/rur)

Ward A

Ward B

- For ward specific results, when computing $H_{t'}(x)$ only consider OR blocks for the ward of interest.

Model: Ward workload as a function of the MSS
> Metric 3: Rates of admissions and discharges

- Admission Rate:
  - Modify $h_t(x)$ as follows, and then continue with the convolutions

$$h_t(x) = \begin{cases} c(x) & \text{when } t = 0 \\ \mathbf{0} & \text{otherwise.} \end{cases}$$

- Discharge Rate:
  - Compute $h'_t(x)$ as follows

$$h'_t(x) = \sum_{k=x}^{C} \binom{k}{x} (d(t))^x (1 - d(t))^{k-x} h_t(k)$$

  - and then set $h_t(x) = h'_t(x)$ and continue with the convolutions

Model: Ward workload as a function of the MSS
> Metric 4: Patients in Recovery day *n*

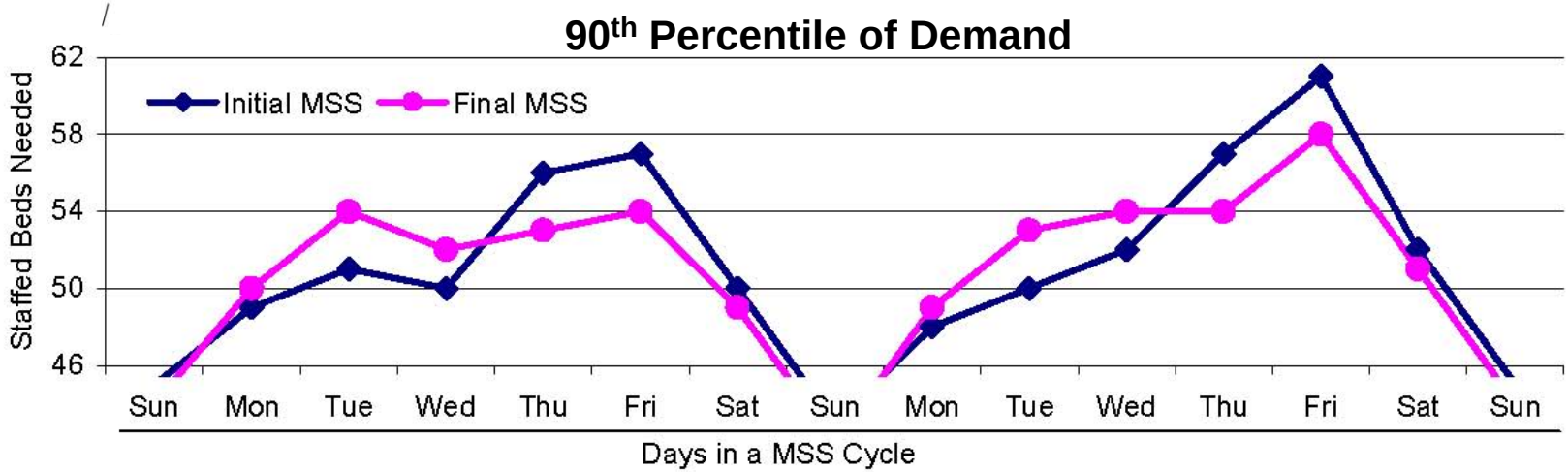
- Keep “day of surgery” index throughout computations
  - index by *t* and *t’*

- Meaningfulness of Metric
  - For some well defined patient groups the recovery “activities” are precisely defined for each recovery day
  - For example: The majority of patients who receive lung cancer surgery are discharged on day 8. On each day the activities of care are stated.

Application

- Evaluation model, not an optimization model
- Manual process
  - Staff from the OR proposed MSS
  - Using the model the proposal was evaluated
  - Staff from the OR and Wards debated the proposal and made suggested modifications
    - This continued until all parties agreed to the MSS
- Advantages of Manual Process
  - Enhanced user “buy-in”
  - Staff from both groups developed intuition for how changing the assignment of Specialties to OR block impacted the wards
  - Began to understand the impact of the OR constraints

Example Result



Initial MSS

- 1/10 days required 61 staffed beds
- 4/10 days required > 54 staffed beds
- 2/10 days required < 50 staffed beds
- Other days required b/w 50 & 54

Final MSS

- 1/10 days required 58 staffed beds
- 9/10 days required b/w 50 & 54
- Further discussion is ongoing to change physician schedules to eliminate peak in week 2

Questions?

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