The Impact of service epochs on waiting times in a healthcare environment
ORAHS’2007

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Problem description

- Problem setting: healthcare and other services
- Measures of interest:
  - Patient waiting time
  - Staff overtime
- Methodology: queueing theory
  - Focus on manufacturing
  - Healthcare modeling requires distinct approach
A basic queueing system
A basic queueing system
A basic queueing system
A basic queueing system
A basic queueing system

Arriving patients

Queue

Server

Idle Server

Exit
A basic queueing system
A basic queueing system

Arriving patients → Queue → Currently in service → Exit

1. Server
2. Queue
3. Patient 3
4. Patient 4
A basic queueing system
A basic queueing system

- Arriving patients
- Queue
- Currently in service
- Server
- Exit

The Impact of service epochs on waiting times in a healthcare environment
Problems in healthcare modeling

- Queue discipline
- Time varying demand
- Waiting creates additional work
- Service outages (absences and interrupts)
- Service epochs
Problems in healthcare modeling

- Queue discipline
- Time varying demand
- Waiting creates additional work
- Service outages (absences and interrupts)
- Service epochs
Problem setting: example

- Doctor’s office with opening hours on Thursday from 6 PM until 8 PM and on Friday from 2 PM until 6 PM
- On Thursday a maximum of 4 patients receives treatment, on Friday 8 patients are allowed
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Performance measures of interest:

- Patient waiting time
  - At the waiting list
  - At the doctor’s office
- Staff overtime
Problem setting: example

Performance measures of interest:
- Patient waiting time
  - At the waiting list
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- Staff overtime

Two methodologies apply:
- Availability
- Vacation models
Availability

- Rescales the service process in order to fit a predefined uniform time scale (e.g., 24 hours per day, 7 days per week)
- Example: doctor’s office with opening hours on Thursday from 6 PM until 8 PM and on Friday from 2 PM until 6 PM
- Availability:

\[ A = \frac{6}{168} = \frac{1}{28} \]
Availability

- Rescales the service process in order to fit a predefined uniform time scale (e.g. 24 hours per day, 7 days per week)
- Example: doctor’s office with opening hours on Thursday from 6 PM until 8 PM and on Fridays from 2 PM until 6 PM
- Mean and variance of the rescaled service times:

\[
\frac{1}{\mu} = \frac{1}{A\mu_0}
\]

\[
\sigma^2 = \frac{\sigma_0^2}{A^2}
\]
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[Diagram showing availability over a week with specific times and days highlighted]
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- Observe a single week, five arrivals with an average service time of 1 hour
Why not use availability?

- Requirement to know capacity in advance
- Availability is inaccurate at modeling service epochs
- Simulation study:
  - Doctor’s office, opening hours on Thursday from 6 PM until 8 PM and on Friday from 2 PM until 6 PM
  - On Thursday a maximum of 4 patients may be treated, on Friday 8 patients are allowed
  - Low variability service, patients always arrive on time, no unscheduled patients, . . .
  - Time between the making of two appointments is highly variable
Why not use availability?

- Requirement to know capacity in advance
- Availability is inaccurate at modeling service epochs
- Simulation study:

\[
\begin{align*}
A &= \frac{6}{168} \\
\rho &= 0.6 \\
C_e^2 &= \frac{1}{3} \\
C_a^2 &= 4
\end{align*}
\]
Why not use availability?

- Requirement to know capacity in advance
- Availability is inaccurate at modeling service epochs
- Simulation study:

<table>
<thead>
<tr>
<th>Availability approach</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$E [W]$</td>
<td>1.8958</td>
<td>days</td>
</tr>
<tr>
<td>Weeks overtime</td>
<td>Ø</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$E [W]$</td>
<td>3.9959</td>
<td>days</td>
</tr>
<tr>
<td>Weeks overtime</td>
<td>46.18%</td>
<td></td>
</tr>
</tbody>
</table>
Why not use availability?

The diagram shows the service epochs from Monday to Sunday, with different days having varying availability. The diagram uses color-coding to indicate availability, with darker colors representing higher availability.

The text suggests that the impact of service epochs on waiting times in a healthcare environment is being discussed.
Why not use availability?
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Why not use availability?
Two queues, two problems

- Two phases in a patients treatment process:
  - External phase (e.g. at home)
  - Internal phase (e.g. at the doctor’s office)

- Division of the problem into 2 subproblems:
  - Bulk Transfer Queueing System (BTQS)
  - Service Epoch Markov Chain (SEMC)
Two queues, two problems

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Linking the BTQS and the SEMC

- At the beginning of each service epoch a number of patients is transferred from the BTQS to the SEMC
- The SEMC has two queues:
  - Internal process arrival queue, which holds patients who have yet to arrive
  - Internal process service queue, which represents the waiting room at the doctor’s office
Linking the BTQS and the SEMC

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Linking the BTQS and the SEMC

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- The SEMC has two queues:
  - Internal process arrival queue, which holds patients who have yet to arrive
  - Internal process service queue, which represents the waiting room at the doctor’s office
- Performance measures of both systems are derived separately and are joined together afterwards
Definition

- The BTQS is a vacation model
  - Gated, $k$-limited service discipline
  - Bulk service queue with instantaneous service
  - After service patients are transferred towards the SEMC
  - State dependent, deterministic vacations
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Gated k-limited service ($k = 4$)

Queue

Server
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Gated k-limited service (k = 4)

Arrival patient during service

Queue

Server

ORAHS'2007 The Impact of service epochs on waiting times in a healthcare environment
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![Vacation Model Diagram]

ORAHS'2007
The Impact of service epochs on waiting times in a healthcare environment
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![Diagram of BTQS vacation model]
Example

- One service epoch (e.g. Thursday from 6 PM until 8 PM)
- Maximum of 4 patients is allowed
- Arrival rate $\lambda$, vacation rate $\mu$

<table>
<thead>
<tr>
<th>$i/j$</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>...</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$\mu$</td>
<td>$\lambda$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>1</td>
<td>$\mu$</td>
<td>0</td>
<td>$\lambda$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>2</td>
<td>$\mu$</td>
<td>0</td>
<td>0</td>
<td>$\lambda$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>3</td>
<td>$\mu$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$\lambda$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>...</td>
</tr>
<tr>
<td>4</td>
<td>$\mu$</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$\lambda$</td>
<td>0</td>
<td>0</td>
<td>...</td>
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BTQS: underlying Markov chain
From the analysis of the BTQS we obtain:

- The stationary distribution of the number of patients in queue
- The waiting time of a patient at the BTQS (i.e. part of the waiting time spent in the waiting list)
- The probability of a certain number of patients being transferred towards the SEMC at the beginning of a particular service epoch (i.e. the input of the SEMC system)
Definition

The SEMC is an absorbing Markov chain in which:

- Each state is represented by a triplet \((A, B, C)\) where:
  - \(A\) denotes the number of patients in the internal process arrival queue
  - \(B\) denotes the number of patients in the internal process service queue
  - \(C\) denotes the number of patients currently in service
- The absorption time indicates the end of service at a service epoch

[ORAHS'2007] The Impact of service epochs on waiting times in a healthcare environment
Example

- One service epoch on Thursday (from 6 PM until 8 PM)
- 4 patients made an appointment
- none of the patients are present at the doctor’s office upon opening
- Arrival rate at the doctor’s office $\lambda$, service rate $\mu$
Example

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Output

- From the analysis of the SEMC we obtain:
  - The overtime performed at a particular service epoch, given a number of patients transferred from the BTQS
  - The waiting time at both the internal process arrival and service queue at a particular service epoch, given a number of patients transferred from the BTQS
- For each service epoch and each possible number of patients transferred, we need to analyze the SEMC
- Combined with the performance measures of the BTQS, general performance measures may be obtained
Combining both subproblems
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Assumptions

- Use of exponential distribution:
  - Vacation length
  - Service times
  - Interarrival times at the doctor’s office
  - Interarrival times between appointments

- Patients:
  - Are assumed to make an appointment (i.e. no unscheduled patients show up)
  - Are assigned the first time slot available
  - Are assumed to arrive and to be served during the assigned service epoch
Numerical example

• Setting: doctor’s office with opening hours on Thursday (6 PM until 8 PM; a maximum of 4 patients may be treated)

• Assumptions:
  • Vacation lengths of exponential duration (168 hours)
  • Exponential service time with mean 30 minutes
  • Exponential interarrival time at the waiting list with mean 3,000 minutes
  • Exponential interarrival time at the doctor’s office with mean 18 minutes
Numerical example

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Exact</th>
<th>Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E[W_\alpha]$</td>
<td>40,768 minutes</td>
<td>40,759 minutes</td>
</tr>
<tr>
<td>$E[W_\beta]$</td>
<td>38.625 minutes</td>
<td>38.627 minutes</td>
</tr>
<tr>
<td>$E[W_\gamma]$</td>
<td>20.999 minutes</td>
<td>21.003 minutes</td>
</tr>
<tr>
<td>$E[W]$</td>
<td>40,828 minutes</td>
<td>40,818 minutes</td>
</tr>
<tr>
<td>$E[O]$</td>
<td>23.894 minutes</td>
<td>23.908 minutes</td>
</tr>
</tbody>
</table>
Conclusions

Contributions:

- Modeling technique that enables the assessment of:
  - Staff overtime
  - Patient waiting time at the waiting list
  - Patient waiting time at the internal facility

Current limitations:

- Use of exponential distribution for vacation lengths and interarrival and service times
- More efficient computation of performance measures is possible
- Various extensions should allow for more realistic models (e.g. unscheduled patients, multiple doctors, . . . )
Upcoming research

- Use of Phase Type distributions to obtain:
  - More realistic models; Phase Type distributions can be used to model a wide variety of existing distributions
  - More detailed performance measures (i.e. not limited to expected values)
- Use of Matrix analytical techniques to optimize computations
- Provide various extensions to the model (unscheduled patients, multiple doctors, . . .)
- Assess impact of size and location of service epochs on performance measures
Time for questions