Scheduling Prenatal Care Visits for Patients With Varying Medical And Social Risk Factors

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### WHAT IS PRENATAL CARE?

Preventive health care that patients receive while pregnant, including:

<table>
<thead>
<tr>
<th>Medical Tests/Screenings</th>
<th>Anticipatory Guidance</th>
<th>Psychosocial Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Laboratory tests</td>
<td>• Pregnancy</td>
<td>• Mental health</td>
</tr>
<tr>
<td>• Imaging (ultrasounds)</td>
<td>• Labor/childbirth</td>
<td>• Social support</td>
</tr>
<tr>
<td>• Vital signs</td>
<td>• Parenting</td>
<td>• Material needs</td>
</tr>
</tbody>
</table>


PRENATAL CARE IN AMERICA

• On average, the US spends approximately $111 billion annually on pregnancy, birth, and postpartum care [1].

• Despite this, the U.S. has the worst maternal mortality rate amongst peer high income nations [2].

• Women of color are disproportionately affected:
  • The maternal mortality rate for non-Hispanic black women is 2.5 times the rate for non-Hispanic white women and 3.1 times the rate for Hispanic women.
CURRENT PRENATAL CARE MODEL

- Despite medical advancements, prenatal care delivery recommendations and guidelines have not changed since 1930.
- Patients generally follow the same “one size fits all” paradigm [3]:

[Diagram showing prenatal care schedule]
REDESIGNING PRENATAL CARE

Need to consider two factors:

- **What** services do we need to provide?
- **How** should we deliver care? (frequency of appointments and modality)

**What**

Evidence-based prenatal care services that correlate with improved maternal and fetal outcomes [3]:

Examples:
- Gestational Diabetes screening
- Vaccinations
- Ultrasounds, etc.

**How**

Reducing the frequency of prenatal visits did not negatively impact maternal and neonatal outcomes for low risk patients [4].

12 – 14 visit pathways can be harmful for low-risk patients [5].

Telemedicine provides similar maternal and fetal outcomes, while providing high patient satisfaction and cost-savings [6].
REDESIGNING PRENATAL CARE

<table>
<thead>
<tr>
<th>Medical Need</th>
<th>Support Need</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Medical Need</td>
<td>Low Support Need</td>
</tr>
<tr>
<td>High Medical Need</td>
<td>High Support Need</td>
</tr>
</tbody>
</table>

Provider Type, Screening, Treatment Recommendations

Education, Counseling, Material Needs

[7, Fig. 1]
RIGHTSIZED APPROACH

• Research shows that medical and psychosocial risk factors contribute to poor maternal and fetal outcomes [7].

• Therefore, patients are assigned a score based on their medical and psychosocial risk factors.

[7, Fig. 1]
INCORPORATING TELEHEALTH

• Four visits *must* be completed **in-person** [8]:
  • First visit (patient history, labs, physical exam)
  • 28 weeks (labs, vaccinations)
  • 36 weeks (strep test, physical exam)
  • 39 weeks (delivery planning)

• Monitoring in pregnancy *can* be completed via **telehealth** [8]:
  • Blood pressure
  • Weight
  • Fetal heart tones
  • Fundal height
Main question: how can we assess the operational impacts and quality of this new prenatal care model?
PROBLEM DESCRIPTION

• Patients arrive to a single clinic.
• Upon arrival patients are classified.
  • Medical & psychosocial factors $\rightarrow$ appointment pathway.
• At the end of each week, the clinic schedules new patients for all pathway appointments.
• The clinic allows for rescheduling of existing patients.

How can we schedule these patients to minimize patient delay and the number of appointments rescheduled?
PROBLEM DESCRIPTION

• To determine the quality of the schedule, two metrics are defined:
  • **Patient delay**: patients should be scheduled as close as possible to the target weeks in their pathways.
  • **Number of appointments rescheduled**: it is inconvenient for a patient to repeatedly need to adjust plans due to appointment rescheduling.
ASSUMPTIONS

• Punctual patients – no tardiness or no-shows.
• Important screenings/tests must be scheduled as close as possible to target date.
• Appointments within a certain time window of the scheduling decision cannot be rescheduled.
  • e.g. appointments within the next month cannot be rescheduled.
• Overbooking is not allowed.
RESEARCH OBJECTIVES

• Propose an operations research driven approach to schedule patients for their prenatal appointments.
  • Optimization-embedded simulation model.

• Provide a flexible methodology to quantify a patient-centered operational impact of the proposed prenatal care model.
METHODOLOGY

Layer 1: Discrete Event Simulation
• This simulation model simulates patient arrivals, their classifications based on medical and psychosocial risk factors, gestational age, and corresponding appointment pathways.

Layer 2: Mixed Integer Linear Programming Model (MILP)
• Embedded within the simulation model, the MILP finds the optimal schedule that minimizes patient delay and number of appointments rescheduled.
• Schedules new patients for all appointment pathways and reschedules existing patients if needed.
SETS:

\{p \in P\}: Set of all patients, including both existing patients and new arrivals.
\{n \in N\}: Set of all new patients (\(N \subset P\)).
\{v \in V^p\}: For each patient, the pathway appointments still left in their treatment. This set does not include appointments that have already passed.
\{w \in W\}: Set of all weeks in the planning horizon.
\{s \in S\}: Set of all stages (i.e. weekly).
MATHEMATICAL FORMULATION

Decision Variables:

$X_{pvw}$: Binary variable; 1 if patient $p$ has pathway appointment $v$ scheduled in week $w$, 0 otherwise.

$Y_{pv}$: Binary variable; 1 if patient $p$ has pathway appointment $v$ moved/rescheduled, 0 otherwise.

$T_p$: Total tardiness per patient $p$. 
MATHEMATICAL FORMULATION

Parameters:

$C$: Number of appointment slots available per week.
$L_p$: Maximum number of appointments rescheduled per patient.
$B_{pv}$: The goal week that pathway appointment $v$ should be scheduled for patient $p$.
$U_{p_0}$: The latest week that pathway appointment $v$ can be scheduled for patient $p$.
$Z_{p_{0w}}$: Schedule from the previous stage (only includes existing patients); 1 if patient $p$ was scheduled for pathway appointment $v$ in week $w$, 0 otherwise.
$A_p$: The number of appointment moves per patient; cumulative, after each stage $A_p$ is incremented by $Y_{p_{0w}}$. 
MATHEMATICAL FORMULATION

Model (for any given stage $s$):

Minimize $\sum_{p \in P} T_p + \sum_{p \in P} \sum_{v \in V_p} Y_{pvs}$

Subject to:

The number of appointments scheduled per week cannot exceed weekly capacity.

Each appointment must be scheduled in some week.
**MATHEMATICAL FORMULATION**

Constraints continued:

- Appointments must be scheduled in sequential order (pathway order).

- Appointments cannot be scheduled before the goal week and cannot be scheduled past some upper bound.

- The number of appointments rescheduled is at least the difference between the current and past schedule.
MATHEMATICAL FORMULATION

Constraints continued:

- Patients can only be rescheduled a certain number of times.
- Appointments within a certain time window cannot be rescheduled.
- Tardiness is the difference between the scheduled week and goal week.

\[ X_{pvws} \text{ binary, } Y_{pvws} \text{ binary, } T_p \geq 0 \] (10)
HIERARCHICAL APPROACH

Obj 1

Minimize \( \sum_{p \in P} T_p \) + \( \sum_{p \in P} \sum_{v \in V_P} Y_{pvs} \)

subject to:

Constraints 1 – 10

Obtain Obj 1*

Minimize \( \sum_{p \in P} \sum_{v \in V_P} Y_{pvs} \)

subject to:

Constraints 1 – 10

\( \sum_{p \in P} T_p \leq \text{Obj 1}^* \)

Obtain Obj 2*
MODEL OUTLINE

**Optimization 1**
- **Inputs**: Patients & pathways
- **Outputs**: Schedule 1

**Optimization 2**
- **Inputs**: New patients & pathways, Schedule 1
- **Outputs**: Schedule 2 & appointments rescheduled

Simulation Time Horizon

Week 0: Patients arrive & assigned to pathway

Week 1: Patients arrive & assigned to pathway

Week 2: ...
EXAMPLE INSTANCE

Data:
• Capacity = 3 appointments/week
• Appointment delay maximum = 2 weeks
• Maximum number of appointments rescheduled/patient = 3
• Can’t reschedule appointments within one week

• Low risk patients follow pathway: 3 weeks → 5 weeks → 10 weeks
• High risk patients follow pathway:
  3 weeks → 5 weeks → 7 weeks → 9 weeks → 11 weeks
EXAMPLE INSTANCE

Week 1:
3 low risk patients arrive to the clinic
→ since capacity = 3, they are scheduled on their goal weeks

Tardiness = 0; Number of appointments rescheduled = 0
**EXAMPLE INSTANCE**

**Week 2:**

2 high risk patients arrive to the clinic

At full capacity for weeks 3 and 5, so we incur delays

What if we want to prioritize high risk patients?

Schedule low risk patients

<table>
<thead>
<tr>
<th></th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
<th>Week 5</th>
<th>Week 6</th>
<th>Week 7</th>
<th>Week 8</th>
<th>Week 9</th>
<th>Week 10</th>
<th>Week 11</th>
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</thead>
<tbody>
<tr>
<td>Patient 1</td>
<td>1</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
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<tr>
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<td>4</td>
<td>5</td>
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<tr>
<td>Patient 5</td>
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<td>3</td>
<td>4</td>
<td>5</td>
<td></td>
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</tr>
</tbody>
</table>

**Tardiness = 4; Number of appointments rescheduled = 0**
FUTURE WORK

• Simulation model

• Policies:
  • Trimester appointments
  • Single appointments

• Shifting risk levels:
  • What happens if a patient becomes high risk mid-pregnancy?

• Telehealth:
  • Varying patient preferences
  • Capacity

• Patient no-shows/tardiness
REFERENCES