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:

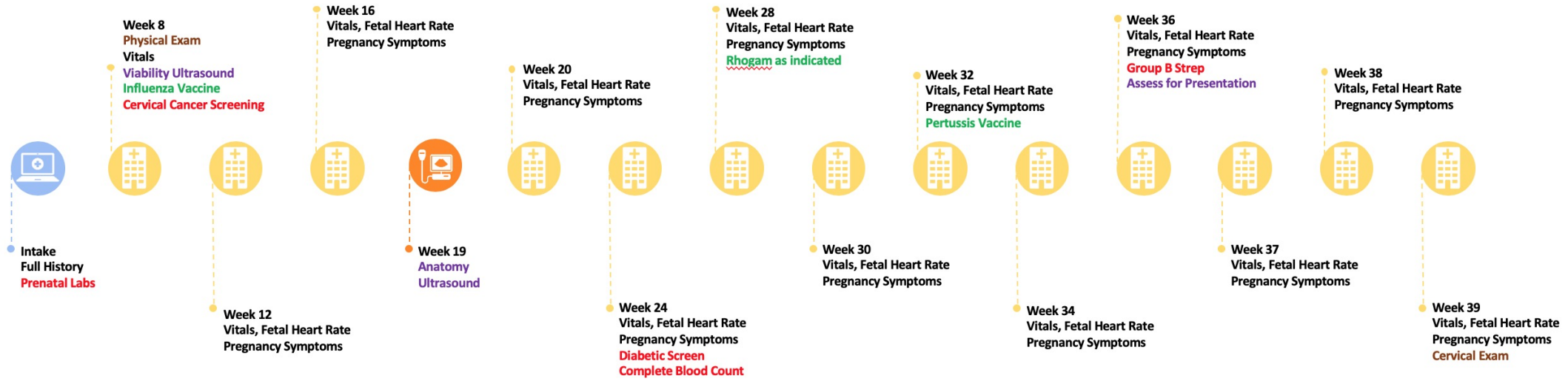
Medical Tests/Screenings	Anticipatory Guidance	Psychosocial Support
• Laboratory tests • Imaging (ultrasounds) • Vital signs	• Pregnancy • Labor/childbirth • Parenting	• Mental health • Social support • Material needs

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]:



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.

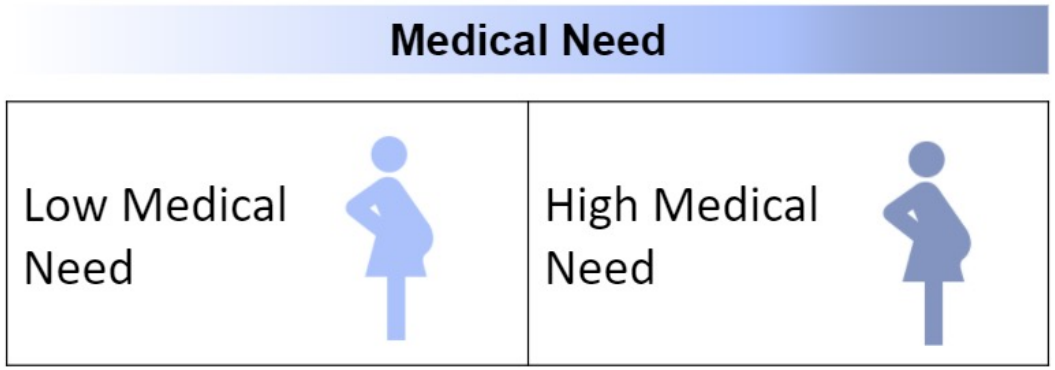
How

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



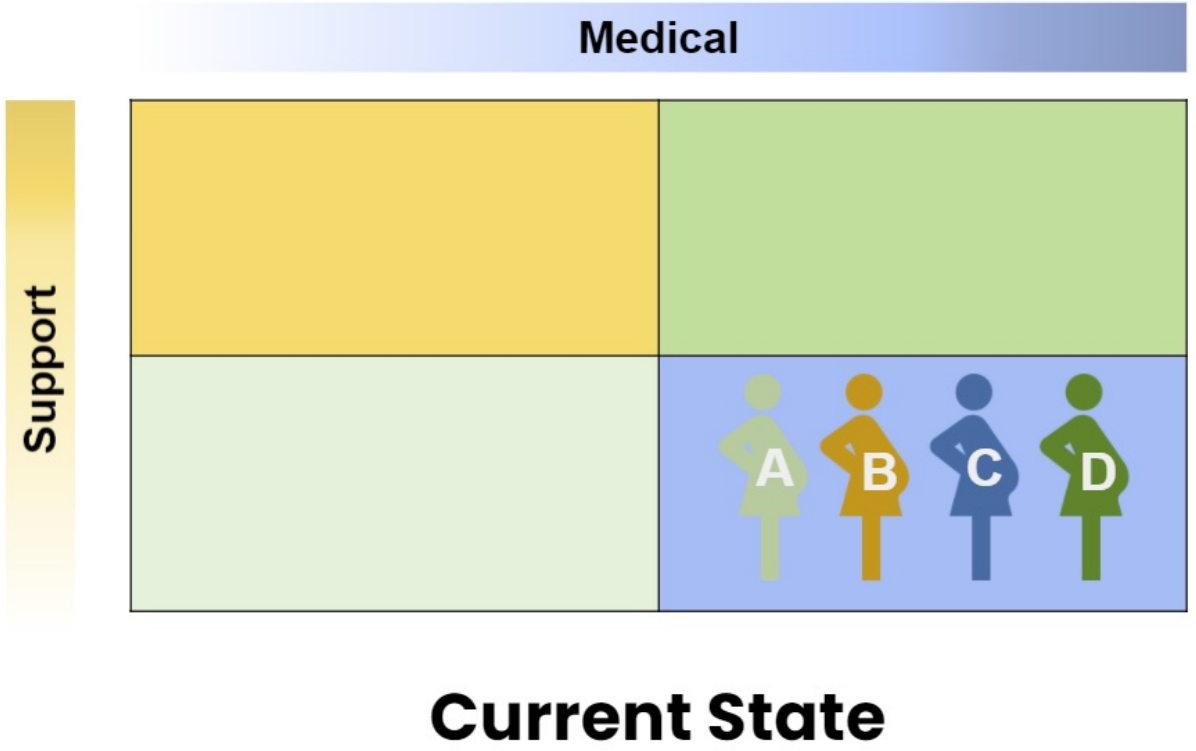
Provider Type, Screening, Treatment Recommendations

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.



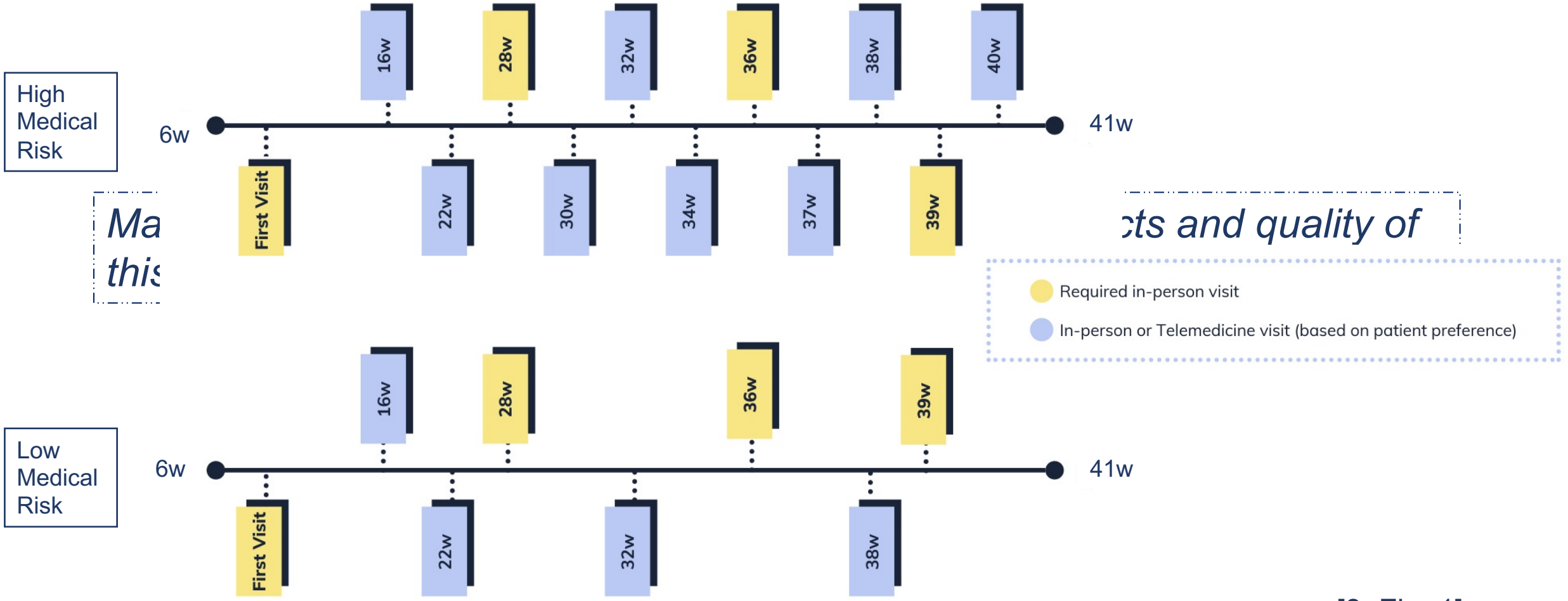
[7, Fig. 1]

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

PROPOSED RIGHTSIZED PATHWAYS



[8, Fig. 1]

PROBLEM DESCRIPTION

- Patients arrive to a single clinic.
- Upon arrival patients are classified.
  - Medical & psychosocial factors → 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.

MATHEMATICAL FORMULATION

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

Y_{pvs}: 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_{pv}: The latest week that pathway appointment v can be scheduled for patient p.
Z_{pvw}: 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_{pvs}.

MATHEMATICAL FORMULATION

Model (for any given stage *s*):

$$\text{Minimize} \sum_{p \in P} T_p + \sum_{p \in P} \sum_{v \in V^p} Y_{pvs}$$

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.

$$X_{pvws}\ binary, Y_{pvs}\ binary, T_p \geq 0 \qquad (10)$$

HIERARCHICAL APPROACH

Obj 1 Obj 2

$$\textbf{Minimize} \sum_{p \in P} T_p + \sum_{p \in P} \sum_{v \in V^p} Y_{pvs}$$

$$\textbf{subject to:}$$

$$\textbf{Constraints } 1 - 10$$

$$\textbf{Minimize} \sum_{p \in P} T_p$$

$$\textbf{subject to:}$$

$$\textbf{Constraints } 1 - 10$$

→ Obtain Obj 1*

$$\textbf{Minimize} \sum_{p \in P} \sum_{v \in V^p} Y_{pvs}$$

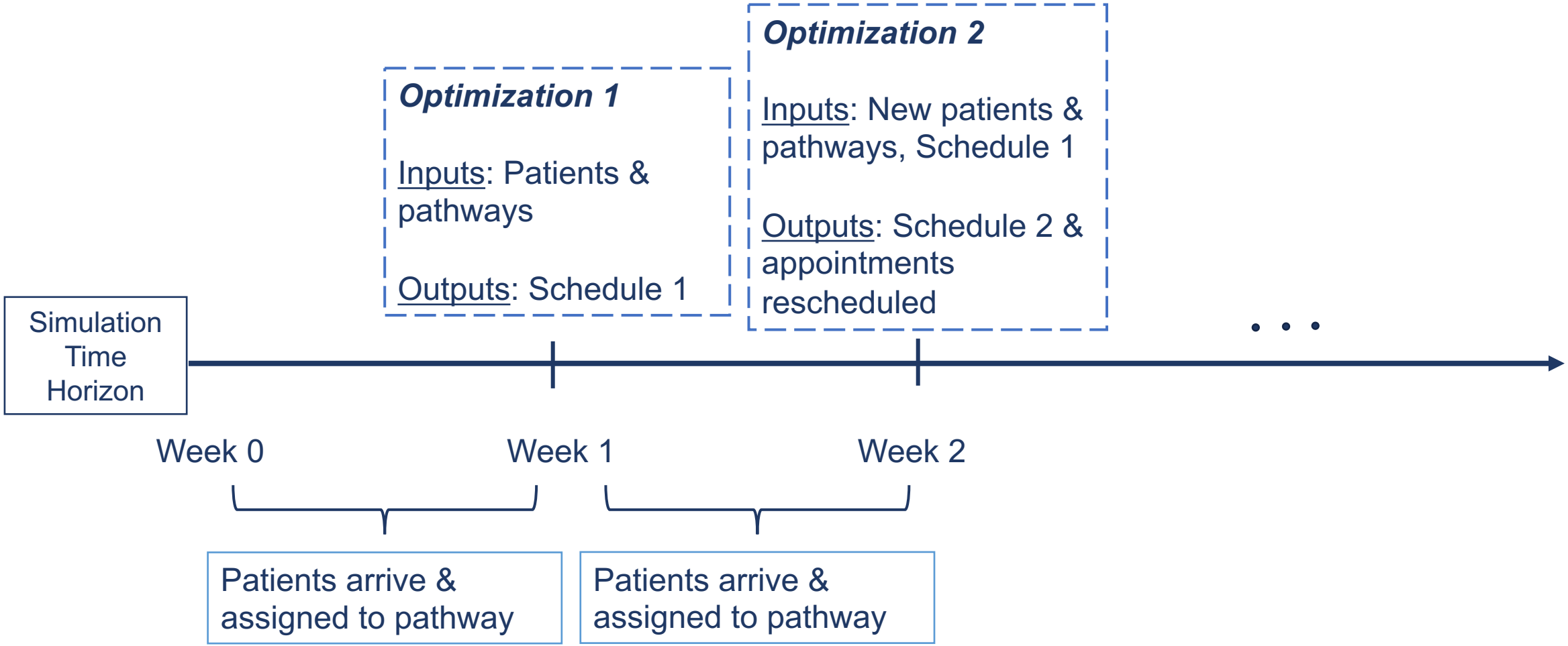
$$\textbf{subject to:}$$

$$\textbf{Constraints } 1 - 10$$

$$\sum_{p \in P} T_p \leq Obj\ 1^*$$

→ Obtain Obj 2*

MODEL OUTLINE



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

	Week 1	*Week 2*	*Week 3*	*Week 4*	*Week 5*	*Week 6*	*Week 7*	*Week 8*	*Week 9*	*Week 10*
Patient 1			**1**		**2**					**3**
Patient 2			**1**		**2**					**3**
Patient 3			**1**		**2**					**3**

Tardiness = 0; Number of appointments rescheduled = 0

EXAMPLE INSTANCE

Week 2:

2 high risk patients arrive to the clinic

What if we have capacity to schedule 3 high risk patients? → delays

What if we have capacity to schedule 5 patients? → delays

What if we have capacity to schedule low risk patients

	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11
Patient 1		1		2					3	
Patient 2		1			2				3	
Patient 3		1			2				3	
Patient 4			1	2		3		4		5
Patient 5			1	2		3		4		5

Tardiness = 4; Number of appointments rescheduled = 0

Tardiness = 4; Number of appointments rescheduled = 2

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

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