STAFFING MODELS FOR BLOOD DONATION CENTRES: A MODEL-DRIVEN APPROACH

by

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Dalhousie University is located in Mi'kma'ki, the ancestral and unceded territory of the Mi'kmaq. We are all Treaty people.

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ABSTRACT

In 2014, Blake & Shimla published a paper outlining a method to determine the minimum staffing requirements for donation clinics operated by *Canadian Blood Services* (CBS). This project builds upon their work by developing a model capable of generating optimized staff schedules based on calculated requirements. The design consists of two integer programming models, both solved using a simplified column generation algorithm. Model 1 determines the optimal clinic length and bed count required to meet user-defined targets. These values are then fed into Model 2, which assigns shifts to the schedule based on the calculated staffing requirements. The intent of the model is to provide an optimal starting point for the user to then manually adapt to fit the unique needs of each clinic. When compared to schedules generated by the client, the model was able to produce solutions of similar or higher quality while also minimizing the operational costs of the clinics. Beyond optimizing clinic scheduling for CBS, this framework can be adapted and applied to other areas within the healthcare industry.

LIST OF ABBREVIATIONS USED

BDSP	Blood Donation Scheduling Problem
CBS	Canadian Blood Services
FTE	Full-Time Equivalent
NSP	Nurse Scheduling Problem

CHAPTER 1: INTRODUCTION

The field of operations research encompasses a broad range of methods and techniques designed to improve user decision-making capabilities and maximize process efficiency. Since the end of World War II, it has played a key role in shaping many industries, ranging from military strategy to supply chain (Potts & Strusevich, 2009). Scheduling problems are a classic application of operations research that focuses on optimizing the allocation of resources over a period of time. This thesis, conducted in collaboration with *Canadian Blood Services* (CBS) and the Industrial Engineering Department at Dalhousie University, explores the use of operations research methods to optimize the staff scheduling process in CBS donation centres. Using deterministic flow shop calculations and integer programming, the project develops a model that improves CBS's ability to efficiently staff their donation centres, ensuring the continued timely delivery of blood and blood products to Canadians.

1.1 BACKGROUND

Across all Canadian provinces and territories, excluding Québec, CBS is responsible for the collection and distribution of blood and blood products, including whole blood, platelets and multi-plasma, and large-volume source plasma. These products are collected through CBS's network of 35 permanent donor centres and over 4,000 mobile donor centres. Mobile donor centers host donation clinics approximately once a month, while permanent centres operate year-round. Regardless of the type of centre, donation appointments must be scheduled in advance and can be booked through CBS's website up to the day of the appointment (Canadian Blood Services).

1.1.1 DONATION PROCESS

Upon arriving at the donation centre, donors are checked in either by a donor services representative or through the self-registration kiosk. If they have not already done so online, the donor will be asked to fill out an electronic questionnaire to assess their eligibility to donate. A screener reviews the questionnaire with the individual and conducts any additional required testing. If no concerns are identified, the donor is then ushered to a bed, where a bed attendant starts the collection process.

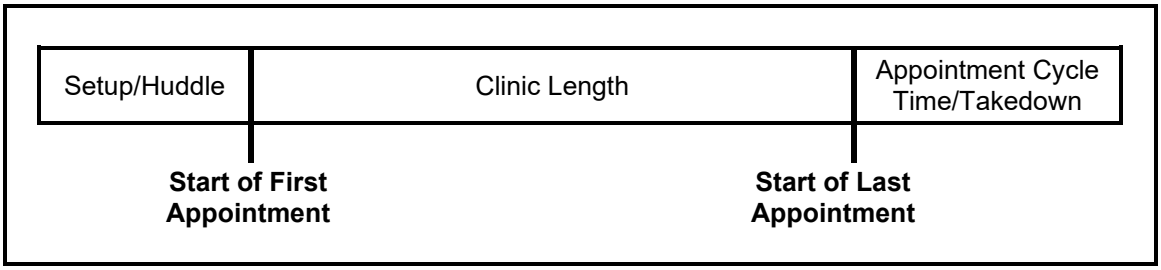
Following the appointment, donors are provided light refreshments and asked to remain in the recovery area for a brief period of time. This allows staff to monitor individuals and ensure that there are no residual side effects from the donation process. The donated units are tested for transmissible diseases, processed into components, and stored in environments that optimize their quality and shelf-life. (Canadian Blood Services, 2019).

1.1.2 CLINIC SCHEDULING

The process begins a year in advance of implementation with the planning team, who provides scheduling parameters such as target donation yield, number of available beds, and clinic duration. If the model includes a whole blood clinic, an industrial engineer on the scheduling team will input the information into an Arena simulation to calculate the number of bed attendants and screeners needed to operate the clinic. Staffing requirements for the remaining clinic types and job classifications are determined using combination tables. These values are then used to develop an initial schedule in Microsoft Excel, which is subsequently reviewed with the clinical or planning team to make any necessary adjustments.

Clinics are identified using an ‘x-hour, y-bed’ nomenclature, where x and y denote the clinic length and number of beds used, respectively. Clinic length refers to the length of time during which the clinic will be accepting donor arrivals and is defined by the start times of the first and last donor appointments. Note that this is not an indicator of the total operational length of the clinic, as there is still work done before and after this period.

Figure 1.1 General Breakdown of Clinic Schedule Elements



As shown in Figure 1.2, clinic schedules display shifts in 15-minute increments and denote each employee’s start time, end time, and assigned breaks. Cells labelled with the letter “C” indicate that the employee is scheduled for a 15-minute break, while those marked with “B” denote a 30-minute meal break. Furthermore, shaded timestamps identify time periods allocated for station setup and takedown activities.

Figure 1.2 Example of Clinic Schedule.

	07:30AM – 07:45AM	07:45AM – 08:00AM	08:00AM – 08:15AM	08:15AM – 08:30AM	08:30AM – 08:45AM	08:45AM – 09:00PM	09:00PM – 09:15PM	09:15PM – 09:30PM	09:30PM – 09:45PM	09:45PM – 10:00PM	10:00PM – 10:15PM	10:15PM – 10:30PM	10:30PM – 10:45PM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	**01:00PM – 01:15PM**	**01:15PM – 01:30PM**	**01:30PM – 01:45PM**
Staff 1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1	1	1	
Staff 2	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1	1	
Staff 3		1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1	1
Staff 4		1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1

This format allows schedulers to manipulate the employee shifts to accommodate any requests made by the operations team while ensuring sufficient break coverage throughout the duration of the clinic. However, the initial drafting process can be time-consuming, and solution quality may vary depending on the proficiency of the scheduler.

1.1.2.1 STAFFING REQUIREMENTS

In order to maintain their operations, clinics require qualified staff to run each of the different stations. Depending on the type of donation being collected, screener and bed attendant roles are filled by either donor care associates or registered nurses. In addition, whole blood and large-volume source plasma clinics require nurse consultants, who are responsible for overseeing clinical operations and intervening if a donor experiences any adverse effects during the appointment. Donor services representatives are considered a shared resource and not assigned to specific clinics.

Table 1.1 Summary of Staff Type Requirements based on Job and Clinic Type.

Job Type	**Clinic Type**		
	Whole Blood	**Platelets & Multi-Plasma**	**Large-Volume Source Plasma**
Screeners	Donor Care Associate	Registered Nurse	Donor Care Associate
Bed Attendants	Donor Care Associate	Registered Nurse	Donor Care Associate
Additional Staff	Nurse Consultant	-	Nurse Consultant
	Donor Services Representative		

It is important to note that although nurse consultants are also registered nurses, they are considered a separate class than those working in the platelets and multi-plasma clinics as they may not necessarily be trained in phlebotomy. The following equation, proposed by Blake & Shimla (2014), uses deterministic flow shop calculations equation to calculate the minimum number of staff required per hour by a clinic.

Table 1.2 Equation for Minimum Staffing Requirements (Blake & Shimla, 2014)

Sets	
I	Set of clinic types, indexed by $i \in \{WB, PLTMP, LVSP\}$.
J	Set of job types, indexed by $j \in \{Screener, Attendant\}$.
Parameters	
E_{ij}	Minimum number of employees of job type j required per hour to operate clinic i.
B_i	Number of beds used in clinic i.
w_{ij}	Labour Time, in minutes, for an employee of job type j in clinic i.
τ_i	Turn Rate, in units per bed per hour, for clinic i.

$$E_{ij} = \left\lceil \frac{(w_{ij})(B_i)(\tau_i)}{60} \right\rceil \quad (1)$$

WORKING EXAMPLE

Consider a 6-bed whole blood donation clinic with a target turn rate of 2.4 donations per hour. If the labour time for screening a donor is 8 minutes, the minimum number of screeners required to operate the clinic would be as follows:

$$E_{WB,Screen} = \left\lceil \frac{(8)(2.4)(6)}{60} \right\rceil = \lceil 1.92 \rceil = 2/\text{hour}$$

Labor time refers to the period during which staff are actively interacting with the donor. During the collection process, there is a 'bleed time' between scheduled tasks, during which the attending donor care associate often engages in other, unrelated work. This time can be deducted from the station's total cycle time to determine the labour time. Assuming a cycle time of 15 minutes and a bleed time of 4 minutes, the minimum number of bed attendants required to operate the whole blood clinic would be as follows:

$$E_{WB,Attend} = \left\lceil \frac{(15-4)(2.4)(6)}{60} \right\rceil = \lceil 2.64 \rceil = 3/\text{hour}$$

NURSE CONSULTANTS

Unlike screeners and bed attendants, the number of nurse consultants required is not dictated by patient flow. Instead, the requirement is that clinics must have at least one nurse consultant active (i.e., not on break) at all times while donors are present. Nurse consultant staffing requirements are calculated based on clinic length (L_i), in hours, and the maximum paid employee shift length (D_{Max}). Let $E_{i,NC}$ is the minimum number of total nurse consultants required to operate clinic i.

$$E_{i,NC} = \left\lceil \frac{L_i}{D_{Max}} \right\rceil \tag{2}$$

At CBS, the total length of an employee's shift cannot exceed 8 hours, or one *full-time equivalent* (FTE). Full time shifts include two 15-minute paid breaks and one 30-minute unpaid break, making the maximum paid shift length 7.5 hours. Assuming the whole blood clinic has a clinic length of 7 hours, the total number of nurse consultants required would be as follows:

$$E_{WB,NC} = \left\lceil \frac{7}{7.5} \right\rceil = \lceil 0.93 \rceil = 1$$

DONOR SERVICES REPRESENTATIVES

Unless there is an extremely considerable number of appointments that day, centres will typically only need to schedule one donor services representative. According to information provided by the client, the number of donor services representatives required can be calculated using a cycle time of 2.7 minutes. Let $E_{WB,DSR}$ be the number of donor services representatives required to operate the whole blood clinic.

$$E_{WB,DSR} = \left\lceil \frac{(2.7)(2.4)(6)}{60} \right\rceil = \lceil 0.648 \rceil = 1/\text{hour}$$

1.1.2.2 EMPLOYEE SHIFT LENGTH

The length of an employee's shift is typically determined by job classification and clinic length. Each job classification has a specific set of roles and responsibilities that may require an on-site presence outside of regular clinic hours. For example, bed attendants are responsible for setup and takedown activities, meaning staff must typically arrive before the first appointment and stay after the last donor has left the clinic. Furthermore, employees are typically required to attend a 15-minute team huddle at or near the start of their shift, ideally before the first donor appointment. Using the working example, let D_{ij} be the length of shift assigned to employees of job type j working in clinic i, and z_H be the length of time, in minutes, allocated for attending the team huddle.

SCREENERS

Screeners are only required from the start of the first appointment until the last donor has been interviewed and processed, plus an additional 15-minutes for team huddle. Recall that CBS displays employee shifts in 15-minute time blocks. To align with the organization's real-world practices, all shifts are rounded up to the nearest 15 minutes.

$$D_{WB,Screen} = z_H + L_{WB} + w_{WB,Screen} = \frac{15}{60} + 7 + \frac{8}{60} = 7.38\ hrs \cong 7.5\ hrs$$

BED ATTENDANTS

Bed attendants are responsible for the setup and takedown of bed stations. Since these tasks must be performed outside of the regular clinic hours, safety protocols require that at least two employees be assigned. Schedulers typically allocate 15 minutes before the team huddle for setup and 60 minutes at the end of the day for takedown. These time windows represent the amount of time required to complete the respective tasks for all stations. Therefore, it can be assumed that the takedown time includes the cycle time of the last donor appointment. Let z_S and z_T be the length of time, in minutes, required to setup and takedown all bed stations, respectively.

$$D_{WB,Attend} = z_S + z_H + L_{WB} + z_T = \frac{15}{60} + \frac{15}{60} + 7 + \frac{60}{60} = 8.5\ hrs$$

Given that the required shift length for bed attendants exceeds one FTE, shift start times must be staggered to ensure the necessary coverage without violating the shift constraint.

NURSE CONSULTANTS

Given that NCs are responsible for managing any medical complications that may arise during appointments, they must be present whenever donors are in the clinic. To calculate the nurse consultants staffing requirements, assume that the duration of a whole blood appointment, denoted by z_A, is 25 minutes.

$$D_{WB,NC} = z_H + L_{WB} + z_A = \frac{15}{60} + 7 + \frac{25}{60} = 7.67\ hrs \cong 7.75\ hrs$$

DONOR SERVICES REPRESENTATIVES

Donor services representatives are responsible for administrative tasks and are not assigned to any specific clinic. As such, their shift duration can be based on the overall length of centre operations, equalling to the duration of the longest clinic with an additional 15-minute buffer on either side.

$$D_{WB,DSR} = \frac{15}{60} + L_{WB} + \frac{15}{60} = \frac{15}{60} + 7 + \frac{15}{60} = 7.5\ hrs$$

1.1.2.3 CALCULATING FLOAT STAFF

To ensure sufficient break coverage throughout the day, additional staff members, referred to as float staff, are required in addition to the previously outlined staffing requirements. Float requirements are calculated on the basis of total amount of coverage required by the clinic and the number of available hours each float can contribute. Employees are unavailable when they are on break or attending the staff huddle as they are unable to tend to patients or other clinic tasks during this time. The number of breaks each employee receives is determined by the length of their shift. Table 1.3 presents a general outline of the break schedule; however, these allocations may vary depending on provincial regulations and employee classifications.

Table 1.3 General Break Allocation by Length of Shift.

Min. Shift (hrs)	Max. Shift (hrs)	Paid Breaks (0.25 hrs)	Unpaid Breaks (0.5 hrs)
0	4	0	0
4	5	1	0
5	7	1	1
7	8	2	1

Using the information provided, the number of float staff required for sufficient break coverage can be calculated using the following equation:

Table 1.4 Equation for Float Staff

Sets	
I	Set of clinic types, indexed by $i \in \{WB, PLTMP, LVSP\}$.
J	Set of job types, indexed by $j \in \{Screener, Attendant\}$.
Parameters	
F_{ij}	Minimum number of float staff of job type j required to cover breaks in clinic i.
E_{ij}	Minimum number of employees of job type j required per hour to operate clinic i.
D_{ij}	Shift Length, in hours, for employees of job type j in clinic i.
z_h	Length of time, in minutes, allocated per shift to team huddles.
α_{ij}	Number of paid breaks allocated to employees of type j in clinic i.
β_{ij}	Number of unpaid breaks allocated to employees of type j in clinic i.

$$F_{ij} = \frac{E_{ij}\left(0.25\alpha_{ij} + 0.5\beta_{ij} + z_H\right)}{D_{ij} - z_H - 0.25\alpha_{ij} - 0.5\beta_{ij}} \quad (3)$$

Applying this formula to the working example, the required float coverage for each job type is as follows:

$$F_{WB,Screen} = \frac{2[(2 * 0.25) + (1 * 0.5) + 0.25]}{7.5 - 0.25 - (2 * 0.25) - (1 * 0.5)} = \frac{2.5}{6.25} = 0.4$$

$$F_{WB,Attend} = \frac{3[(2 * 0.25) + (1 * 0.5) + 0.25]}{8 - 0.25 - (2 * 0.25) - (1 * 0.5)} = \frac{3.75}{6.75} = 0.55$$

$$F_{WB,NC} = \frac{1[(2 * 0.25) + (1 * 0.5) + 0.25]}{7.75 - 0.25 - (2 * 0.25) - (1 * 0.5)} = \frac{1.25}{6.5} = 0.19$$

Due to the extended bleed time required during platelets and multi-plasma appointments, registered nurses are able to provide break coverage for one another and therefore, do not require floats. Additionally, donor services representatives do not require any break coverage. Donor care associate floats are the most versatile, as they can cover for screeners and bed attendants in both whole blood and large-volume source plasma clinics. However, donor care associates cannot cover for NCs, and similarly, nurse consultant floats can only provide coverage for NCs and donor care associate screeners.

Float staff are not assigned to specific clinics but rather function as a shared resource for the donation centre. Once the float staffing requirements have been calculated, values can be consolidated based on the type of employee coverage needed. This process will be further detailed in Chapter 3.

1.2 PROJECT DEFINITION

This project aims to develop a model-driven staff scheduling approach for CBS based on the work conducted by Blake & Shimla (2014). The proposed design must be able to reduce reliance on employee experience and combination tables, while producing high-quality clinic schedules that meet user-defined targets and parameters.

Overall effectiveness of a staffing model is defined by its ability to balance between minimizing idle staff time and maintaining sufficient resources for the clinic to operate smoothly throughout the day. Overstaffing decreases efficiency, measured in labour hours per unit, and wastes resources that could be better utilized elsewhere, while understaffing can cause productivity issues like appointment backlogs, donor delays, and employee burnout.

1.2.1 DESIGN OBJECTIVES

Through semi-structured interviews and walkthroughs, the client was able to provide feedback on their user experiences, highlighting both the advantages and limitations of the current process. From these conversations, several key concepts emerged that would be used to drive application design.

(1) Adaptable Requirements for Scheduling Diversity

It is not uncommon for donation centres to run several clinics at one time, each with their own unique set of scheduling requirements. In addition, schedulers often use techniques, such as staggering shift start times, to ensure clinics have adequate break coverage throughout the day. It is important that the application accommodate these requests while adhering to universal requirements such as maximum shift lengths and provincial health and safety regulations.

(2) Shift From Resource-Based Scheduling

Historically, CBS has based its schedule development on resource availability, such as staff and beds. However, the organization has adopted a yield-driven approach, focusing on creating schedules driven by target collection yields.

(3) Prioritizing Full Time Shifts

To maintain a stable workforce and ensure a consistent flow of donations, CBS offers staff full-time shift work, regardless of its impact on optimization metrics.

1.2.2 WORKING ASSUMPTIONS

Scheduling problems are highly influenced by external factors, including resource downtime, conflicts in interests or objectives, and unforeseen events such as weather disruptions or machine breakdowns. This project establishes a foundation for standardizing the scheduling process, necessitating a certain level of generalization, to serve as a baseline. As such, the following assumptions have been made:

- The relationship between physical factors (beds, staff, clinic duration) and the desired outcome (donation yield) was assumed to be calculable using mathematical equations and modelling.
- Appointments of the same clinic type yield the same number of units and, if kept by the donor, is completed without interruption.

Depending on the clinical team, schedules may need to account for unique circumstances or special requests. To maintain a manageable scope, the project has determined that such adjustments to the baseline scheduling process are out of scope. Instead, the aim is to provide an optimal starting point, allowing schedulers the flexibility to make modifications as needed.

CHAPTER 2: LITERATURE REVIEW

Scheduling problems are typically defined by a need to allocate limited resources over a set period of time. Often used to optimize metrics such as overall cost, user satisfaction and staff productivity, this set of optimization problems is applicable to a wide range of industries and academic disciplines (Potts & Strusevich, 2009). The sub-problem addressed in this project is the *blood donation scheduling problem* (BDSP), which focuses the management of blood collection clinics.

The following literature review was conducted using Google Scholar in order to develop a better understanding of previous research and help establish the theoretical framework for the project. To avoid over restricting the search engine by using specific keywords (i.e., “blood donation scheduling”), articles were filtered using several broader terms, including “blood collection” “scheduling”, “integer programming”, “operations research” and “healthcare”, as well as limiting the list to articles published in the past decade. This process yielded an initial list of 157 papers, of which two literature reviews were found to be relevant to the project.

2.1 BLOOD DONATION SCHEDULING PROBLEM

In 2017, Baş Güre et al. conducted a literature review that identified a notable gap in operations research related to the optimization of blood donation processes. Of the 218 papers reviewed, 17% focused on blood collection, while the remaining addressed aspects of storage and utilization of the blood product. Using the example of donor appointment scheduling, the authors theorize that the gaps in literature stem from the unique challenges of the system being both service-oriented and production-driven. They highlight the need for blood collection systems to balance product-related goals, such as meeting collection targets and reducing costs, with service-related metrics like minimizing wait times and ensuring donor satisfaction. Furthermore, due to the limited shelf life of blood donations, BDSPs cannot stockpile inventory to create buffers. This prevents them from leveraging the extensive literature available for optimizing manufacturing schedules, further complicating the scheduling and resource allocation process. While Baş Güre et al. (2017) effectively highlight the lack of research on blood collection in operations

research, their donor-centered review of the blood donation supply chain system does not fully align with the focus of the current project and thus may overlook relevant literature.

The second literature review, written by Williams et al. (2020), provides a focused literature review specifically addressing the blood collection process. Of the 46 articles analyzed by the authors, only 5 focused on staff utilization, one being the paper by Blake & Shimla (2014), which serves as the foundation for the current project. Each of the articles proposed a different method for calculating general staffing requirements, such as simulation, queuing theory, and data mining. However, only two of these articles utilized this information to generate staff schedules. Williams et al. (2020) comments on the lack of attention given to the impact of employee break times on intra-day scheduling and call for an increase in both the quantity and diversity of literature surrounding this topic.

2.2 EXPANDING THE SEARCH CRITERIA

To broaden the scope to include adjacent areas of study, “blood collection” was removed from the list of search keywords. This led to a series of studies on the *nurse scheduling problem* (NSP), a widely studied extension of the scheduling problem focusing on nurses within healthcare facilities. Like the BDSP, NSPs must account for factors such as break requirements, patient flow, and shift coverage.

One article, written by Wong et al. (2014), proposes a two-step heuristic approach for scheduling nurses within the emergency department. The process begins with generating an initial schedule that meets all hard constraints (i.e., union requirements, shift coverage, and approved days off) through the use of shift assignment heuristics. The schedule is then refined using a local search algorithm to incorporate as many nurse preferences as possible. When compared to a 0-1 programming model developed for the same scheduling period, the heuristic approach was notably faster, though it did not always reach the optimal solution. Despite this, the clinic favored the heuristic method due to its cost-effectiveness, adaptability, and user-friendly interface over the optimal, but less efficient, programming model.

Upon further exploration of the literature, there are two key characteristics of NSPs that would make applying proposed scheduling methods to the BDSP challenging. First, NSPs operate under the assumption of 24/7 service (Sulak & Bayhan, 2016), meaning their

solutions are not constrained by specific start and end times. In contrast, BDSPs typically operate within fixed hours of service. Second, NSPs primarily focus on scheduling a single type of employee—nurses. BDSPs, however, often require scheduling multiple employee types, each with distinct needs, and may involve managing relationships and dependencies between different roles.

2.3 INTEGER PROGRAMMING IN SCHEDULING PROBLEMS

Across both sets of literature, exact methods, particularly integer programming, are commonly used to address scheduling problems. These methods are known for their ability to guarantee an optimal solution by systematically examining all feasible options within the problem's constraints. A foundational example of this approach is Dantzig's set-covering model, introduced in 1954 to address the toll booth scheduling problem described in Edie's "Traffic Delays at Toll Booths." By assigning an integer variable to each shift type, start time, and combination of break placements, Dantzig used combinatorial optimization to determine both the minimum number of employees needed to cover all toll booths and the optimal worker schedule (Dantzig, 1954). However, when this method is applied to large-scale problems, the limitations of exact methods become evident. As the number of variables increases and the model becomes more complex, the number of feasible solutions grows exponentially, requiring significantly greater computational resources to evaluate each option for optimality. The challenge lies in balancing the need to simplify the model by reducing variables while retaining sufficient complexity to produce meaningful and accurate results. As demonstrated by Wong et al. (2014), when the computational cost of solving the problem exceeds the model's value, individuals often resort to more time-efficient approaches, such as heuristics or metaheuristics, to obtain "good enough" solutions.

Aykin (1996) addressed this limitation by proposing that rather than assigning variables to each element of a schedule (i.e., start/end time, break slot, shift type, etc.), the number of decisions can be reduced by having the model make selections based on a pre-determined set of solutions. The integer programming model developed by Aykin (1996) incorporates four sets of decision variables: one for shift assignment and three for break placement. Each variable within these sets corresponds to a valid scheduling option. Test results by the author shown a significant reduction in number of decision variables (from 69% to 90%) and a decrease in the average processing time by up to 7.69 CPU minutes.

CHAPTER 3: METHODOLOGY

The design proposed by the project uses two integer programming models to generate schedules based on the user-provided information. Both models were formulated using a simplified version of column generation, a method commonly employed to solve large-scale linear programming problems where evaluating the entire solution space is infeasible. The classical approach decomposes the original problem into a master problem and at least one subproblem, often referred to as the pricing problem. The master problem mirrors the original problem but only considers a small subset of potential solutions, known as columns. Once the master problem is solved, the subproblem generates more columns, which are subsequently added to the master problem. The process repeats by re-solving the master problem with the updated columns. The algorithm is considered optimal when the subproblem can no longer generate columns that improve the solution to the master problem (Fernandez & Hoyos, 2025). Fortunately, the number of feasible solutions is small enough that a subproblem is unnecessary, and an optimal solution can be obtained by solving a single iteration of the master problem.

The client's scheduling process is primarily influenced by two key variables: clinic length and bed count. Each combination of these variables is represented by a column in the solution set. The user defines the upper and lower bounds for the variables and may impose additional constraints, such as requiring an even bed count or ensuring that all staff members share the same start time. Clinic length values are considered in 15-minute intervals (e.g., 5 hrs, 5.25 hrs, 5.5 hrs, etc.) to ensure a comprehensive exploration of all potential durations. This level of customization and detail tailors the model to the specific real-world practices and operational needs of the organization.

3.1 MODEL 1: CLINIC CONFIGURATIONS

The purpose of the first model is to select the optimal configuration of bed count and clinic length by minimizing total costs. Solution sets are denoted using Q_i, where $i \in \{WB, PLTMP, LVSP\}$. Each solution, indexed by $q \in Q_i$, represents of a feasible configuration of bed count and clinic length based on the upper and lower limit values for clinic i set by the user. Clinic configurations are assigned penalty values based on how much their values deviate from the user-defined targets: expected collection yield, bed

count, and clinic duration. Furthermore, each is assigned a penalty modifier that reflects the relative importance the user places on achieving that specific target.

Of the three targets, expected collection yield is the primary driver of the selection process, and the only value required by the user. However, as there may be multiple clinic configurations that result in the same expected yield, the remaining targets, in addition to the penalty modifiers, provide users with the opportunity to guide the model toward a schedule that aligns with their operational needs without hindering the model's ability to reach a feasible solution.

Table 3.1 Model 1 Formulation for Clinic $\boldsymbol{i}$.

Sets	
I	Set of clinic types, indexed by i.
Q_i	Set of configurations of clinic length and bed count for clinic i, indexed by q.
Decision Variable	
x_q	Let x_q be one if configuration $q \in Q_i$ is assigned to clinic i; otherwise, $x_q = 0$.
Parameters	
B_q	Number of Beds used in clinic i for configuration q.
L_q	Clinic Length, in hours, used in clinic i for configuration q.
Y_q	Expected Collection Yield of clinic i for configuration q.
$P_{i,Beds}$	Penalty modifier for target number of beds for clinic i.
$P_{i,Length}$	Penalty modifier for target clinic length, in hours, for clinic i.
$P_{i,Yield}$	Penalty modifier for target collection yield for clinic i.
$T_{i,Beds}$	User-generated target value for number of beds for clinic i.
$T_{i,Length}$	User-generated target value for clinic length, in hours, for clinic i.
$T_{i,Yield}$	User-generated target value for collection yield for clinic i.

$$\min \sum_{q \in Q_i} x_q \left(P_{i,Yield} \left| Y_q - T_{i,Yield} \right| + P_{i,Beds} \left| B_q - T_{i,Beds} \right| + P_{i,Length} \left| L_q - T_{i,Length} \right| \right)$$

3.1.1 EXPECTED COLLECTION YIELD

As seen in Table 3.2, the expected collection yield is calculated based on the number of available appointments, multiplied by the clinic's collection-to-appointment ratio.

Table 3.2 Equations to Calculate Expected Collection Yield.

Sets	
I	Set of clinic types, indexed by $i \in \{WB, PLTMP, LVSP\}$.
Q_i	Set of configurations of clinic length and bed count for clinic i, indexed by q.
Parameters	
A_q	Number of available appointments in clinic i using configuration q.
Y_q	Expected Collection Yield for clinic i using configuration q.
R_i	Collection-to-Appointment ratio for clinic i.
r_i	Appointment Deferral Rate for clinic i.
τ_i	Turn Rate, in units per bed per hour, for clinic i.

$$A_q = \left\lceil \left(\lfloor L_q * \tau_i \rfloor \right) * B_q * r_i \right\rceil \quad (4)$$

$$Y_q = A_q * R_i \quad (5)$$

To demonstrate this, recall the working example introduced in Chapter 1. Assuming a turn rate and collection-to-appointment ratio of 2.4 and 1, respectively, and no deferral rate, the expected collection yield would be as follows:

$$A_q = (\lfloor 7 * 2.4 \rfloor + 1) * 6 = 102$$

$$Y_q = 102 * 1 = 102$$

3.1.2 LABOUR HOURS PER UNIT

In the unlikely event of a tie, the model is designed to select a set of configurations based on the lowest labour hours per unit. As shown in Table 3.3, this secondary criterion is calculated by dividing the total amount of paid shift time by the expected collection yield.

Table 3.3 Equation for Labour Hours per Unit.

Sets	
I	Set of clinic types, indexed by i.
Q_i	Set of configurations of clinic length and bed count for clinic i, indexed by q.
Variables	
W_q	Labour hours per unit for clinic i for configuration q.
E_{jq}	Minimum number of staff of job type j required for clinic i for configuration q.
F_{jq}	Number of floats of job type j required for clinic i for configuration q.
D_{jq}	Shift Length, in hours, for staff of job type j at clinic i for configuration q.
β_{jq}	Number of unpaid breaks allocated to staff of job type j for configuration q.

$$W_q = \frac{\sum_{j \in J}\left(E_{jq} + F_{jq}\right)\left(D_{jq} - 0.5\beta_{jq}\right)}{Y_q} \quad (6)$$

Applying the equation to the working example, the labour hours per unit for a 6-bed, 7-hour whole blood donation clinic is:

$$W_q = \frac{(2+0.4)[7.5-(2*0.5)]+(3+0.55)[8-(2*0.5)]+(1+1)[7.75-(2*0.5)]+[7.5-(2*0.5)]}{101} = 0.6$$

3.1.3 MODEL CONSTRAINTS

To ensure that the generated solutions more accurately represent the real-world environment, Model 1's formulation incorporates two sets of constraints. Constraint (1.1) requires the model to select exactly one solution for clinic $i \in I$, while Constraints (1.2) and (1.3) limit the solution space to configurations where the expected collection yield falls within the accepted tolerance levels (∅).

$$\sum_{q \in Q_i} x_q = 1 \quad (1.1)$$

$$\sum_{q \in Q_i} x_q Y_q \leq T_{i,Yield}(1 + \emptyset) \quad (1.2)$$

$$\sum_{q \in Q_i} x_q Y_q \geq T_{i,Yield}(1 - \emptyset) \quad (1.3)$$

3.2 MODEL 2: EMPLOYEE SHIFTS

Using parameters established by Model 1, the second model identifies the optimal combination of shifts that minimizes the clinic's labour hours per unit while maintaining the staffing requirements calculated in Chapter 1. For a schedule to considered feasible, the following criteria must be met:

- Assigned shift provides the correct number of paid and unpaid breaks that the individual is entitled to based on the length of their shift.
- The number of active employees (i.e., those not on break) in each job classification meets or exceeds the minimum required to operate the clinic at all times.

If multiple clinics are being run simultaneously, the model must also take into consideration any float coverage that spans several types of clinics and assign shifts accordingly.

3.2.1 REVISITING FLOAT STAFF

Float staff are considered a shared resource and can be categorized according to their qualifications. Since registered nurses and donor services representatives do not require floats, the remaining float types can be denoted using set variable k, where $k \in \{DCA, NC\}$.

To optimize coverage, float staff are assigned to shifts matching the duration of the employees they support. If a float employee type provides coverage for more than one role (e.g., donor care associates covering both screeners and bed attendants), they are allocated the longer shift length of the two. Consequently, each calculated float value is rounded up to the nearest whole number to represent the additional employees needed. Consolidating these values by float type in advance minimizes the overall float staffing requirements without compromising break coverage.

Recall the float values previously calculated for the working example clinic in Chapter 1. As seen below, rather than requiring one float staff of each job type, the proposed method decreased the total requirement by one. As such, F_{ij} can be rewritten as F_k, where k represented the set of float types.

$$F_{DCA} = \lceil F_{WB,Screen} + F_{WB,Attend} \rceil = \lceil 0.4 + 0.55 \rceil = 1$$

$$F_{NC} = \lceil F_{WB,NC} \rceil = \lceil 0.19 \rceil = 1$$

3.2.2 TIME BLOCK CONVERSIONS

As illustrated in Figure 1.2, each shift can be depicted as a series of 15-minute time blocks. By breaking down shifts into these intervals, the model can efficiently optimize staffing assignments while ensuring that operational needs are met.

3.2.2.1 LENGTH OF TIME (N)

Before assigning a start time and break slots, shift duration must first be calculated in terms of time blocks. Let N_l represents the total number of 15-minute time blocks corresponding to length l, in hours.

$$N_l = \frac{l * 60}{15} \tag{7}$$

In the working example, the setup, takedown and staff huddle cycle times were identified as 15 minutes, 60 minutes, and 15 minutes, respectively. As such, applying Equation (7), the number of time blocks required to complete each task can be easily calculated:

Setup	$N_{0.25} = (0.25 * 60)/15 = 1$
Takedown	$N_1 = (1 * 60)/15 = 4$
Huddle	$N_{0.25} = (0.25 * 60)/15 = 1$

3.2.2.2 TIME OF DAY (n)

In addition to length conversions, the time block equation can also be used to express a time of day as a specific timeslot within the 24-hour period. Let n_h be equal to the number of 15-minute time blocks that have passed between midnight and time h.

$$n_h = \frac{h * 60}{15} \tag{8}$$

Note that the n-value represents the start of a time block. Therefore, when used in conjunction with an N-value, it provides an "up to, but not including" value as the endpoint. For instance, assume that in the whole blood example, the first donor is scheduled to arrive at 11:00 AM.

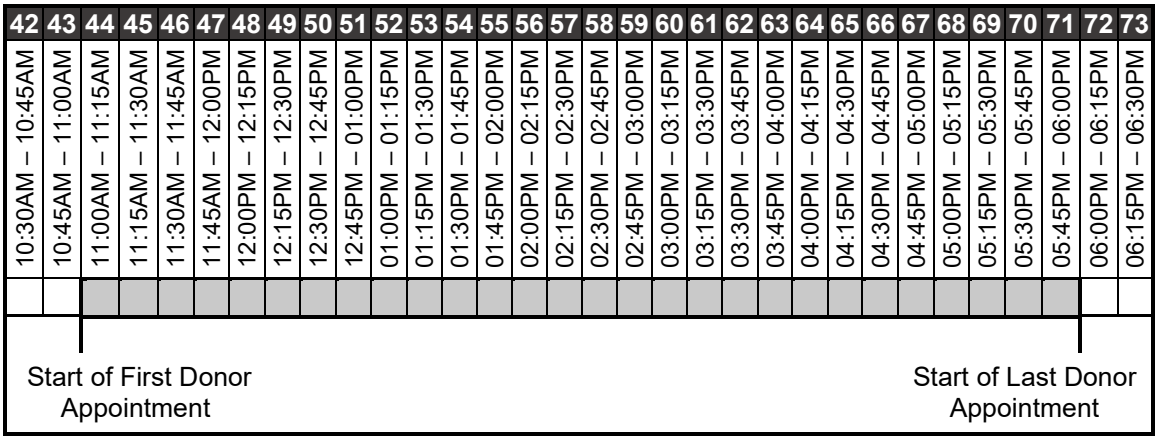
$$n_{11} = \frac{11 * 60}{15} = 44$$

This indicates that between midnight and 11:00 AM, 43 intervals of 15-minutes have passed, and the current time corresponds to the start of the 44th time block. Recall that in the working example, the whole blood clinic had a clinic length of 7 hours.

$$N_7 = \frac{7 * 60}{15} = 28$$

Using a starting point of $n = 44$, the endpoint of the clinic duration is determined by adding N, resulting in $n = 72$. This indicates that the clinic length extends up to, but does not include, the start of the 72nd time block. Therefore, this duration can be represented as follows:

Figure 3.1 Time Block Representation of Working Example Clinic Length.



3.2.3 SHIFT STRUCTURE

Each feasible shift in a solution set represents a unique combination of the three key shift elements: start time, duration, and allocated break slots. The range of feasible values for these components vary depending on the type of employee and clinic.

3.2.3.1 SHIFT DURATION

To maximize shift length, it can be assumed that all shifts are either equal to the required on-site time for each employee type, or, if that exceeds 1 FTE, the shift is limited to 8 hours. This approach minimizes the number of feasible solutions, thereby reducing the computational complexity of the model. Applying this reasoning to the whole blood clinic, the shift duration for each job classification can be determined using Equation (7).

Donor Services Representatives	$N_{7.5} = (7.5 * 60)/15 = 30$
Screeners	$N_{7.5} = (7.5 * 60)/15 = 30$
Bed Attendants	$N_{8} = (8 * 60)/15 = 32$
Nurse Consultants	$N_{7.75} = (7.75 * 60)/15 = 31$

3.2.3.2 STAFF START TIMES

Staggering shift start times allows clinics to operate for longer periods and reduces idle time for employees at the beginning and end of operations, enhancing overall efficiency. Potential start times are determined by job classification and the clinic's operational duration. In the working example, bedside attendants are assigned the maximum shift length of 8 hours. However, due to the clinic's total operating time, these shifts do not fully cover the required duration. As a result, staggered start times are necessary so that some attendants begin their shifts before the clinic opens to manage setup tasks, while others start later to ensure takedown activities are completed at the end of the day. Using the previously calculated information, the period during which the bed attendants are required to be onsite can be determined.

$$\text{Earliest Shift Start Time} = n_{11} - N_{0.25} - N_{0.25} = 44 - 1 - 1 = 42$$

$$\text{Latest Shift End Time} = n_{11} + N_{7} + N_{1} = 44 + 28 + 4 = 76$$

As seen in Figure 3.2, there are six feasible start times that each bed attendant can be assigned to. If necessary, the number of start times can be reduced, provided that there is at least one shift to cover every time block of the required operational period.

Figure 3.2 Feasible Start Time for Bed Attendants.

n	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
	10:30AM – 10:45AM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	04:45PM – 05:00PM	05:00PM – 05:15PM	05:15PM – 05:30PM	05:30PM – 05:45PM	05:45PM – 06:00PM	06:00PM – 06:15PM	06:15PM – 06:30PM	06:30PM – 06:45PM	06:45PM – 07:00PM
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					
2		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
3			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
4				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
5					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
6						1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

3.2.3.3 BREAK ASSIGNMENT

Depending on the length of the shift, employees may be entitled to up to three breaks: two 15-minute paid breaks and one 30-minute unpaid break. The order of these breaks must always alternate, starting with a paid break, and they can begin as early as 15 minutes after the start of the shift. Additionally, provinces may have designated meal windows during which staff are expected to take their 30-minute break. These constraints should be followed as closely as possible; however, in certain situations, it may not always be feasible.

3.2.3.4 PENALTY VALUES

To deter the model from selecting shifts with breaks that are clustered together, each shift is assigned a penalty value based on how evenly dispersed its breaks are. First, the ideal length of time between break slots is calculated using the following equation:

$$b_{ij} = \frac{D_{ij}}{\alpha_{ij} + \beta_{ij} + 1} \tag{9}$$

where b_{ij} is the target duration, in hours, between break slots for employees of job type j in clinic i, D_{ij} is the shift length, in hours, for employees of job type j in clinic i, and α_{ij} and β_{ij} are the number of paid and unpaid breaks, respectively, allocated to an employee of job type j in clinic i.

In the working example, bed attendants are assigned 8-hour shifts and require two paid and one unpaid break. Therefore, the ideal amount of time between breaks is as follows:

$$b_{WB,Beds} = \frac{8}{2 + 1 + 1} = \frac{8}{4} = 2$$

This value can then be converted into number of 15-minute slots and used to determine the ideal slot of each break.

$$N_2 = (2 * 60)/15 = 8$$

Assuming a start time of 10:30 AM ($n = 42$), let the ideal break locations for the first paid break, the meal break, and the second paid break be equal to b_1, b_m, and b_2, respectively.

$$b_1 = 42 + 8 = 50$$

$$b_m = 50 + 8 = 58$$

$$b_2 = 58 + 8 = 66$$

Penalty costs are incurred based on the calculated percentage error between the actual break placement and the corresponding target. For shifts with three break slots, the difference in distance between each paid break and the meal break is also included. Finally, shifts may receive additional penalties if their assigned meal breaks are outside of the designated time windows.

3.2.4 MODEL FORMULATION

Rather than solving for the donation centre as a whole, Model 2 can be decomposed into smaller, less complex sub-models based on the combination of active clinics. For instance, if a donation centre operating both whole blood and large-volume source plasma clinics simultaneously, the model must account for inter-departmental resources (e.g., NCs and floats). In contrast, if the centre is running whole blood and platelets and multi-plasma clinics, each can be solved individually, since there is no staff overlap. Each sub-model is designed to optimize staff scheduling by minimizing overall costs.

3.2.4.1 DONOR SERVICES REPRESENTATIVE MODEL

The number of donor services representatives is determined by adding together the staffing requirements of each active clinic and rounding the resulting total up to the nearest whole number. Constraint (2.1) ensures that the model does not schedules more than the required number of donor services representatives.

Table 3.4 Donor Services Representative Model Formulation.

Sets	
S	Set of feasible donor services representative shifts, indexed by s.
Decision Variable	
x_s	Number of employees assigned to shift s.
Parameters	
c_s	Cost of assigning an employee to shift s.
$E_{i,DSR}$	Number of donor services representatives required by clinic i to operate.

$$\min \sum_{s \in S} c_s x_s$$

subject to

$$\sum_{s \in S} x_s = \left\lceil \sum_{i} E_{i,DSR} \right\rceil \tag{2.1}$$

$x_s \geq 0$, and integer.

3.2.4.2 SINGLE CLINIC MODEL

Building on the donor services representative model, single-clinic scheduling introduces an added layer of complexity, as it requires uninterrupted break coverage throughout the day. To address this, a second decision variable is introduced to assign shifts for each type of float. The objective function has been adjusted to penalize the model if the number of scheduled employees exceeds the minimum required. This discourages the model from overstaffing clinics using zero cost shifts (i.e., shifts with an ideal distribution of breaks) to satisfy constraints.

Table 3.5 Single Clinic Model Objective Function.

Sets	
J	Set of job classes, indexed by j.
K	Set of float types, indexed by k.
S_j	Set of shifts that can be assigned to employees of job type j, indexed by s.
M_k	Set of shifts that can be assigned to floats of type k, indexed by m.
T	Set of 15-minute time slots within a 24-hour timespan, indexed by t.
Decision Variables	
x_{js}	Number of employees of job type j assigned to shift s.
f_{mk}	Number of floats of type k assigned to shift m.
Parameters	
c_{js}	Cost of assigning shift s to an employee of job type j.
d_{km}	Cost of assigning shift m to a float staff of type k.
E_j	Minimum number of employees of job type j required to operate the clinic.
F_k	Minimum number of float staff of type k required for break coverage.
u_{st}	If employees assigned to shift $s \in S_j$ is active at time $t \in T$ then $u_{st} = 1$; otherwise, $u_{st} = 0$.
v_{mt}	If float staff assigned to shift $m \in M_k$ is active at time $t \in T$, then $v_{mk} = 1$; otherwise, $v_{mk} = 0$.

$$\min \sum_{j \in J} \sum_{s \in S_j} c_{js} x_{js} + \sum_{k \in K} \sum_{m \in M_k} d_{km} f_{km} + \sum_{j \in J} \left(\sum_{s \in S_j} x_{js} - E_j \right) + \sum_{k \in K} \left(\sum_{m \in M_k} f_{km} - F_k \right)$$

$x_{js}, f_{km} \geq 0$, and integer.

MODEL CONSTRAINTS

The single clinic model is defined by three sets of constraints. The first ensures that a minimum number of active staff (i.e., not on break) is maintained for each job type throughout the duration of the clinic. Quotas are based on the staffing requirements calculated in Chapter 1 and can be filled by both employees assigned to the job type, as well as any available float staff who are qualified to perform the necessary tasks.

In whole blood and large-volume source plasma clinics, screening stations can be operated by three types of employees (screeners, donor care associate floats and nurse consultant floats), whereas bed attendants and NCs can only be covered by their respective float types. Constraints (2.2), (2.3), and (2.4) define the minimum active requirements for screening, bed attendant, and nurse consultants stations, respectively.

$$\sum_{s \in S_{Screen}} x_{Screen,s}\, u_{st} + \sum_{m \in M_{DCA}} f_{DCA,m} v_{mt} + \sum_{m \in M_{NC}} f_{NC,m} v_{mt} \geq E_{Screen,t} \qquad \forall t \in T \qquad (2.2)$$

$$\sum_{s \in S_{Attend}} x_{Attend,s} u_{st} + \sum_{m \in M_{DCA}} f_{DCA,m} v_{mt} \geq E_{Attend,t} \qquad \forall t \in T \qquad (2.3)$$

$$\sum_{s \in S_{NC}} x_{NC,s}\, u_{st} + \sum_{m \in M_{NC}} f_{NC,m} v_{mt} \geq E_{NC,t} \qquad \forall t \in T \qquad (2.4)$$

Platelets and multi-plasma clinics are operated exclusively by registered nurses and do not require floats. As such, they only require the following constraint:

$$\sum_{s \in S_{RN}} x_{RN,s}\, u_{st} \geq E_{RN,t} \qquad \forall t \in T \qquad (2.5)$$

In addition to the active staff quota, clinics also require specific distributions of job types to operate. If left to its own devices, the model prioritizes maximizing the number of donor care associate floats, as they are the most versatile job classification and can contribute to the active quota of multiple employee types. As seen below, the second set of

constraints prevents this by ensuring that the model maintains the staffing distribution calculated in Chapter 1.

$$\sum_{s \in S_j} x_{js} \geq E_j \qquad \forall j \in J \qquad (2.6)$$

$$\sum_{m \in M_k} f_{km} \geq F_k \qquad \forall k \in K \qquad (2.7)$$

During model testing, it was observed that the model frequently assigned large numbers of staff to the same break slots. This behavior was a result of the model attempting to minimize costs incurred from scheduling meal breaks outside the designated windows. In theory, this is not an issue, as the model still maintained the minimum active staff quotas. However, in practice, these sudden reductions in staffing could lead to significant disruptions in the clinic's workflow and temporary spikes in workload for those covering the breaks. To better reflect real-world conditions, Constraint (2.8) was introduced, allowing the user to limit the number of staff taking breaks simultaneously. Let N_t be the maximum number of staff that can be assigned break block t, as specified by the user.

$$\sum_{j \in J} E_{jt} - \sum_{j \in J} \sum_{s \in S_j} x_{js} u_{st} - \sum_{k \in K} \sum_{m \in M_k} f_{km} v_{mt} \leq N_t \qquad \forall t \in T \qquad (2.8)$$

3.2.4.3 MULTIPLE CLINIC MODEL

When running whole blood and large-volume source plasma clinics simultaneously, sharing the same pool of floats can help to reduce idle time and increase the overall efficiency of the donation centre. Table 3.6 illustrates a modified version of Model 2 that accommodates for this overlap in staff coverage. Note that the platelets and multi-plasma clinic is not included in this model as it does not share any common resources and therefore can be solved independently using single clinic model.

Table 3.6 Model 2 Formulation for Multiple Clinics.

Sets	
J_i	Set of job classes for clinic i, indexed by j, where $i \in \{WB, LVSP\}$.
K	Set of float types, indexed by k.
S_j	Set of shifts that can be assigned to employees of job type j, indexed by s.
M_k	Set of shifts that can be assigned to floats of type k, indexed by m.
T	Set of 15-minute time slots within a 24-hour timespan, indexed by t.
Decision Variables	
x_{ijs}	Number of employees of job type j assigned to shift s at clinic i.
f_{mk}	Number of floats of type k assigned to shift m.
Parameters	
c_{ijs}	Cost of assigning shift s in clinic i to an employee of job type j.
d_{km}	Cost of assigning shift m to a float staff of type k.
E_{ijt}	Minimum number of employees of job type j required to operate the clinic i at time t.
F_k	Minimum number of float staff of type k required for break coverage.
N_t	Maximum number of staff that can be assigned break block t, as specified by the user.
u_{st}	If employees assigned to shift $s \in S_j$ is active at time $t \in T$, then $u_{st} = 1$; otherwise, $u_{st} = 0$.
v_{mt}	If float staff assigned to shift $m \in M_k$ is active at time $t \in T$, then $v_{mk} = 1$; otherwise, $v_{mk} = 0$.

$$\min \sum_{i \in I} \sum_{j \in J_i} \sum_{s \in S_j} c_{ijs} x_{ijs} + \sum_{k \in K} \sum_{m \in M_k} d_{km} f_{km} + \sum_{i \in I} \sum_{j \in J_i} \left(\sum_{s \in S_j} x_{ijs} - E_{ij} \right) + \sum_{k \in K} \left(\sum_{m \in M_k} f_{km} - F_k \right)$$

subject to

$$\sum_{s \in S_{Screen}} x_{i,Screen,s}\, u_{ist} + \sum_{m \in M_{DCA}} f_{DCA,m} v_{mt} + \sum_{m \in M_{NC}} f_{NC,m} v_{mt} \geq E_{i,Screen,t} \quad \begin{matrix} \forall i \in I \\ \forall t \in T \end{matrix} \qquad (2.9)$$

$$\sum_{s \in S_{Attend}} x_{i,Attend,s} u_{ist} + \sum_{m \in M_{DCA}} f_{DCA,m} v_{mt} \geq E_{i,Attend,t} \qquad \begin{matrix} \forall i \in I \\ \forall t \in T \end{matrix} \quad (2.10)$$

$$\sum_{s \in S_{NC}} x_{i,NC,s}\, u_{ist} + \sum_{m \in M_{NC}} f_{NC,m} v_{mt} \geq E_{i,NC,t} \qquad \begin{matrix} \forall i \in I \\ \forall t \in T \end{matrix} \quad (2.11)$$

$$\sum_{s \in S_j} x_{is} \geq E_{ij} \qquad \begin{matrix} \forall i \in I \\ \forall j \in J \end{matrix} \quad (2.12)$$

$$\sum_{m \in M_k} f_{km} \geq F_k \qquad \forall k \in K \quad (2.13)$$

$$\sum_{j \in J_i} E_{ijt} - \left(\sum_{j \in J_i} \sum_{s \in S_j} x_{ijs} u_{ist} + \sum_{k \in K} \sum_{m \in M_k} f_{km} v_{mt} \right) \leq N_t \qquad \begin{matrix} \forall i \in I \\ \forall t \in T \end{matrix} \quad (2.14)$$

$x_{ijs}, f_{km} \geq 0$, and integer.

CHAPTER 4: RESULTS

To assess the feasibility of the proposed model, a prototype was developed using Python and Microsoft Excel. Benchmarking was conducted using client-provided schedules, evaluating the generated solutions for quality, validity, and reliability. Since the model was built on generalized principles, direct comparisons could not be made with clinic schedules that had been altered to accommodate the needs of specific clinics. As such, the client-provided examples were generated solely based on the staffing requirements produced by the Arena model, which is currently only used for scheduling whole blood clinics. As a result, this section focuses primarily on comparing solutions for this specific clinic type.

4.1 MODEL VALIDITY

A model's validity is determined by its ability to generate solutions that align with accurately align with user requirements. To assess this, the model incorporated various constraints and target values (collection yield, bed count, and clinic duration) based on scheduling examples provided by the client.

Figure 4.1 presents the client-generated schedule for a 7-hour, 6-bed Whole Blood clinic. Recall that in previous chapters, this clinic was used to illustrate each step of the modelling process. Given that whole blood appointments have a cycle time of approximately 30 minutes and the latest donor care associate shift ends one hour after the last donor appointment begins, it can be inferred that takedown activities require approximately 30 minutes. The client also noted that this schedule does not include huddle time, as it was not required at the time of creation. As such, the duration of setup activities can be assumed to be 15 minutes. To keep the schedule as concise as possible, donor service representatives, donor care associates, registered nurses, and nurse consults are abbreviated as DSR, DCA, RN, and NC, respectively. Furthermore, float staff are denoted by (F).

Figure 4.1 Client Solution for 7-Hour, 6-Bed Whole Blood Clinic.

	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	04:45PM – 05:00PM	05:00PM – 05:15PM	05:15PM – 05:30PM	05:30PM – 05:45PM	05:45PM – 06:00PM	06:00PM – 06:15PM	06:15PM – 06:30PM	06:30PM – 06:45PM	06:45PM – 07:00PM
DCA	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1			
DCA	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1				
DCA	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1		
DCA	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1		
DCA		1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1
DCA		1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1
DCA		1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1
NC		1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1
NC (F)		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1				
DCA (F)		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1	
DSR	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1			

To generate a comparable solution, the model required clear working parameters. In addition to the details mentioned above, the following constraints were provided:

- The target collection yield, bed capacity, and clinic duration are 101 units, 6 beds, and 7 hours, respectively.
- The first donor appointment will start at 11:00 AM.
- No more than 2 employees can be scheduled to a single break slot.

As shown in Figure 4.2, the model not only generated a schedule meet all three targets, but also used the appropriate timeframe based on the initial appointment time. Note that the solution generated by the model requires two fewer employees to operate, reducing the labour hours per unit from 0.7 to 0.64. This staffing distribution aligns with the calculations presented in Chapter 1.

Figure 4.2 Model Solution for 7-Hour, 6-Bed Whole Blood Clinic.

	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	04:45PM – 05:00PM	05:00PM – 05:15PM	05:15PM – 05:30PM	05:30PM – 05:45PM	05:45PM – 06:00PM	06:00PM – 06:15PM	06:15PM – 06:30PM	06:30PM – 06:45PM	06:45PM – 07:00PM
DCA		1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1			
DCA		1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	
DCA		1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1
NC		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1	1		
NC (F)		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1		
DCA (F)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	
DSR	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1			

The model also proposes different shift lengths and break distributions compared to the client's schedule. Unlike the model's structured calculations, schedulers can make dynamic decisions based on experience and expertise—factors that cannot always be fully captured in a formal scheduling process. That being said, the objective of the model is not to perfectly replicate the original schedule but rather to generate solutions of equal or higher quality, which can then be adjusted by the user to meet the clinic's specific needs. This solution demonstrates the model's ability to achieve that goal by adhering to the constraints outlined in the previous chapter while ensuring adequate coverage throughout the clinic's operations.

4.2 MODEL RELIABILITY

Highly reliable models consistently generate accurate results without significant errors or outliers. To evaluate the model's performance, a second comparative study was conducted using a 6-hour, 4-bed scenario. The schedule presented in Figure 4.3 shares similar characteristics with the first example, as it does not include a staff huddle and allocates 15-minutes and 30-minutes for the setup and takedown of stations, respectively. Target values set for this scenario were 58 units, 4 beds, and a 6-hour clinic duration. Additionally, the first donor was scheduled to arrive at 8:00 AM. This is important to note as it can significantly impacts how the model allocates shift breaks. Aside from these adjustments, no other changes were made.

Figure 4.3 Client Solution for 6-Hour, 4-Bed Whole Blood Clinic.

	07:45AM – 08:00AM	08:00AM – 08:15AM	08:15AM – 08:30AM	08:30AM – 08:45AM	08:45AM – 09:00PM	09:00PM – 09:15PM	09:15PM – 09:30PM	09:30PM – 09:45PM	09:45PM – 10:00PM	10:00PM – 10:15PM	10:15PM – 10:30PM	10:30PM – 10:45PM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	**02:30PM – 02:45PM**	**02:45PM – 03:00PM**
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1		
DCA	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1
DCA		1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1
DCA		1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	C	1	1	1	1	1	
DCA		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1		
NC		1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	
NC (F)		1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1			
DCA (F)		1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1			
DSR	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1

As seen in Figure 4.4, the model was once again able to generate a solution that met all three target values while reducing total staffing requirements and, consequently, decreasing the number of labour hours per unit. Additionally, this scenario evaluated the model's ability to allocate varying numbers of breaks based on shift length, demonstrating its adaptability in optimizing scheduling while maintaining compliance with labour constraints.

Figure 4.4 Model Solution for 6-Hour, 4-Bed Whole Blood Clinic.

	07:45AM – 08:00AM	08:00AM – 08:15AM	08:15AM – 08:30AM	08:30AM – 08:45AM	08:45AM – 09:00PM	09:00PM – 09:15PM	09:15PM – 09:30PM	09:30PM – 09:45PM	09:45PM – 10:00PM	10:00PM – 10:15PM	10:15PM – 10:30PM	10:30PM – 10:45PM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	**02:30PM – 02:45PM**	**02:45PM – 03:00PM**
DCA	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1
DCA		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			
DCA		1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			
NC		1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1			
NC (F)		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1			
DCA (F)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1
DSR	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1			

4.3 MODEL AUTONOMY

A key indicator of a well-calibrated model is its ability to autonomously identify optimal outcomes based solely on its internal logic and constraints. This can be evaluated using labour hours per unit as a metric. Lower values suggest a more efficient and streamlined operation, reflecting better resource utilization and improved time management within the clinic.

Using the model solution generated for the 7-hour, 6-bed clinic as a benchmark, the model was recalibrated to only consider the target collection yield. This approach limits the influence of external factors, allowing for an accurate assessment of the model's autonomy. As illustrated in Figure 4.5, when clinic length and bed count are left undefined, the model instead produces a 5.25-hour, 8-bed clinic, requiring 11 employees to operate.

Figure 4.5 Model Solution for Whole Blood Clinic (Target Collection Yield Only)

	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	**04:45PM – 05:00PM**	**05:00PM – 05:15PM**
DCA		1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1			
DCA		1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1
DCA	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1
DCA		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1			
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1
DCA	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1
NC		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			
NC (F)		1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1			
DCA (F)	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	1
DSR	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			

Despite increasing the staffing requirements by 2, the model was able to reduce the clinic's labour hours per unit from 0.64 to 0.6. This reduction makes sense in terms of patient flow; a greater number of available staff enables the clinic to process more donors simultaneously, allowing them to collect the same number of units in a shorter period. This suggests that by decreasing operational duration and increasing the number of available beds, the clinic can utilize its staff more effectively, thereby improving workplace efficiency.

The results of this scenario provide evidence that the model is capable of autonomously optimize solutions, making it a valuable tool for decision-making, especially when it operates without biases or constraints imposed by the user's subjective preferences.

4.4 ADDITIONAL MODELLING CONSTRAINTS

One limitation of integer programming models is their inherent inability to accommodate dynamic adjustments. These models are constructed statically, meaning that all parameters and constraints are pre-defined, preventing any deviation from the original formulation. To make the model ‘dynamic’, each potential customization path would need to be anticipated ahead of time and encoded into the program. This would significantly increase computational complexity and resource demands, potentially making the model infeasible to run. Additionally, any new customization would require reconfiguring the model, further limiting its flexibility and practical applicability.

While many clinic-specific requests need to be managed manually by the scheduling team, common adjustments can be integrated into the model without overloading the system. Two such adjustments incorporated into the program were staff huddles and aligned shift start times, as they can be applied universally across all schedules. To evaluate the model’s ability to accommodate these modifications, both were applied to the working example, and the results were analyzed.

4.4.1 STAFF HUDDLES

At CBS clinics, staff huddles function as a point of contact for the team to debrief and share information before the start of the day. Based on the needs of the donation centre, daily huddles may not be necessary and can be adjusted to two or three times a week. Figure 4.6 presents a schedule generated by the model for the 7-hour, 6-bed clinic, incorporating an additional requirement for a 15-minute huddle to be included in all staff shifts.

Figure 4.6 Model Solution for 7-Hour, 6-Bed Whole Blood Clinic (Staff Huddle).

	10:30AM – 10:45AM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	04:45PM – 05:00PM	05:00PM – 05:15PM	05:15PM – 05:30PM	05:30PM – 05:45PM	05:45PM – 06:00PM	06:00PM – 06:15PM	06:15PM – 06:30PM	06:30PM – 06:45PM	06:45PM – 07:00PM
DCA		1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1			
DCA		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1		
DCA		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	
DCA			1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA			1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1
NC		1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1		
NC (F)		1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1		
DCA (F)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1		
DSR		1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1			

Note this solution requires one additional donor care associate compared to the original scenario. Staff huddles are typically conducted before the first donor arrives; thereby, requiring staff to arrive 15 minutes earlier and increasing the overall clinic operation time. To accommodate this change, the model must adjust staffing levels, as the original allocation can no longer provide sufficient coverage without exceeding the maximum shift duration. This outcome highlights how even minor adjustments to shift lengths can significantly impact the solution, emphasizing the need to account for such factors when implementing the model.

4.4.2 SYNCHRONIZED SHIFT START TIMES

As an organization, CBS has begun moving away from the use of staggered start time in donation centres. Recall that in the working example, the total amount of time donor care associates were required to be onsite was calculated to 8.5 hours. To ensure all employees have aligned start times without exceeding the maximum shift duration, the total onsite requirement for any staff type cannot exceed 8 hours. As such, the original solution for the 7-hour, 6-bed clinic is no longer a feasible solution.

As seen in Figure 4.7, the model responds to this shift in requirements by generating a solution with a reduced clinic length of 5.25 hours while increasing the bed count to 8 beds. As noted in Chapter 3, the expected collection yield is influenced by two variables: bed count and clinic length, which are inversely related. This means that a decrease in

clinic length necessitates an increase in the number of beds to achieve the desired collection yield. Therefore, the behavior observed in the model aligns with this established relationship.

Figure 4.7 Model Solution for 7-Hour, 6-Bed Whole Blood Clinic (Single Start Time).

	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM	03:45PM – 04:00PM	04:00PM – 04:15PM	04:15PM – 04:30PM	04:30PM – 04:45PM	**04:45PM – 05:00PM**	**05:00PM – 05:15PM**
DCA	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	1
DCA	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			
DCA	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1
DCA	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1
DCA	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1
NC	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1		
NC (F)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1		
DCA (F)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1
DSR	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1			

4.5 MULTI-CLINIC SCHEDULING

To assess its ability to evaluate the interdependencies between various clinics, the model was presented with a multi-clinic donation centre scenario. As shown Figure 4.8, the scenario includes a 7-hour, 6-bed whole blood clinic, along with a 4-hour, 2-bed platelets and multi-plasma clinic and a 6-hour, 2-bed large-volume source plasma clinic. Similar to the previous scenarios, all clinics included a 15-minute setup period, no staff huddle, and followed the same shift start principle. Furthermore, both the platelets and multi-plasma and large-volume source plasma clinics incorporated a 20% deferral rate, allowing the model's ability to accommodate for a multitude of scenarios.

Figure 4.8 Client Solution for Multi-Clinic Donor Centre.

	07:45AM – 08:00AM	08:00AM – 08:15AM	08:15AM – 08:30AM	08:30AM – 08:45AM	08:45AM – 09:00AM	09:00AM – 09:15AM	09:15AM – 09:30AM	09:30AM – 09:45AM	09:45AM – 10:00AM	10:00AM – 10:15AM	10:15AM – 10:30AM	10:30AM – 10:45AM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM
DCA (WB)	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	**C**	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	**C**	1	1	1	1
DCA (F)(WB)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	**C**	1	1	1	1	1	1
NC	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1
NC (F)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	**C**	1
DCA (LVSP)	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA (LVSP)	1	1	1	1	1	1	1	1	C	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1
RN (PLT)	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1					
RN (PLT)	1	1	1	1	1	1	**C**	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1					
DSR	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1		

As shown in Figure 4.9, the model successfully replicated the staffing distribution for all clinics, with the exception of the whole blood donor care associates. However, the whole blood clinic configuration remains identical to the solution presented in Section 4.1, which aligns with the staffing requirements calculated in Chapter 1. Notably, in this scenario, the model was provided a takedown time of 15 minutes. This decision was made because incorporating the full 30 minutes would require a shorter schedule with more employees, as the additional 15 minutes would necessitate a staggered shift start schedule. That being said, most whole blood shifts include a 15-minute takedown period, except for two donor care associates. Additionally, the shifts generated by the client are all full 8-hour shifts, despite the model's calculations indicating that shorter shifts would suffice. This suggests that by extending shifts, the scheduler can not only provide full-time hours for all whole blood employees but also allocate additional staff to assist with takedown. This, in turn, reduces the operational clinic length while ensuring it fits within the maximum 8-hour duration. This example illustrates how the model can generate an optimal schedule that serves as a foundation, which can then be adjusted to meet organizational needs, even if the final schedule deviates from strict optimality.

Figure 4.9 Model Solution for Multi-Clinic Donor Centre.

	07:45AM – 08:00AM	08:00AM – 08:15AM	08:15AM – 08:30AM	08:30AM – 08:45AM	08:45AM – 09:00AM	09:00AM – 09:15AM	09:15AM – 09:30AM	09:30AM – 09:45AM	09:45AM – 10:00AM	10:00AM – 10:15AM	10:15AM – 10:30AM	10:30AM – 10:45AM	10:45AM – 11:00AM	11:00AM – 11:15AM	11:15AM – 11:30AM	11:30AM – 11:45AM	11:45AM – 12:00PM	12:00PM – 12:15PM	12:15PM – 12:30PM	12:30PM – 12:45PM	12:45PM – 01:00PM	01:00PM – 01:15PM	01:15PM – 01:30PM	01:30PM – 01:45PM	01:45PM – 02:00PM	02:00PM – 02:15PM	02:15PM – 02:30PM	02:30PM – 02:45PM	02:45PM – 03:00PM	03:00PM – 03:15PM	03:15PM – 03:30PM	03:30PM – 03:45PM
DCA (WB)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1		
DCA (WB)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1		
DCA (WB)	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1	1	1
DCA (WB)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	**C**	1	1	1	1	1
NC	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	
NC (F)	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	**C**	1	1	1	1	1
DCA (F)	1	1	1	1	1	1	1	**C**	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1
DCA (LVSP)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1										
DCA (LVSP)	1	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1					
RN (PLT)	1	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	1	1					
RN (PLT)	1	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1					
DSR	1	1	1	1	1	1	1	**C**	1	1	1	1	1	1	1	**B**	**B**	1	1	1	1	1	1	**C**	1	1	1	1	1	1		

Similar to the schedule generated by the client, it assigned several full-time or near full-time shifts. The one notable exception was one of the large-volume source plasma donor care associates, who was assigned a significantly shorter shift than their counterpart. This discrepancy resulted from the calculated balance between screening and bed attendant shifts. Further investigation into the interdependencies between these two roles in large-volume source plasma clinics may be necessary to better understand why the client deemed it essential to assign full-time shifts to both employees and how that could be reflected in the model.

Lastly, the platelets and multi-plasma clinic schedule generated by the model was nearly identical to that of the client. The only notable difference between the two solutions was that the client's schedule includes an additional 15-minute break for the staff. Based on the data provided by the client, the model allocated the correct number of breaks according to the shift length. Therefore, it is assumed that the additional break was a discretionary decision made by the scheduler and is considered a customization to the schedule.

4.6 MODEL RUNTIME ANALYSIS

The value of the model is determined by two key factors: the quality of the solutions and the computational demands of the system. If the resource requirements to run the model exceed what the user is willing to provide, the quality of the solutions becomes irrelevant. Each of the scenarios outlined in this chapter was run 10 times to ensure consistency. Table 4.1 presents the average run time and standard deviation of 10 runs for each of the model scenarios described in this chapter.

Table 4.1 Model Runtime, in seconds, by Test Scenario.

Run/Scenario	1	2	3	4A	4B	5
Average	8.75	2.35	1.11	12.82	1.20	10.63
Standard Deviation	0.06	0.07	0.07	0.10	0.07	0.30

CHAPTER 5: CONCLUSION

As the national provider and distributor of blood and blood products across Canada, excluding Québec, CBS has a responsibility to Canadians to provide high-quality products and services. Blake & Shimla (2014) introduced a deterministic flow shop equation to calculate the minimum staffing requirements necessary for maintaining continuous donor flow within CBS' clinics. The aim of this project was to expand upon their work by developing a scheduling model grounded in this equation, thereby optimizing staffing allocation and improving operational efficiency across CBS' donor centres.

After examining the existing literature on BDSPs, it was apparent that there was a significant gap in studies aimed at optimizing staffing processes in collection centres. Several literature reviews highlighted the limited diversity of research topics in this field, specifically noting the underrepresentation of studies examining the impact of staff break times on clinic operations. One article speculated that the complexity of balancing customer service and production metrics within this system may have deterred researchers from exploring this area further (Baş Güre, Carello, Lanzarone, & Yalçindağ, 2017). Extending into adjacent subsets of schedule problems, several studies on the NSP was also reviewed. However, while there are some similarities, the cyclical nature of NSPs and the limited diversity of staffing roles in the system makes it challenging to apply findings directly to BDSPs.

The proposed approach is two-fold, utilizing integer programming to generate optimal staffing schedules based on user input. Using a user-defined set of target values, the model first determines the optimal configuration of clinic length and bed count for each active clinic. These parameters are then fed into a second model, which assigns staff shifts according to a set of previously calculated staffing requirements.

Integer programming is a popular application of exact methods characterized by its ability to evaluate complete problem sets and determine the optimal solution. The caveat, however, is that when applied to large-scale or complex problems, it can be highly resource-intensive and time-consuming. In an article publish by the Institute for Operations Research and the Management Sciences, Aykin (1998) proposed that rather than assigning individual variables to every scheduling element (i.e., start/end time, break slot, shift type, etc.), one could reduce the number of decision points by having the model make

selections based on a pre-generated set of solutions. Using a similar methodology, the project model applies a simplified version of column generation that eliminates the need for a subproblem, as all potential "columns" are predefined prior to solving the master problem.

To assess the validity and reliability of the model, a prototype was developed using Python and Microsoft Excel. The model's performance was evaluated across multiple test scenarios, with results compared to schedules generated by the client. Using labour hours per unit as the primary metric of comparison, the model consistently produced solutions of equal or higher quality. Moreover, the model demonstrated a high degree of autonomy and adaptability, offering alternative solutions based on user-defined constraints (such as the inclusion of staff huddles, synchronized start times, etc.) in both single and multi-clinic scenarios.

Due to the static nature of integer programming, the fluidity of the project model is limited to the number of scenario contingencies that can be effectively incorporated into the formulation. To address this limitation, future efforts should focus on developing a more dynamic approach, using the proposed model as a foundational framework. Furthermore, while the project scope encompassed all three clinic types, the model was primarily built using data from whole blood clinics, as this data was the most readily available. Although the model has proven adequate for these clinic types, additional testing and investigation are necessary before its broader implementation across the organization.

The model proposed by the project offers a balanced scheduling approach capable of generating optimal solutions without the need for excessive amounts of computational resources. Despite being developed for CBS collection clinics, the model framework is not exclusive to BDSP and, with minor modifications, can be applied to other areas within the healthcare industry.

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