Appointment Planning and Scheduling in Outpatient Procedure Centers

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Abstract This chapter provides a summary of the planning and scheduling decisions for outpatient procedure centers. A summary and background of outpatient procedure centers and their operations is provided along with the challanges faced by managers. Planning and scheduling decisions are discussed and categorized as either long or short term decisions. Examples and results are drawn from the literature along with important factors that influence planning and scheduling decisions. A summary of open challenges for the operations research community is presented.

6.1 Introduction

Outpatient procedure centers (OPCs), also known as ambulatory surgery centers (ASCs), are a growing trend for providing specialty health care procedures (surgical or non-surgical) in the U.S. From 1996 to 2006, the rate of visits to OPCs in the U.S. increased 300% while the rate of similar visits to surgery centers in a hospital setting remained constant (Cullen et al, 2009). The increase in OPC visit frequency is in part due to the patient benefits for surgery in an OPC including lower costs, appointment systems that are often more amenable to patient preferences, the ability to recover at home, lower complication rates, lower infection rates, and shorter procedure durations.

Many procedures previously required resources only available in hospital settings; however, advances in medical care and technology have made it pos-

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sible to provide these services through minimally (or non) invasive procedures that can be provided at low risk in outpatient settings. Such procedures often use methods such as laparoscopy, endoscopy, or laser surgery. The improvement and simplification of the care process that results from these advances translates to lower costs and the expectation to see more patients in these environments. As a result OPCs are often associated with higher profit, for certain types of procedures, and high daily patient throughput.

The differences in the OPC and hospital settings create challenges for OPCs. Patient appointment scheduling, staff scheduling, allocation of equipment and resources, and decisions about how to interface with the rest of the health care system each have their own nuances in an OPC setting. OPCs operate for a fixed period (e.g. 8 A.M. - 5 P.M.) typically Monday to Friday. Since most of the procedures done in OPCs are elective in nature, OPC managers are presented with more opportunity than hospital based practices to decide and influence how to allocate their patient demand. Improving advanced planning and daily appointment scheduling systems can play an influential role in an OPC's efficiency and utilization. However, in order to optimally plan and design patient schedules there are many factors to consider including staff and resource levels, pre and post procedure processes, and patient characteristics such as case mix, no-shows, and short notice add-on patients.

From an operations management perspective there are many criteria used to evaluate the performance of OPCs. Patient waiting time, staff and resource utilization, patient throughput, and overtime costs are all important criteria related to the cost and quality of care provided. However, making decisions based on these criteria can be complicated because some criteria, such as patient waiting and resource utilization, are competing. In other words, changes that positively affect one often negatively affect the other. Furthermore, there are many stakeholders, such as patients, nurses, providers (surgeons, physician specialists), and administrators, with varying prospectives about the importance of each criterion.

In this chapter we provide an overview of patient planning and scheduling in OPCs. We also discuss issues that influence these types of decisions including procedure and recovery duration uncertainty, availability of staff and physical resources, common bottlenecks, demand uncertainty, and patient behavior. We give special attention to the unique challenges for OPC managers and how they relate to patient planning and scheduling.

The remainder of this chapter is organized as follows. In the next section we provide some general background on OPC operations. In Section 6.3 we describe some of the challenges faced in making long term planning and short term scheduling decisions. We discuss several specific types of decisions and we provide two examples based on a real outpatient procedure center. In Section 6.4 we discuss factors which affect OPC planning and scheduling decisions. Where relevant, we provide a review of literature on methods that have been used to address these factors. Finally, we conclude by discussing some future research opportunities.

6.2 Background

OPCs are referred to using various terminologies including ambulatory surgery centers, ambulatory procedure centers, outpatient surgery centers, and same day surgery centers. While the terms surgery and procedure are used interchangeably in these references, the health care services provided in these settings are generally classified as requiring more specialized care than can be provided in an office visit, but less intensive than the care provided in a hospital setting.

Procedures most commonly provided in OPCs include endoscopies of both the large and small intestines for colorectal cancer screening, lens extraction and insertion for cataract care, and administration of pain management agents into the spinal canal (Cullen et al, 2009). Other common procedures include certain orthopedic procedures, urological procedures, tonsillectomies, gallbladder removal, and various cosmetic surgeries. The wide spectrum of services now offered at OPCs means many patients are candidates. However, requirements are generally more strict concerning the health state of the patient due to the lack of supporting care for emergencies that are otherwise available in a hospital.

Some OPCs specialize in a specific type of procedure, such as endoscopy suites where the facility is equipped and staffed to provide various endoscopic procedures such as colonoscopies or esophagogastroduodenoscopies (EGDs), while other OPCs are shared by providers from a variety of specialties. Other health care service settings that are not commonly classified as OPCs but have many similarities in how care is provided include catheterization labs, chemotherapy infusion centers, and various diagnostic settings such as those for CT scans. While OPCs are not directly part of a hospital, many are affiliated with a local hospital. As a result it is often necessary to coordinate planning and scheduling decisions for staff with other commitments. For example, some providers may work certain days at an OPC and other days at the affiliated hospital.

OPCs have multiple stages of care, each involving many individual activities. The stages for a patient can be aggregated into intake, procedure, and recovery. The resources most commonly associated with each stage of a typical OPC are listed in Table 6.1. In the intake stage the patient first checks in to the OPC. Next, they are called back to change into a procedure gown, physiological information is recorded, and the patient's proper preparation (e.g. fasting) is ensured. The patient may also consult with the provider (e.g. surgeon, endoscopist, or other type of proceduralist depending on the type of OPC) or nurse at this stage of the process. The procedure begins once a procedure room is available, the patient is ready, and the necessary staff and physical resources are available. Certain procedures may require support staff such as nurses or technicians who are responsible for specialty equipment such as diagnostic imaging devices. OPCs affiliated with academic teaching hospitals may have medical fellows assisting in the procedure. Following the procedure, the patient proceeds to recovery where they recover from any anesthetic and await a follow-up consultation with the provider prior to being discharged.

Table 6.1 The resources at each stage of a typical outpatient procedure center

	Intake	Procedure	Recovery
Resources	• Check-in Staff • Nurses • Intake Beds	• Providers • Nurses • Procedure Rooms • Anesthesiologists • Support Staff • Procedure Specific Equipment (e.g. endoscope, arthroscope, laproscope)	• Nurses • Recovery Beds

The provider and staff may continue with the next procedure where the previous patient recovers depending on resource availability and other activities. The start time of the next procedure is dependent on many factors. First, the procedure room must be *turned over* following each procedure. During turn over material resources are restocked, equipment is sterilized, and the room is prepared for the next procedure. In between procedures the provider's activities may include consulting with other patients, dictating notes from previous procedures, or other administrative activities.

Figure 6.1 illustrates the typical activities a patient may go through on the day of their procedure. Many of these activities are brief in duration, but they often require multiple resources (e.g. nurse, provider, recovery bed, procedure room). High resource dependency combined with uncertainty in activity durations, and the high volume of patients each day, make coordinating the entire process challenging. Uncertainty arises from a number of sources including uncertainty in procedure and recovery durations, no-shows, short notice add-on patients, patient punctuality, staff availability, and patients requiring additional resources such as an interpreter. Challenges also arise due to the need to coordinate all of the activities for many patients (often 30 or more) within a fixed period of time (e.g. 8 A.M - 5 P.M). If the completion of procedures runs beyond the planned closing time then overtime costs result.

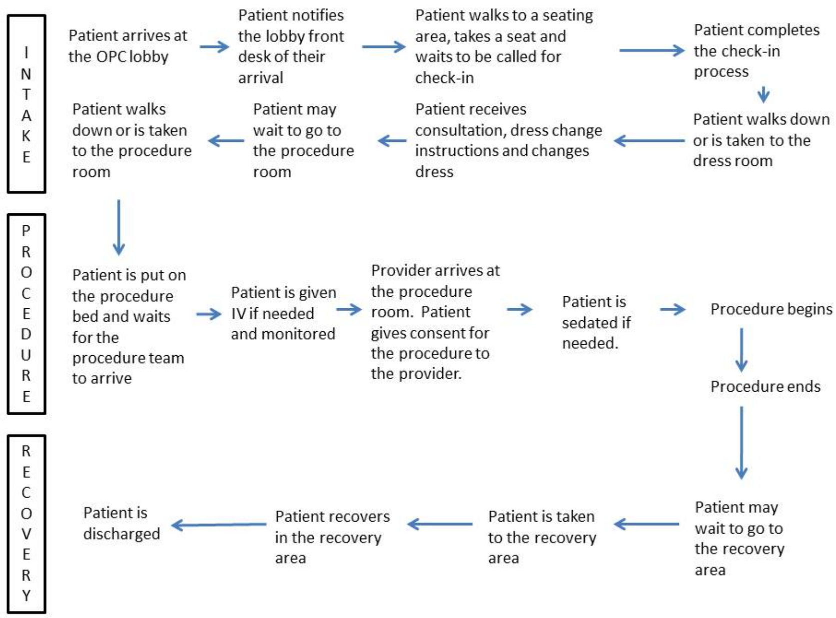

Fig. 6.1 Patient activities during intake, procedure, and recovery stages of the process in a typical OPC

There are many opportunities for bottlenecks in the patient flow process. Common bottlenecks include procedure rooms, recovery beds, providers and their teams, anesthesiologists, and equipment that needs to be sterilized between each procedure. Because the OPC operates on a daily basis it is not likely to reach a steady state. It is also not uncommon for bottlenecks to shift throughout the day. For example, intake is often a bottleneck at the beginning of the day as patients start to arrive; later in the day recovery may become a bottleneck as recovery beds fill up. The occurrence of bottlenecks can be influenced by many factors including provider availability during the day, patient punctuality, procedure room turn over time, and variation in procedure mix during the day resulting from the sequencing of procedures.

Figure 6.2 depicts the patient flow process in a particular OPC studied by Gul et al (2011). In this example, the intake and recovery area resources referred to as pre/post rooms are pooled, i.e., the same rooms are used for intake and recovery. Pooling the intake and recovery stage resources can increase flexibility in how limited space is used, reduce variation in the number of patients in intake and recovery, and reduce the risk of intake or recovery becoming a bottleneck in the system. It may also reduce the number of nurses needed overall, or else reduce the need for nurses to move from intake to recovery during the day as the number of patients in each area changes. However, equipping areas to be used for both intake and recovery may result in higher design costs since the entire area needs to be capable of serving multiple purposes. An alternative is to separate intake and recovery resulting in a linear (rather than reentrant) flow of patients through the OPC.

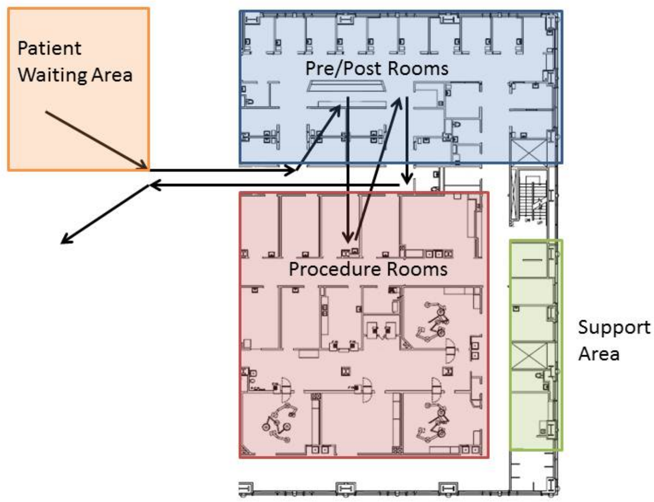

Fig. 6.2 An example of a common layout for an OPC and the patient flow process

Some OPCs choose to staff and equip procedure rooms for complete flexibility for all types of procedures. This creates flexibility in the assignment of patients and providers to rooms. As a result, a first come first serve queue discipline could be used in the the procedure stage to reduce the risk of procedure rooms becoming a bottleneck. OPCs that provide a wider variety of procedures, however, may choose to allocate specific procedures to specific rooms thereby saving equipment costs and allowing staff to specialize in a service. For example, certain procedures such as endoscopies may frequently use imaging equipment during the procedure, but outfitting each procedure room with imaging equipment may not be desirable due to the associated high capital costs. Further flexibility may be attained by not assigning patients to specific providers prior to their procedure. This could reduce patient waiting and increase utilization of OPC resources; however, the preferences of the patients for certain providers, and the benefits of continuity of care from clinic to OPC must be considered. Each of these opportunities for flexibility and resource pooling is specific to a particular OPC. The related decisions must carefully weigh the costs and benefits associated with increased flexibility.

Uncertainty has a significant impact on planning and scheduling decisions for OPCs. Some sources of uncertainty can be reduced with some cost and effort, while others are largely unavoidable. For example, OPC managers may be able to mitigate no-shows by calling patients in advance. On the other hand, the uncertainty in procedure and recovery duration is often difficult or impossible to reduce. This is because it is difficult to predict the complexity of a patient's procedure or their physiological reaction to a sedation agent following the procedure. However, by incorporating these sources of uncertainty in the planning and scheduling process, through the use of appropriate methods, such as simulation, queueing, and stochastic optimization, the extent to which the efficiency of the OPC is affected can be reduced.

6.3 Planning and Scheduling

The need to coordinate resources across multiple stages (intake, procedure, recovery) makes patient scheduling and planning a challenge to OPC managers. OPCs share many similarities with the scheduling of outpatient clinics and surgical practices. However, there are several differences. First, the complexity of the patient flow process is much higher than that of a typical outpatient clinic because the overall process involves multiple steps and many types of resources. Second, OPCs do not have the same planning and scheduling complexities as hospital based practices, such as the need to manage inpatients and trauma cases that arise during the day. Therefore there are typically more opportunities to improve efficiency through better planning and scheduling decisions.

Previous articles provide reviews of appointment scheduling in several settings including outpatient clinics (Cayirli and Veral, 2003) and hospital surgical practices (Gupta, 2007; Guerriero and Guido, 2011). There are also reviews in areas such as operating room planning (Cardoen et al, 2010) and surgical process scheduling (Blake and Carter, 1997) that are not specific to OPCs. In this chapter we focus specifically on patient planning and scheduling for OPCs. In the remainder of this section we discuss the most significant issues related to longer term planning and short term scheduling decisions.

6.3.1 Long Term Planning

OPC managers face many decisions in planning and scheduling appointments, both short and long term. Long term planning and scheduling decisions include the following:

- How far in advance should the appointment system be open to ensure adequate access for patients and flexibility in staff schedules (e.g., weeks or months)?
- How many patients should be scheduled in a day and what is the best mix of different types of patients and procedures?
- Should any appointment slots be left open for procedures that are likely to be scheduled on short notice?
- Should additional patients be scheduled to compensate for no-shows?
- What is the required nurse staffing?
- How many procedure rooms are needed, and how should procedure rooms be assigned to providers?

In this subsection we discuss each of these decisions and we provide specific examples of how they arise in the OPC setting. We also review some of the relevant literature related to these types of decisions.

The *booking horizon* determines how far into the future an OPC will schedule patient appointments. Selecting the length of the booking horizon is an important planning decision that requires coordination among staff schedules. If an OPC is going to make appointments available for a future date, administrative managers need to ensure that the necessary resources will be available on that date. Using a longer booking horizon allows schedulers and patients greater flexibility in choosing an appointment. However, a longer booking horizon also requires an OPC to design and commit to a staffing schedule far in advance. Furthermore, changes in staff availability over time may cause disruptions to schedules, requiring cancellations and rescheduling which can be a source of patient dissatisfaction.

Short booking horizons have been shown to be successful in some outpatient clinic settings. In order to mitigate the effects of no-shows and cancellations in an outpatient clinic, heuristic policies for dynamically scheduling requested appointments to specific days have been shown to work well by Liu et al (2010). In their study, the authors assume that the no-show and cancellation rates increase with appointment delay. That is, patients have a higher propensity to not attend their appointment when the difference in their request date and appointment date are large. The authors use a Markov decision process to dynamically assign patients an appointment date when they call to request an appointment. This decision is based on the current number of appointments scheduled on each day in the booking horizon. They show that their proposed heuristics, including a two day booking horizon, perform particularly well in the context of high patient demand. However, booking horizons in OPCs will typically be longer since many procedures require adequate advanced notice in order for patients to prepare for the procedure.

The number of patients to plan for each day affects the distribution of workload over time, and therefore staffing and other resource planning decisions. Further, when multiple types of procedures are scheduled, determining the right mix of procedures can influence planning decisions. Scheduling too many patients can result in high patient waiting time, overtime costs, and in some cases cancellations. The problem of dynamically allocating appointments to patients over time has been considered in the context of diagnostic resources by Patrick et al (2008). The authors consider the problem of planning in the presence of patient wait time targets that require patients be scheduled within a predefined time window. The authors use approximate dynamic programming methods and show that by carefully using overtime the patient wait list can be successfully managed.

The number and mix of procedures that can be scheduled depends on the availability of providers performing certain procedures. Further, OPC managers must decide if patients should be scheduled to see specific providers, or if there is flexibility in which provider performs each patient's procedure. While allowing provider flexibility decreases the bottleneck effect at the procedure stage, certain patients or procedures may require the skill or consultation of a specific provider. Furthermore, patients often have a preference for a certain provider.

OPC managers must also decide on the booking policy to be used. Two common alternatives are *block booking* and *open booking*. In block booking, a provider or group of providers is reserved specific procedure rooms on a recurring basis for certain days and times on a weekly or monthly schedule. Patients are then scheduled into blocks by their provider who is free to allocate patients provided the total procedure time can be completed in the allocated block. On the other hand, open booking consists of allocating patient appointment requests on a first come first serve basis for a given day of service. The OPC constructs a schedule of patient/provider room assignments, in some cases allocating multiple procedure rooms for a single provider, shortly before the day of service (e.g. 24 hours in advance). Thus, in open booking systems the OPC is treated more as a pooled resource.

Allocating certain types of procedures to specific rooms is common, and provides a means of balancing workload and resource requirements that may be necessary when there are a wide variety of procedures. Procedure information including type, provider, and type of anesthesiology have been used to classify and allocate procedures to rooms in an OPC by Dexter and Traub (2002). The authors used heuristics such as the earliest available start time, or the latest available start time, to allocate a procedure to a specific room at the time of scheduling. They compared the heuristics using a discrete event simulation model where multiple surgical groups shared procedure rooms. Similarly, some studies have compared online (decisions are made when appointment is requested) and offline (decisions are made after all appointment requests have been made) algorithms for allocating procedures to procedure rooms (Dexter et al, 1999). In order to maximize procedure room efficiency, Dexter et al (1999) concluded that it was optimal to allocate additional procedures in descending order of expected duration to rooms with the least amount of available time that was still sufficient to accommodate the additional procedure.

In some OPCs there is a need to ensure that there is sufficient space in the schedule for high priority procedures that need to be scheduled on short notice. This is another example of competing criteria in OPC planning. For example, filling a schedule with appointments scheduled in advance will help maximize capacity utilization; however, any procedures that need to be scheduled on short notice will likely be disruptive to the OPC operations and cause high patient waiting and overtime. Erdogan and Denton (2011) study this problem in the context of a single server and provide evidence that allocating time at the end of the day is optimal provided that patients do not have a high indirect waiting cost, i.e., the urgency is such that they can afford to wait until the end of the day to complete their procedure.

The number of cases scheduled on a daily basis directly influences revenue. The problem of deciding how many elective surgery cases to schedule on a particular day has been considered by Gerchak et al (1996). The authors consider the decision of whether or not to accept an additional elective case while faced with the uncertainty of how much space to leave for potential urgent add-on cases that arise stochastically in the future. Scheduling up to and no more than a predefined number of elective cases each day is common in practice. This is referred to as a *control limit* or *cut-off* policy. Formulating the problem as a stochastic dynamic program with the competing criteria of revenue, overtime and wait time, the authors show that the optimal number of elective cases to schedule on a day is related to the number of elective surgery cases on the wait list, as opposed to being of a control limit type. That is, the optimal number of elective cases to schedule does not follow a strict control limit, but will dynamically change based on the number that are waiting to be scheduled.

Many OPCs face high no-show rates and need to schedule additional patients to compensate for lost revenue. This is commonly referred to as *overbooking*. Dynamically allocating patient appointment requests to appointment slots for a single day with patient no-shows has been considered using overbooking by Muthuraman and Lawley (2008). The authors assume that appointment slots are equally spaced, visit durations are exponentially distributed, and no-show rates vary based on patient attributes. Revenue, patient waiting, and overtime are used as criteria in their objective in the context of an outpatient clinic. In addition to sequential scheduling decisions, overbooking along with careful planning of appointment schedules has also been demonstrated to help mitigate the burden of no-shows in OPCs (Berg et al, 2011).

The capacity of an OPC to see patients depends on staff availibility and physical resources (procedure rooms, recovery beds). The nursing staff required for OPCs is often an important consideration for planning decisions since nurses are necessary at each stage of the process. OPC nursing staff may be dedicated to specific responsibilities and stages, or they may be more flexible and *float* to where they are needed in the OPC. While the latter case provides more flexibility and can mitigate bottlenecks, this requires that the nursing staff be highly skilled with experience in multiple settings.

6.3.1.1 Example: Optimal Allocation of Procedure Rooms

In this section we provide a specific example of a long range planning decision based on an analysis of an endoscopy suite reported by Berg et al (2010). The example involves determining how many procedure rooms to assign to endoscopists, and how the decision affects competing performance criteria.

The endoscopy suite considered in this example is part of a large academic medical center and follows the general process structure in Figure 6.1. Appointments can be made up to 12 weeks in advance and schedules typically fill up within the last 48 hours. Patients arrive at the endoscopy suite according to a predetermined set of assigned appointment times. Intake is staffed by six nurses, the number of procedure rooms and endoscopists available on a given day can both range between four and eight, and the recovery stage includes three rooms with eight beds in each room.

As illustrated in Figure 6.3, opening two procedure rooms for each provider will allow providers to move to their next procedure while the previous procedure room is being turned over. Thus, the allocation of an additional procedure room can reduce provider waiting time and increase patient throughput per provider. However, the costs of staffing and equipping two procedure rooms for each provider is high relative to the total number of patients that can be seen in the endoscopy suite.

Figure 6.4 compares the utilization rates for procedure rooms and endoscopists as well as patient throughput to the number of endoscopists operating in an endoscopy suite with eight procedure rooms. As the number of endoscopists operating within the eight procedure rooms increases from four to eight, endoscopist utilization decreases, but total procedure room utilization and patient throughput both increase. These results illustrate the type of trade off in performance criteria that OPC managers face in making long term planning decisions.

In addition, daily processes can also affect long term planning decisions. For example, the decision of allocating procedure rooms to providers is influenced by the time required to turn over a room. If room turn over time is short relative to procedure time, fewer procedure rooms may be necessary. However, with longer turn over times more procedure rooms may be desirable to avoid bottleneck effects at the procedure stage.

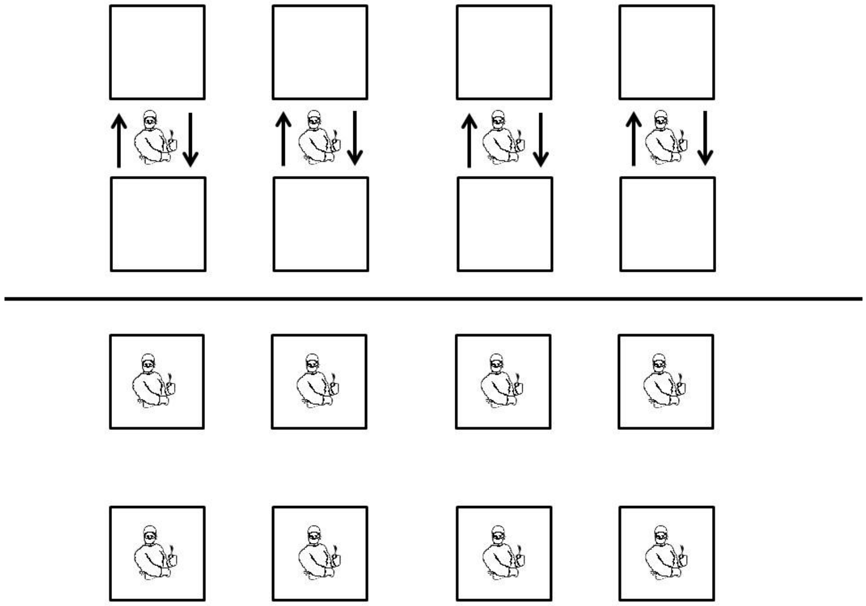

Fig. 6.3 Two scenarios for allocating providers to procedure rooms

6.3.2 Short Term Scheduling

The remainder of this section focuses on short term scheduling challenges in OPCs. Research related to short term scheduling decisions has received more focus than that of long term planning and scheduling for OPCs. Challenges for short term planning in OPCs include the following:

- How should procedures be sequenced throughout the day?
- When should patients be scheduled to arrive at the OPC?
- When is it necessary to cancel procedures?

The resources involved in the procedure stage of the process are often the most expensive and constraining to the OPC. Therefore the procedure is frequently the bottleneck in the system, and as a result much of the existing literature has focused on scheduling procedures. In this section we discuss examples of each of the above decisions in the context of OPCs. We also present a standard single server model that has been used for scheduling of OPCs. Finally, we provide a specific example of appointment scheduling in the context of an endoscopy suite.

Although the procedures in OPCs are done in high volumes and may be considered to be routine, there is often a large amount of uncertainty in the time required for the procedure. The high uncertainty is a result of many

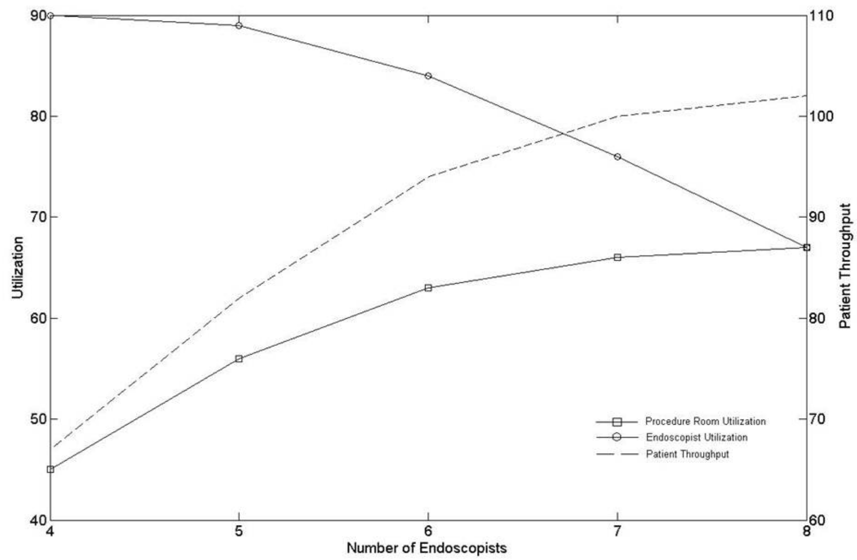

Fig. 6.4 Expected endoscopist and procedure room utilization and patient throughput as a function of the number of endoscopists in the endoscopy suite

factors that influence the procedure duration including procedure type, individual provider, type of anesthetic, and patient physiological characteristics (Dexter et al, 2008). Figure 6.5 illustrates the uncertainty in procedure durations for colonoscopies performed in a particular outpatient endoscopy suite. It illustrates two features that are common for any type of procedure. First, there is a finite time (5 minutes in this example) for which the probability of being below is very low. Second, there is a long tail indicating a low (but non-zero) probability the procedure will take a very long time. Long tails such as this are a result of unpredictable complications associated with procedures. For example, a patient who receives a routine colonoscopy may have multiple polyps discovered requiring biopsies that significantly lengthen the procedure time. While a variety of distributions have been found useful for modeling purposes (Cayirli and Veral, 2003), the log-normal distribution is often found to be an appropriate fit (Strum et al, 2000; Zhou and Dexter, 1998).

As an example of a short term daily scheduling problem, we discuss the single server appointment scheduling problem. The single server problem is a useful example because OPCs can often be disaggregated into multiple single server problems in which each procedure room corresponds to a server. Berg

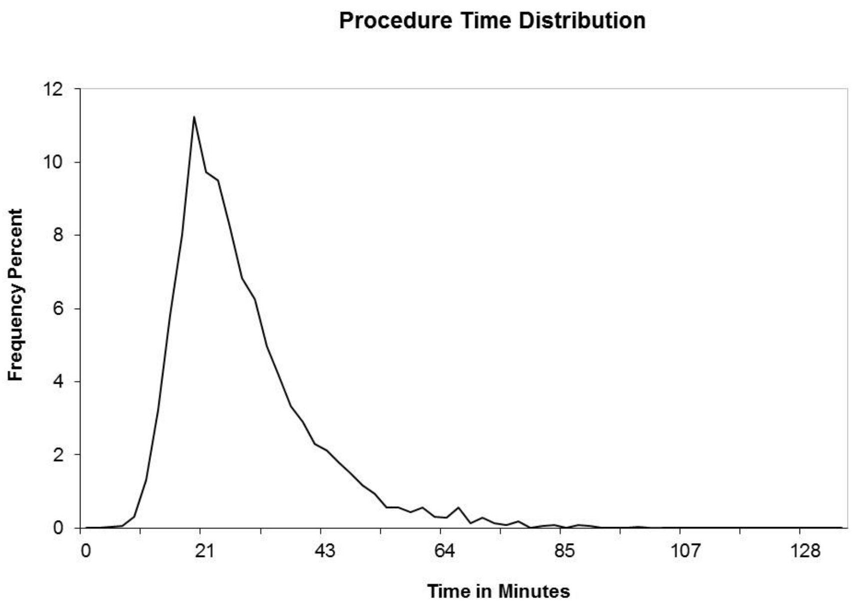

Fig. 6.5 The procedure duration distribution for colonoscopies can have a long tail due to many factors

et al (2011) show this can be a reasonable approximation when the procedure room is the bottleneck in the overall process. The appointment times for each patient $i = 1, \ldots, n$, denoted by vector $\mathbf{a}$, must be decided upon in advance. Suppose that the objective is to minimize the weighted sum of costs, c_i^w and c^o, associated with expected patient waiting time and overtime, respectively. The patient waiting times and overtime, $w_i(\mathbf{d}, \mathbf{a})$ and $o(\mathbf{d}, \mathbf{a})$, are functions of a vector of random variables, $\mathbf{d}$, the durations for each patient's procedure, and a vector of appointment times, $\mathbf{a}$. The objective can be formulated as follows:

$$\min_{\mathbf{a}}\{\sum_{i=1}^{n} c_i^w E[w_i(\mathbf{d}, \mathbf{a})] + c^o E[o(\mathbf{d}, \mathbf{a})] | \mathbf{a} \in A\}, \qquad (1)$$

and the waiting an overtime can be written as

$$w_1 = 0, w_i = \max\{0, w_{i-1} + d_{i-1} - a_i + a_{i-1}\},$$
$$\text{and } \ o = \max\{0, a_n + w_n + d_n - p\}$$

where p is the planned length of the OPC day and A represents the feasible region of appointment schedules that adhere to a specific OPC's constraints. Constraints may include requirements to schedule procedures for a certain provider during the hours they are working at the OPC (as opposed to associated hospital or clinical practice) or constraints on allowable or preferred sequences of procedures during the day.

The single server example illustrates the trade off that administrative managers must consider between multiple criteria, in this case patient waiting time and overtime. The focus of short term scheduling problems such as this is typically on *direct* waiting time, i.e. the time the patient spends waiting beyond their appointment time on the day of service. This is in contrast to *indirect* waiting time which measures total time from an appointment request to the day of service (indirect waiting is a common criterion for long term planning problems).

The stochastic nature of procedure times and other activities in OPCs makes finding optimal schedules very challenging. In practice schedules are commonly based on the mean procedure time. Thus, the appointment times for patient arrivals are defined as follows:

$$a_i = a_{i-1} + \mu_{i-1}, \forall i \quad (2)$$

where the first patient arrives at the beginning of the day ($a_1 = 0$) and μ_i represents the procedure duration mean for patient i.

Because the above scheduling rule is easy to implement it is commonly used in practice. However, it typically leads to very high expected patient waiting times. This is a result of procedures having duration distributions with long tails and waiting time accumulating for each patient throughout the day. For example, if the service time distribution is symmetric then there is a probability of 0.5 that a procedure will run longer than the allotted time, and each time this occurs waiting time accumulates.

Many heuristics for determining appointment schedule times for outpatient clinics have been proposed and examined (Bailey, 1952; Ho and Lau, 1992; Robinson and Chen, 2003). Specific to OPCs, setting interarrival times through *hedging* may be useful to reduce patient waiting time at the risk of increase overtime (Gul et al, 2011). Hedging refers to using a percentile (e.g., 50th, 65th) of a procedure's duration distribution to set appointment times. Elaborating on the heuristic in (2), job hedging can be represented by

$$a_i = a_{i-1} + \mu_{i-1} + \gamma, \forall i \quad (3)$$

where γ represents additional time added to act as a buffer to reduce the likelihood of a patient waiting.

Denton et al (2007) demonstrated that the sequencing decisions have a high impact on the performance of an appointment schedule, especially when overtime and patient waiting time costs are relatively evenly matched. Further, the authors demonstrated that the simple heuristic of sequencing procedures by decreasing procedure duration variance can provide significant improvements. Sequencing patients with greater variability in their procedure duration or propensity to not attend their appointment later in the day can lead to lower expected costs (Berg et al, 2011). However, combining procedure sequencing and start time scheduling leads to a challenging stochastic combinatorial optimization problem. As a result, many studies have considered heuristics. In the context of scheduling multiple procedure types by procedure duration, the shortest processing time (SPT) heuristic has been shown to work well in OPCs over other heuristics such as sequencing according to longest processing time, procedure variation, and a procedure's coefficient of variation (Gul et al, 2011).

6.3.2.1 Example: Appointment Scheduling in an OPC

In OPC settings, it has been demonstrated that using hedging can often reduce expected patient waiting time significantly with minimal effect on the expected length of day (time to complete all procedures). As an example drawn from Berg et al (2010), Figure 6.6 illustrates this in the context of the endoscopy suite described in Section 6.3.1.1.

In this example, each endoscopist has their own set of patients that are scheduled according to the heuristics defined in (2) and (3). That is, there is a patient arrival *stream* for each individual endoscopist in the suite. The appointment schedule generated by using the procedure duration means for interarrival times is identified in Figure 6.6. This corresponds to the heuristic defined in (2). The hedging parameter in (3), γ, is varied to generate the rest of the appointment schedules in Figure 6.6.

The appointment schedules in Figure 6.6 illustrate the trade off in the competing criteria that is made in designing appointment schedules. The results in this example show that using interarrival times for patients greater than the procedure duration mean can reduce patient waiting time while not incurring a significantly longer length of the clinic day. In Figure 6.6, the length of the clinic day is correlated with overtime and is the same as overtime when $p = 0$ for example, as defined in (1).

6.4 Factors Influencing Scheduling

In this section we identify some of the most important factors that detract from efficient performance of OPCs, and must be considered in planning and scheduling. These include uncertainty in intake and recovery durations, variation in patient demand and provider availability, material resources, and patient characteristics and behavior.

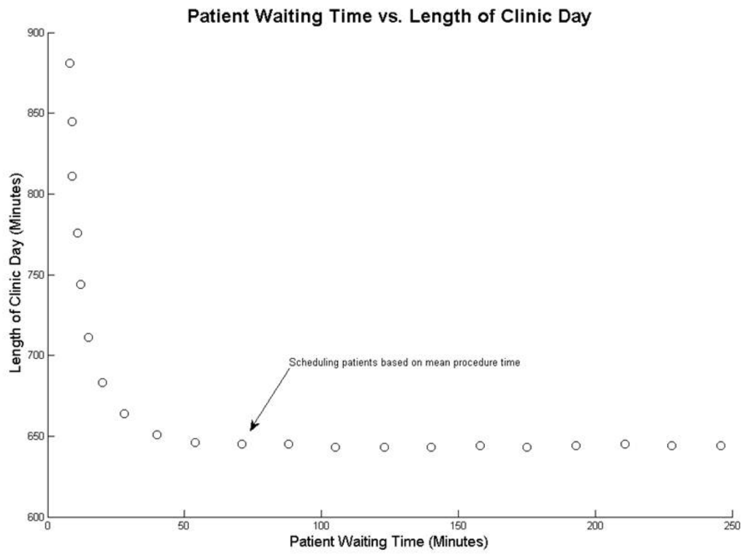

Fig. 6.6 Expected length of day (time to complete all cases) v. expected patient waiting time (averaged over all patients) with respect to the interarrival time for the patient arrival schedule.

6.4.1 Intake and Recovery

Just as procedure durations vary significantly by procedure types and patient characteristics, so do the durations for intake and recovery (Huschka et al, 2007). When resources are limited in intake (e.g. nurses) or in recovery (e.g. recovery beds) these stages in the process can affect planning and scheduling. Figure 6.7 illustrates the variation associated with intake and recovery at an endoscopy suite. Variation in intake time is due to the varying levels of preparation required for different procedures. For example, less invasive procedures may have the patient enter the procedure room directly upon arrival, while others may involve additional intake activities such as administration of anesthetic. Recovery times can vary as well, since certain procedures may require different sedation methods which can influence the time it takes for a patient to recover following a procedure. Thus, the uncertainty in the duration of intake and recovery coupled with the limited capacity in each stage may deserve careful consideration as appointment schedules are designed.

The uncertainty in recovery duration can have very different effects on an OPC than the intake stage due to the nature of recovery being at the

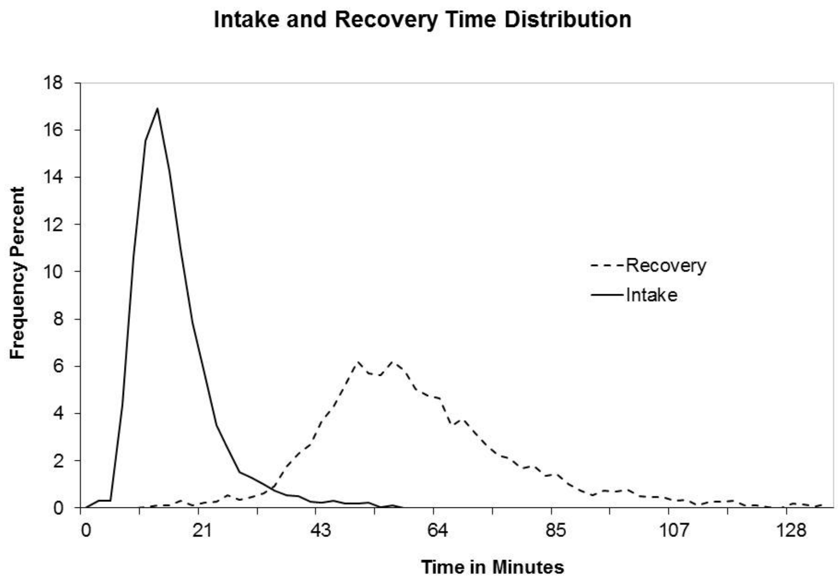

Fig. 6.7 The distributions for intake and recovery durations can have high variances contributing to potential bottlenecks in these stages.

end of the process. High recovery utilization rates can result in the entire system backing up. This is particularly true if there is no recovery alternative for patients finishing their procedure other than recovering in the procedure room, thus blocking subsequent procedures from beginning.

Due to the similarities in OPC recovery areas and the post anesthesia care unit (PACU) in hospitals, drawing on surgery scheduling insights from hospital based practices can be informative to recovery planning for OPCs. Queueing models are often used in these environments, but the assumption of a steady state may be restrictive in the setting of an OPC. Schoenmeyr et al (2009) justify their model assumptions based on historical data and show that the arrival process into the PACU following surgery can be modeled as a Poisson process. They use their model and simulation to conclude that significant decreases in PACU congestion could be gained by proportionally small changes in capacity. However, this relationship is sensitive to the number of procedures planned.

Controlling the sequence in which procedures are performed across multiple procedure rooms can help balance the arrival rate into the PACU. Although many providers prefer to have longer procedures earlier in the day, discrete event simulation has been used to show this sequencing rule may perform poorly as the variation of the longer procedures can disrupt the schedule later in the day by Marcon and Dexter (2006). Furthermore, the PACU tends to be empty for much of the beginning of the day, and then has a peak of workload following completion of the firt procedures of the day. The authors conclude that sequencing heuristics that balance the longer procedures at the beginning and end of the day tend to smooth the flow of patients into the PACU.

In the scheduling literature, when jobs remain on a machine following processing, and there is no buffer capacity, it is referred to as *blocking*. Blocking and *no-wait* scheduling problems have been discussed in several manufacturing contexts (Hall and Sriskandarajah, 1996). A similar situation occurs in OPCs; when the recovery room is full, patients may start their recovery in a procedure room. However, this blocks the use of the procedure room and can cause delays. Augusto et al (2010) explicitly modeled the possibility of patients recovering in an operating room (OR) as a mixed integer program. The authors recommend a decision rule for when to use the OR for recovery, based on case load and the ratio of ORs to recovery beds. Although this problem was formulated in the context of a hospital practice, the relationship between the ORs and PACU is analogous to OPCs with procedure rooms and shared recovery areas.

6.4.2 Patient Demand and Provider Availability

Variation in supply and demand can create scheduling challenges and inefficiencies for an OPC. The problem of supply and demand being mismatched is very common in many industries and is prevalent in OPCs. Patient demand variation can be high from week to week as well as from day to day. Even more, month to month variation may be high as demand for procedures may be high when patients have time off (e.g. summer for students) or when patients will be less active (e.g. winter for orthopedic patients). Further, supply factors contributing to the supply and demand mismatch include provider availability and upstream referring sources. The first, provider availability, may result from variation in provider schedules for a variety of reasons, such as vacation, administrative or research obligations, or attending a conference for their specialty. The second, referrals, depends on an OPC's affiliation with other practices. For example, specialty clinic consultations result in newly generated referrals for procedures at the OPC. Thus, the OPC's position downstream in the overall health service supply chain exposes them to variation associated with other upstream practices. Figure 6.8 illustrates the weekly variation for procedures in an endoscopy suite affiliated with a large academic medical center.

The challenge of leveling patient demand across available capacity in order to gain operational efficiencies needs to be considered when attempting to ac-

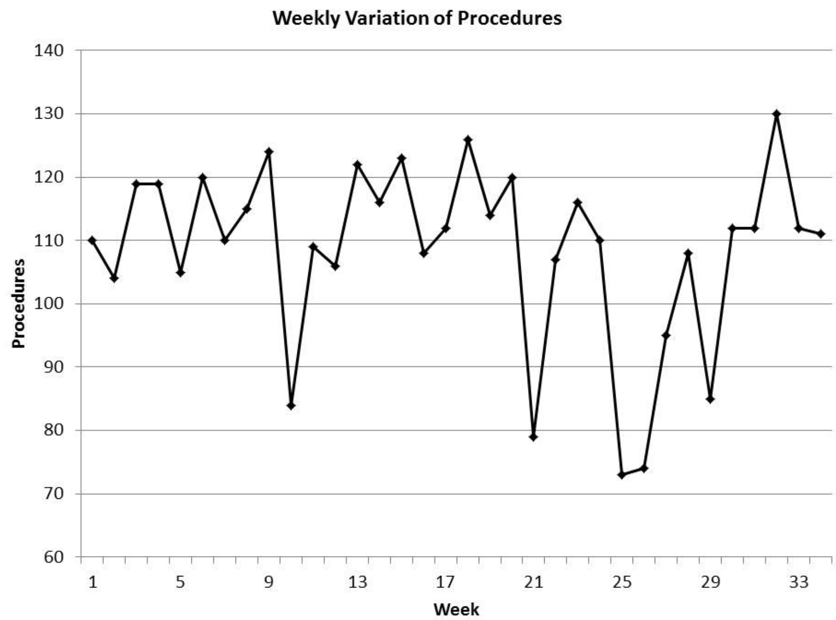

Fig. 6.8 The number of procedures done each week in an endoscopy suite vary week to week. Data is presented from July to February.

commodate patient appointment preferences. The loss of efficiency resulting from demand variation can include being under (or over) staffed, resources being under utilized, and patients having poor access to services as well as long wait times at the OPC. Schedules for nurses, other personnel, and physical resources are often fixed day to day and week to week. Thus, supply is not easily varied to match demand.

6.4.3 Material Resources

Materials management contributes to the operating costs of an OPC. This includes the purchasing, ordering, inventory, and opportunity costs for any medical and surgical supplies that an OPC uses. Examples include medical equipment, lab equipment, surgical instruments, and medical apparel.

Sterilization of procedure equipment can be a timely as well as resource intensive process. For example, the sterilization of endoscopes in an endoscopy suite requires trained personnel, disinfection and sterilization equipment, and can take a up to a few hours to process. Further, since procedure equipment such as endoscopes are expensive, purchasing additional equipment is not always feasible. Single-use equipment for certain types of procedures has the advantage of avoiding the costs of sterilization and maintenance, but has been found to be very costly in the long run (Schaer et al, 1995). The trade off between the capital costs of equipment and the effects of limited resources on an OPCs efficiency needs to be considered in both the long term planning and short term scheduling contexts.

The trade off between the use of mobile and fixed diagnostic resources is another example of material resource planning. Many procedures require the use of diagnostic resources, but equipping every procedure room with such resources can be expensive. While mobile equipment affords flexibility in the location and use of the equipment, the mobile equipment may be cumbersome and/or difficult to setup and use. Therefore there is a natural trade off between the cost of investing in mobile diagnostic resources and the flexibility such resources offer to the scheduling process.

The design of surgical equipment kits for OPCs requires careful consideration. Different types of procedures require different supplies. Preparing universal kits that contain the supplies and equipment necessary for all procedure types can be costly as it requires high inventory levels; however, preparing kits for individual procedures can be time intensive and susceptible to errors in packing kits. As a result there are challenging decisions about how best to trade off cost and the benefits of flexibility.

Efforts to use appointment scheduling information to manage the inventory of physical material resources has also been considered. Generally, OPCs use economic order quantity (EOQ) models to manage inventory levels. However, using just in time (JIT) models that are based on when procedures are scheduled in an OPC has been proposed by Epstein and Dexter (2000). The authors use simulation and conclude that while there may be possible savings in a JIT system used in conjunction with the appointment scheduling system, it is unlikely that the savings would be substantial when compared to the cost of implementing such a system. Thus, traditional EOQ models with higher inventory levels are likely best for OPCs.

6.4.4 Patient Characteristics and Behavior

The patient population served by an OPC is likely to be diverse in their characteristics as well as how they interact with the health care system. Relevant patient characteristics include age, gender, and physiological background, which are often correlated with procedure times, and therefore can be useful for appointment scheduling. For example, obese patients tend to be at higher risk of complications, and have longer procedure and recovery times. By patient behavior, we primarily refer to patients' (non) attendance and punctuality, as well as their preference for certain appointment times.

Designing appointment schedules that compensate for patient behavior is a challenge faced by OPC managers.

An OPC's ability to serve a patient case mix relies on its ability to adapt to a variety of patient characteristics, preferences, and behavior. Cayirli et al (2006) demonstrated that the performance of an appointment schedule is very sensitive to patient characteristics and behavior such as walk-ins (add-ons or patients that need to be scheduled the same day), no-shows, and punctuality. Although the authors' analysis was specific to a clinical office setting (primary care), the role of patient characteristics and behavior in scheduling decisions is informative to OPCs.

No-shows occur when patients do not attend their scheduled appointment and do not cancel before hand. No-shows have been reported in OPC settings and present a challenge to managers of many types of healthcare practices (Adams et al, 2004; Sola-vera et al, 2008). The reasons for patients failing to adhere to their scheduled appointments include illness, stress about the procedure, improved symptoms, forgetting about the appointment, improper preparation for the procedure, or balking when informed of the cost of the procedure. In many ambulatory settings, *advanced access* has become a popular method for dealing with the uncertainty in patient demand (Murray and Berwick, 2003). Advanced access refers to scheduling appointments for the same day that they are requested and "doing today's work today." This scheduling policy requires providers being able to match demand with supply and not having any backlog of appointment requests. By offering appointments to patients on the same day that they call, providers reduce the problem of patients failing to attend their previously scheduled appointment as well as patients having long delays for an appointment. However, due to the preparation necessary for many OPC procedures, advanced access is not a feasible policy for appointment scheduling in OPCs.

In contrast to patients failing to attend their scheduled appointments, many OPCs (especially those affiliated with a hospital) will also receive high priority add-on cases that need to be fit into the current day's schedule. For example, endoscopy suites are sometimes asked to see a patient with indications of colorectal cancer on short notice. Heuristics were evaluated via simulation to determine how to allocate add-on cases to specific procedure rooms in order to maximize utilization (Dexter et al, 1999). Dynamically scheduling appointment times while considering no-show rates and uncertainty in future demand has also been examined as a stochastic programming formulation (Erdogan and Denton, 2011). A dome shaped schedule is observed for routine patients (non-add-ons) where patients earlier and later in the day are scheduled closer together and patients in the middle of the day are given more time between arrivals.

Patients receiving surgery in OPCs may have a preference for the day and time of their appointments. In a survey of cataract surgery patients, the authors found that the patients value appointment flexibility very highly and strongly preferred morning appointments (Dexter et al, 2009). Due to the high cost of OPC resources and the challenges in balancing supply and demand, patient preferences are often not as high a priority for managers when compared to other environments such as primary care. Incorporating the consideration of patient preferences into OPC planning and scheduling decisions is an important direction for future research.

6.5 Operations Research Challenges

As demand for services in OPCs continues to rise, the need to provide services in a cost-effective manor makes planning and scheduling in OPCs an important challenge for OR researchers and practitioners. Considerable effort has been put into scheduling inpatient surgeries and ambulatory clinics where queueing and mathematical programming methods are applicable to single stage and single server environments. However, a number of unique challenges remain in planning and scheduling for the OPC setting.

The multi-stage (intake, procedure, recovery) and multi-server nature of OPCs make optimization models that accurately represent the system a challenge to formulate. The single server model presented in Section 6.3.2 illustrated the challenges in designing an appointment schedule with competing criteria for a single stage and single provider. However, the design of an OPC appointment schedule may need to include multiple servers in the model since there are many shared resources between each server such as nurses, equipment, and procedure rooms. Further, there is uncertainty in the intake and recovery stages that will impact the design of an appointment schedule. Finally, all of the activities required for a patient's procedure need to occur within a limited time frame. The complex interactions between many resources across multiple patient care stages requires significant coordination and conveys the challenges in formulating models for OPCs.

Due to the complexity of OPCs, mathematical programming models may not always be possible, or even desirable. The complexity of OPCs, resulting from multiple stages and the coordination of many resources, makes discrete event simulation a natural methodology. While descriptive simulation models that accurately represent an OPC are helpful in diagnosing bottlenecks and evaluating hypothetical scenarios, simulation optimization methods could be used to make optimal or near optimal planning and scheduling decisions. This remains on open challenge for future research.

In addition to developing new models, there is also a need for implementable recommendations that can be gleaned from this body of research. The process of making such recommendations includes demonstrating the value of a model's solution (with data from real OPCs) and abstracting easy to implement rules or insights. Advanced OR models can serve as a means to evaluate the effectiveness of easier to implement scheduling rules.

6.6 Conclusions

This chapter has summarized typical OPC operations, described the similarities, differences, and interactions between OPCs and other health care service settings, and has explained some of the unique challenges in the planning and scheduling decisions that OPC managers face. The decisions were categorized as either long term planning decisions or short term scheduling decisions and were presented with models and results drawn from examples in the literature. Factors that influence OPC planning and scheduling decisions were summarized along with methods used to address these challenges.

There has been a lot of research and focus on appointment scheduling in the context of ambulatory clinics and hospital based surgery practices. While some of these methods are relevant to planning and scheduling in OPCs, the unique nature of OPCs presents challenges that have yet to receive the same attention. With demand for surgery in the outpatient setting continuing to rise, designing appointment systems specific to OPCs that accommodate timely access to services while utilizing resource efficiently will continue to increase in importance.

The complexity of OPCs will lead to opportunities for the development of new models and methodological advances, particularly in the areas of stochastic optimization methods such as stochastic programming, stochastic dynamic programming, and simulation optimization.

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