Open Forum Infectious Diseases
REVIEW ARTICLE

Improving the Efficiency of Antimicrobial Stewardship Action in Acute Care Facilities

Emily L. Heil,[1] Julie Ann Justo,[2,3] and Jacqueline T. Bork[4,5]

[1]Department of Practice, Sciences and Health Outcomes Research, School of Pharmacy, University of Maryland, Baltimore, Maryland, USA, [2]Department of Clinical Pharmacy and Outcomes Sciences, College of Pharmacy, University of South Carolina, Columbia, South Carolina, USA, [3]Department of Pharmacy, Prisma Health Richland Hospital, Columbia, South Carolina, USA, [4]Division of Infectious Diseases, Institute of Human Virology, Department of Medicine, School of Medicine, University of Maryland, Baltimore, Maryland, USA, and [5]Veterans Affairs (VA) Maryland Health Care System, Baltimore, Maryland, USA

Inpatient antimicrobial stewardship (AS) programs are quality improvement programs tasked with improving antibiotic practices by augmenting frontline providers' antibiotic prescription. Prospective audit and feedback (PAF) and preauthorization (PRA) are essential activities in the hospital that can be resource intensive for AS teams. Improving efficiency in AS activities is needed when there are limited resources or when programs are looking to expand tasks beyond PAF and PRA, such as broad education or guideline development. Guidance on the creation and maintenance of alerts for the purpose of PAF reviews, modifications of antibiotic restrictions for PRA polices, and overall initiative prioritization strategies are reviewed. In addition, daily prioritization tools, such as the tiered approach, scoring systems, and regression modeling, are available for stewards to prioritize their daily workflow. Using these tools and guidance, AS programs can be productive and impactful in the face of resource limitation or competing priorities in the hospital.

Keywords. antimicrobial stewardship; efficiency; prioritization.

Antimicrobial stewardship (AS) programs are well-recognized quality improvement initiatives with patient-level and institutional benefits that span the acute, long-term care, and outpatient settings [1–3]. AS actions are outlined in the Centers for Disease Control and Prevention (CDC) core elements of hospital AS programs such that programs are expected to implement interventions that are considered "priority" [4]. According to these CDC core elements, priority interventions include prospective audit and feedback (PAF), preauthorization (PRA), and development of facility-specific treatment guidelines. Each action requires significant AS resources and organizational support. The first 2 priorities, PAF and PRA, represent foundational actions of AS programs; these generally occur daily and impact the quality of care at an individual patient level. The latter priority, facility-specific treatment guidelines, represents a complementary action that occurs on a more intermittent basis at the level of a health system.

Although priority interventions are a major focus, AS teams perform several other tasks and responsibilities that are equally important. These often include provider and patient education, coverage on the infectious diseases (ID) consultation service, and quality improvement projects, as well as AS data tracking, analysis, and reporting. Additionally, traditional AS duties were dramatically impacted by the COVID-19 pandemic, where significant stewardship time was shifted to pandemic management [5]. Improving efficiency in the priority interventions at the patient level (ie, PAF and PRA) allows time for these additional systems-level tasks while providing an essential service for patients and the institution. This flexibility is particularly vital when institutional priorities shift, such as the COVID-19 pandemic or urgent antimicrobial shortages. As AS programs remain understaffed, stewardship personnel grapple with high rates of burnout and insufficient time for professional growth [6, 7]. Herein, we describe strategies for improving efficiency in the patient-level priority stewardship actions of PAF and PRA to optimize efficiency and resource utilization among AS programs. While these strategies do not represent a replacement for adequate program staffing, improving AS efficiency and optimizing stewardship workflows can help to protect the current workforce [8, 9]. The key steps include (1) identifying AS resources, (2) prioritizing candidate AS initiatives and determining which to pursue based on available resources, (3) developing ideal AS alerts to operationalize each initiative, and (4) prioritizing daily AS tasks and actions for an efficient workflow.

IDENTIFYING RESOURCES

To implement and foster the growth of a successful AS program, 3 core resources must be addressed: personnel, technology, and

Received 01 June 2023; editorial decision 20 July 2023; accepted 28 July 2023; published online 1 August 2023

Correspondence: Jaqueline T. Bork, MD, University of Maryland School of Mediciton, Department of Medicine, 29 S. Greene St. Suite 300, Baltimore, MD 21201 (jabork@som.umaryland.edu).

Open Forum Infectious Diseases®

https://doi.org/10.1093/ofid/ofad412

time. Additional resources, such as administrative support and financial resources (eg, discretionary budget), can augment 1 or more of these core resources, often because of advocacy on the part of AS personnel. The proportions of core resources utilized for given AS actions can vary widely and are highly interconnected (eg, improved technology can help with time required).

Personnel

AS personnel are a key resource for a functional AS program. The ideal core members include an ID physician and ID clinical pharmacist. Additional members optimally include a clinical microbiologist, an information technology (IT) specialist, a hospital epidemiologist, nursing representation, an infection control professional, and other ad hoc stakeholder representatives as needed [10]. Each AS program should identify the full-time equivalents available to perform PAF and PRA interventions directly, with adequate resources for anticipated program growth and for emergency/pandemic preparedness [9].

Technology

Technology capability for AS programs ranges from fully automated and integrated to entirely manual and outside the electronic health record (EHR) system. At a basic level, technology can assist with the daily tasks of AS personnel. This includes generating targeted lists for review as part of PAF, facilitating communication between antimicrobial prescribers and AS personnel as part of PRA, and generating data needed for AS tracking and reporting. More advanced functionality includes the ability for the technology to interface with numerous general prescribers directly and to provide clinical decision support for individual patient cases (eg, best practice alerts). This advanced use can supplement and reinforce AS interventions provided by AS personnel. The technology can be integrated within a local EHR system, exist in a separate third-party program, or be a combination of the two. Each AS program should verify the capabilities of its available technology and estimate the general time and effort that it would take to edit the technology to meet the needs of a chosen AS initiative. This could include estimating the time that it would take for an IT request for a new targeted list to be completed and/or whether automated reports regarding initiative outcomes could be generated. Ideally, AS programs would have dedicated IT personnel for EHR design and build work and for data tracking, collation, and analysis, which may be unique resources depending on the local EHR.

Time

Time refers to the physical work hours necessary to develop, implement, and maintain an AS initiative. Of these, maintenance time is the most long-lasting and often underestimated. If a local institution has 1.0 full-time equivalent of an ID-trained pharmacist dedicated to its AS program, it generally has 40 hours of time dedicated to all AS activities in a given workweek. What proportion of that time should be dedicated to priority AS actions of PAF and/or PRA? Published examples vary by institution, yet 1 study of 4 community hospitals (100–400 beds each) that performed either PAF or PRA reported that stewardship personnel spent a median 5 to 19 hours per workweek on such interventions (approximately 1–3.8 hours per workday) [11]. Each AS program should consider the realistic amount of time available for all PAF and/or PRA in a given workday. This time can be spread across 1 or more personnel, depending on local resources.

PRIORITY ANTIMICROBIAL STEWARDSHIP ACTIONS

Preauthorization

Restricting certain antibiotics can be an effective strategy for limiting antibiotic use. However, operationalizing an effective and safe approval process may be a challenge [12]. Traditional restriction requires a call to an AS team member to review the chart and adjudicate the antibiotic appropriateness for select antibiotics before the order is processed by pharmacy. With this strategy, the following need to be determined: the AS team member's availability to approve requests, the time in which the AS team member is available to respond (eg, specific hours during the week, any time including nights or weekends), and the depth of review (eg, chart review or bedside evaluation).

A large academic center, a small community hospital, and everything in between may have different approaches to implementation. Having 24-hour coverage for an approval pager may pose a problem for short-staffed programs, and other hospital members may be called to provide PRA (eg, ID physicians or trainees, pharmacy trainees, non-ID clinical pharmacists). Another approach employed in various acute care settings is requiring bedside ID consultation for approval [13]. This strategy may be appropriate as nuances in treatment often require understanding more information that is not readily available from the chart or the requesting clinician. PRA strategies can be associated with delays in providing antibiotics to patients, given the time needed to complete the review and approval process [14]. A common modification to the PRA strategy allows for unrestricted first-dose administration but requires AS member approval prior to any further administration [11]. Another modification is to customize a list of preapproved indications for a specific antibiotic, such as "documented systemic infection due to a resistant gram-negative organism" or "other" for a carbapenem antibiotic. Selection of the preapproved indication would automatically be approved (with optional verification via PAF, if desired), yet any indication selected as "other" would require direct approval from an AS member prior to antibiotic administration. Such modified PRA strategies may be more acceptable to clinicians and minimize delays in patient care during the PRA process [15].

Of course, stewards must be aware that restriction policies can be circumvented and audits gamed. Frontline providers that perceive inefficiencies in stewardship workflows may engage in workarounds of these PRA systems, so periodic audit of pre-approved indications or similar workflows is required [15].

Prospective Audit and Feedback

The PAF strategy is the preferred action for many programs, though combining it with a PRA for select antibiotics may ultimately be the most desired approach [16]. PAF consists of the following [17]:

- Reviewing a chart for a specific purpose (eg, extended-spectrum antibiotic at a specific time after order initiation)
- Adjudicating the appropriateness of the prescribed antibiotic based on institutional guidelines and practices
- Applying core AS principles to optimize antibiotic use (eg, the 4 moments of antibiotic decision making)
- Communicating recommended interventions to the prescriber, often with education built into the encounter with the prescriber

The 48- to 72-hour antibiotic audit is a standard AS PAF review with the intent of optimizing antibiotic selection, dose, route, frequency, and duration, after initial workup has been done and culture data are available to drive action. Depending on personnel resources and hospital size and resources, priorities of this PAF review can be stratified to areas of interest or need (eg, excluding patients who have ID consultation, focusing on a unit with high broad-spectrum antimicrobial utilization, or reviewing select agents at 24 hours based on rapid diagnostic results). Reviewing targeted antibiotic types or infectious syndromes (eg, genitourinary infections) at the initial time of order may be another approach that programs choose.

Reviewing laboratory-based data prospectively in real time can also be effective. Certain microbiological data, such as positive blood cultures and/or rapid diagnostics (eg, molecular diagnostics for blood cultures), may be highly impactful in identifying patients in need of intervention [18, 19]. The specific array of PAF and PRA that an AS program ultimately pursues at any given time will likely be dictated by the limits of the aforementioned resources as well as AS initiative prioritization discussed next.

Importance of AS Initiative Prioritization

While it is recommended that local AS programs continually advocate for adequate resources, it is essential for those programs to simultaneously select AS initiatives with the greatest potential for success. Particularly in cases where the local AS program has more candidate ideas for PAF and/or PRA than there are resources to operationalize, decisions of their relative priority become paramount. The ideal AS initiative should be impactful, feasible, actionable, and measurable (Table 1). These 4 characteristics ensure that AS resources of personnel, technology, and time are being used efficiently to address chosen AS goals.

Whether an AS program is just getting started or is long-standing, program initiatives should be routinely reviewed and prioritized. The Antimicrobial Stewardship Initiative Prioritization Tool (Table 2) has been developed to aid AS programs in identifying the top actions that follow these core

Table 1. Ideal Qualities of an Antimicrobial Stewardship Initiative/Alert

Quality	Description/Comments
Impactful	Initiative/alert should have the potential to significantly impact outcomes at the patient level and the systems level An impactful initiative/alert tends to demonstrate the following features at baseline: • A large gap between current clinician practices and best practices (eg, local need for a culture change) • A large impact of suboptimal practices on individual patient care (eg, inappropriate antimicrobial use adversely impacts individual patient outcomes, including length of stay, readmission, morbidity, and/or mortality) • Infectious syndromes affected by the initiative are relatively common (ie, high volume of patients affected) • Address a regulatory/administrative priority
Feasible	Alert should ideally be automatically generated and timely Feasibility generally based on local technology resources Team should decide on capturing "most" vs "all" relevant targets Consider total volume of alerts requiring review
Actionable	Defined as the proportion of reviews resulting in an AS intervention among all reviews performed, often reported as a percentage Actionability generally based on local AS personnel and technology resources Threshold for sufficient actionability varies by program and initiative Consider testing and validating the alert prior to implementation Chronic low actionability may result in alert fatigue and poor morale among AS personnel
Measurable	Alert should align with anticipated impacts (eg, proportion of appropriate antimicrobial orders/prescriptions, proportion of guideline-concordant therapy, time to targeted therapy, days of antimicrobial therapy, length of stay, readmission rate, mortality) Documentation of daily AS interventions should also be tracked and reported Measurability generally based on local technology resources Ideally automatically generated and timely

Abbreviation: AS, antimicrobial stewardship.

Table 2. Example of the Antimicrobial Stewardship Initiative Prioritization Tool

				Impact				Feasibility	Actionability	Measurability	Priority	
	Initiative Type?			Gap Between Current Clinician Practices and Best Practices?	Impact of Suboptimal Practices on Individual Patient Care?[a]	How Common Are the Infectious Syndromes Affected by this Initiative?	Address a Regulatory Priority (eg, CMS, Joint Commission, Local Administration)	Feasibility of Building Functional Targeted Alert(s) for the Initiative?	Likely Actionability of Targeted Alert(s)?	Measurability of Initiative Outcomes?	Risk Score[b]	Priority Rank
Initiative	*PAF*	*PRA*	*Other*	*1 = Small* *2 = Moderate* *3 = Large*	*1 = Low* *2 = Moderate* *3 = High*	*1 = Less Common (CDI, IE, OM)* *2 = Moderately Common (BSI, IAI)* *3 = Very Common (PNA, UTI, SSTI)*	*1 = No* *2 = Yes*	*1 = Difficult* *2 = Moderate* *3 = Easy*	*1 = Low (≤33% of Alerts)* *2 = Moderate (34%–66% of Alerts)* *3 = High (≥67% of Alerts)*	*1 = Difficult* *2 = Moderate* *3 = Easy*	*Total*	*1 = Highest Rank*
PAF of all piperacillin-tazobactam and cefepime orders at 72 h	☒	☐	☐	1	2	2	2	2	2	2	13	3
PRA of carbapenems	☐	☒	☐	1	3	1	1	2	2	2	12	4
PAF of all positive multiplex PCRs in blood	☒	☐	☐	3	3	2	2	3	3	2	18	1
PRA of ciprofloxacin indicated as treatment for UTIs	☐	☒	☐	2	3	3	2	2	2	1	15	2

Abbreviations: BSI, bloodstream infection; CDI, *Clostridioides difficile* infection; CMS, Centers for Medicare and Medicaid Services; IAI, intra-abdominal infection; IE, infective endocarditis; OM, osteomyelitis; PAF, prospective audit and feedback; PCR, polymerase chain reaction; PNA, pneumonia; PRA, preauthorization; SSTI, skin and soft tissue infection; UTI, urinary tract infection.

[a]Scale: 1 = low (no increased length of stay, readmission, morbidity, and/or mortality), 2 = moderate (mild-moderate increased length of stay, readmission, morbidity, and/or mortality), 3 = high (markedly increased length of stay, readmission, morbidity, and/or mortality).

[b]Risk score analysis: low priority, ≤8; moderate priority, 9–14; high priority, ≥15.

qualities of an ideal initiative. It is recommended that this tool be completed by the local AS program as a group and based on local information and experiences. Additional instruction for how to use this tool is provided as follows.

QUALITIES OF AN IDEAL ALERT FOR AN ANTIMICROBIAL STEWARDSHIP INITIATIVE

Each AS initiative represents a systems-level goal or concept; yet, the triggering event that spurs local AS action at the patient level is typically a targeted alert developed for the initiative. Such a targeted alert fires directly to the local AS team and can meet a variety of needs (eg, identifying patient cases for PAF, monitoring adherence to PRA policies). These alerts can be fired in real time or at a predictable set time (eg, midnight pull). The design of each alert should uphold the same 4 ideal characteristics of the overarching AS initiative: impactful, feasible, actionable, and measurable (Table 1). These characteristics are detailed in turn.

Will the Alert Have an Impact?

Stewardship alerts should be impactful with the potential to influence patient- and system-level outcomes. Although the literature on stewardship is relatively young, there is already a growing body of data regarding select interventions that are known to carry an impact. For instance, efforts targeting less fluoroquinolone utilization can have rapid and sustained decreases on *Clostridioides difficile* infection rates, or formal PAF on broad-spectrum antibiotics in the intensive care unit can decrease inappropriate use and improve susceptibility to those agents [20, 21]. Initiatives that align with quality measures, CDC core element priorities, or other administrative priorities, such as reducing hospital-acquired *C. difficile* infection or optimizing the care of patients with sepsis, are also likely to have significant potential impact and administrative buy-in. Other institution-specific factors that can capture potential impact are outlined in Tables 1 and 2. For example, the gap between current clinician practices and best practices may be large (ie, scored 3 in Table 2) for PAF of all multiplex polymerase chain reactions in blood if local clinicians are generally unaware of how to interpret these data and adjust antimicrobial therapy accordingly. Conversely, the gap may be moderate (ie, scored 2 in Table 2) for PRA of ciprofloxacin indicated as treatment for urinary tract infections if ciprofloxacin is only the third-most common therapeutic option of local cystitis (ie, prescribed in 25% of cases). Other factors contributing to the potential impact of an initiative/alert include the gravity of the suboptimal impact on the individual patient (eg, unmonitored creatine phosphokinase levels while taking daptomycin) and frequency of the infectious syndrome (eg, pneumonia is more common than meningitis).

Is the Alert Feasible?

Ultimately, the feasibility of some AS initiatives will depend on the technology resources available at the institution. For example, if a stewardship program has decided to prioritize the PAF of patients with methicillin-resistant *Staphylococcus aureus* (MRSA) bacteremia, the logical first step would be to identify patients with blood cultures positive for MRSA. However, if the EHR cannot pull a list of patients by culture site with organisms and susceptibility, the AS team would have to develop other potential criteria to narrow the focus (eg, a list of patients with vancomycin orders with a specified indication of bacteremia). Alternatively, the AS team could utilize a separate reporting system in the microbiology laboratory where these patients could be identified. The capabilities of the EHR often dictate the feasibility of desired AS initiatives. If the system cannot identify the targeted population with sufficient discrimination, then the time spent sorting through the excess noise in the report can render the initiative useless. Designing a 48- to 72-hour rule can be particularly challenging since reorders from dose changes or patient transfers may result in errors when reporting the true duration of antimicrobial therapy. In the era of rapid diagnostics, more immediate antibiotic reviews (eg, ≤24 hours) could improve empiric therapy.

The timeliness of the information must be considered when evaluating the feasibility of a potential intervention. For example, implementation of a rapid diagnostic in the microbiology laboratory is unlikely to have an impact unless results are conveyed in real time with proactive stewardship intervention to adjust therapy based on test results [22]. What if the alert cannot provide the information in real time? In that situation, the stewardship provider could request notification of the scenario in real time. Microbiology laboratory personnel could page, email, or text message an alert through a secure system, if able (as their own staffing may be limited). Additionally, many third-party surveillance systems can provide real-time alerts via email when certain criteria are triggered.

Another consideration for alert feasibility is the approximate frequency of the triggering event. If your stewardship program has identified decreasing unnecessary utilization of vancomycin, a baseline estimate of the average number of patients taking vancomycin per day or new vancomycin orders per day would be helpful. If the volume of alerts generated is so high that this PAF initiative would take away valuable stewardship time needed for other tasks, then the system could prioritize and/or trim the list such that it ranks the patients from highest to lowest risk for suboptimal outcomes or limits the list to only certain high-risk criteria for review. For instance, limiting the targeted list to patients taking vancomycin who have negative MRSA surveillance cultures may be a better starting point than reviewing all patients taking vancomycin.

Is the Alert Actionable?

Stewardship alerts should ultimately be actionable. Alerts that do not result in meaningful action for a stewardship team member to provide feedback—either to intervene and optimize care or to provide assurance to continue current care plans—will result in loss of valuable time and alert fatigue for stewardship team members. Alerts should be validated and tested prior to going live to ensure that they result in an actionable intervention at a threshold that is acceptable to the local AS team. We typically prefer that the reviews be actionable at least 50% of the time for any individual AS initiative, though this can vary by AS program and even by individual AS initiatives within a program. The stewardship team at Cleveland Clinic implemented a clinical decision support system to identify opportunities for stewardship intervention and evaluated the frequency in which the alerts were actionable. Of the 749 alerts reviewed in their study, 306 (41%) were determined to be actionable [23]. Fortunately, the most common reason for a nonactionable alert was no need for intervention, as therapy was deemed appropriate at the time of review.

Nonetheless, duplicate alerts, alerts based on old data, and alerts that were errors did make up around 17% of the nonactionable alerts, and the stewardship team members still spent a median of 6 minutes on nonactionable alerts. The authors estimated that if >70% of alerts are noted to be nonactionable, then the majority of the stewardship team time would be spent evaluating those specific alerts [23]. It is important to note that actionability is related to, but distinct from, the impact of an initiative/alert. While impact focuses on the potential of an initiative/alert to optimize patient- and systems-level outcomes, actionability focuses on the experience of AS personnel in their daily workflow and whether the alerts that they are reviewing represent the correct patient cases or, conversely, duplicative, inaccurate, or otherwise inefficient alerts.

Decentralizing surveillance of certain nonactionable alerts to other allied health professionals (eg, pharmacists, nurses) may be an alternative strategy for AS teams to handle the workload. This is where routine reevaluation of alerts and developing a daily task prioritization schema for reviews might be helpful; such potential schemas are detailed as follows.

Will the Alert Produce Measurable Outcomes?

The last ideal of a stewardship alert is to produce measurable outcomes. The optimal alert would allow for the stewardship team to evaluate outcomes via existing data collection efforts in the hospital. Infection prevention colleagues are already collecting data regarding *C. difficile* infection, so any initiatives potentially affecting *C. difficile* reduction would be easy to evaluate with preexisting data. Additionally, any intervention that can be evaluated with automated data collection and reporting is helpful. Many institutions are reporting to the National Healthcare Safety Network Antibiotic Use and Resistance Module, which generates metrics such as the standardized antimicrobial administration ratio [24]. Most stewardship programs also track antibiotic utilization through other standardized metrics—for example, days of therapy over a denominator to normalize for patient volume, such as days present. These metrics can be valuable tools in evaluating trends and changes in the use of a targeted antibiotic or antibiotic class before and after a stewardship initiative is implemented. Analysis of the changes can be performed between groups (a pre- and postgroup) with a simple *t* test, or a more sophisticated segmented regression of interrupted time series analysis can be used to evaluate the changes in trends of a particular drug over time. Both analyses can be done with online statistical calculators and Microsoft Excel without requiring sophisticated statistical software.

Unfortunately, some alerts that rely on infectious syndromes or target more specific populations (eg, immunocompromised) may not be as easily measured. For example, PRA of ciprofloxacin indicated as treatment for urinary tract infections may be difficult to measure (ie, scored 1 in Table 2) since this often requires time-intensive manual chart abstraction by AS personnel or their proxies. Many IT systems offer platforms for AS personnel to track their daily interventions in a standardized fashion that can be reported out. Building stewardship intervention documentation into these existing systems yields easier tracking and reporting of the AS initiative's impact down the road. This process measure may be useful in some of these more difficult initiatives as long as the AS team PAF can capture some of these missing elements of syndrome and hospital service.

APPROACHES TO INITIATIVE/ALERT PRIORITIZATION

Using the Antimicrobial Stewardship Initiative Prioritization Tool (Table 2; see supplementary materials for blank form), an AS team should jointly answer the questions in each column to assign likely projections of a desired activity in impact, feasibility, actionability, and measurability. Once all questions are answered, a score is calculated, and candidate initiatives are ranked from highest to lowest score (ie, highest to lowest priority). The AS team should implement initiatives from highest to lowest priority until they meet the limit of time—that is, the number of hours that frontline stewards can dedicate on a daily basis to all PAF and PRA initiatives combined (often 1–4 hours daily, depending on the site). This tool was developed to prioritize future candidate AS initiatives; however, current, past, and future initiatives can all be included on the same table for easier comparison, if desired.

Once the priority AS initiatives have been listed and selected for implementation, the AS program should summarize all targeted alerts that could be generated for a given day to meet these initiatives and prioritize the order of their daily review. This ensures that if time for PAF or PRA is interrupted or acutely decreased, AS personnel have likely already reviewed the highest-priority alerts first. There are 3 general approaches to daily activity prioritization: tiered approach, scoring systems, and predictive modeling with or without machine learning.

Tiered Approach

In the absence of sophisticated decision support, stewardship interventions and targets can be ordered in a tiered approach based on their priority, actionability, and impact potential (Table 3). Bucketing individual stewardship targets (eg, reviewing all patients with rapid blood culture identification, reviewing all orders for ciprofloxacin indicated as treatment for urinary tract infections) based on their tiered priority can help a steward organize workflows capturing the highest-acuity interventions first, with the lower-tiered interventions potentially being completed only once or twice per week as time allows. With this system, frontline AS personnel typically review all tier A and B alerts on a daily basis, evaluate tier C alerts periodically throughout the workweek, delegate tier D alerts to other allied health professionals (eg, pharmacists, physicians, nurses), and entirely eliminate any review of tier E alerts. Removal of tier D and E alerts allows stewards to focus on the highest-priority interventions and complete their task lists daily without feeling as though they have not accomplished all that they want.

Scoring Systems

Prioritizing patients for stewardship review by using scoring systems that are integrated into EHR systems is another approach to efficiently identify patients for AS review. The Epic system, a common EHR used in many hospital systems across the United States, offers a dedicated AS and infection control module called "Bugsy," which provides a platform to prioritize alerts by assigning a score to each alert [25]. The higher the score, the higher the priority. A patient list is generated with a column that displays an overall score that can be sorted from highest to lowest. A patient may have several high-scoring alerts that, when added, places one in the highest priority. Scores can be classified into "intervene" or "monitor," thereby providing an extra layer of prioritization. Up-front customization requires that scores be tailored to the AS needs specific to the institution and ranked similar to the tiered approach (Table 3).

Table 3. Tier Method to Prioritize Daily Antimicrobial Stewardship Tasks

Tier	Priority	Actionability	Impact
A	Must Do	Majority	High
B	Should Do	Frequently	Moderate to high
C	Nice to Do	Sometimes	Low to high
D	Delegate	Routinely	Low to high
E	Eliminate	Infrequently	Low

Predictive Modeling

The last approach to prioritization is the use of predictive modeling and machine learning, which provide information on what characteristics predict AS intervention in a desired population [26–29]. For example, a newly staffed stewardship program with a dedicated stewardship pharmacist at a small community hospital may not be immediately equipped with the knowledge of current antibiotic use challenges. A reasonable first approach to inform stewardship practice is to perform PAF on preselected and frequently prescribed antibiotics at 48 to 72 hours and document guideline compliance, details of the intervention, and whether it was accepted. Using the PAF data with linked variables that can be easily identified and sorted at the time of an alert (eg, antibiotic type, indication, hospital service), the AS member or technology specialist can enter them into prebuilt models available in the literature [26]. Discrete variables of importance can be identified for future targets with the goal to decrease the case load while not appreciably lowering the sensitivity of actionable alerts. For example, the model may find that genitourinary infections in patients admitted to the hospitalist service have a high probability of intervention. These data can also be incorporated into the prioritization tool, as some interventions may not need to be implemented hospital-wide but rather focused on a service or unit. Using this information, the AS team may focus the PAF for genitourinary infections in the hospitalist department in addition to enhancing education on asymptomatic bacteriuria and perhaps implementing a diagnostic stewardship intervention.

In addition, prediction tools can be applied at the point of prescription (eg, assessment for risk of antimicrobial resistance) and alerted to the prescriber [30, 31]. As part of AS workflow, outlying prescriptions—such as meropenem for a patient with a low risk for gram-negative resistant infection—can be alerted during PAF and streamlined on the prioritization tool, eliminating unnecessary reviews of appropriate meropenem. The use of novel prediction tools in stewardship activities is a promising area, but there is insufficient real-world implementation and thus limited knowledge on how to best integrate them into existing workflow.

How Do We Know When to Retire an Alert?

Often alerts that were previously fruitful may become less so over time as education and reinforcement correct the practice and generate genuine culture change. As an example, envision a technology has been implemented in the microbiology laboratory to identify gram-positive organisms and genetic mechanisms of resistance (eg, mecA/C, vanA/B) and is launched with an accompanying algorithm for treatment. In this case, AS team members would directly communicate to the patient care team within an hour of test results. Eventually, the primary care teams will become familiar with the test results and know where to find treatment recommendations. The stewardship team's time making those phone calls could be shifted to a new priority since this intervention has become self-sufficient. Alternatively, the EHR can be leveraged to assist in those interventions [32]. To maintain optimal efficiency long-term, AS programs should plan to reevaluate and reprioritize all initiatives and alerts at regular intervals (eg, monthly, quarterly, annually).

FUTURE DIRECTIONS

Whether related to staffing challenges or expanding the scope of AS activities, improving efficiencies is an important ongoing goal for AS programs. However, there remain gaps in the literature on how to best prioritize stewardship interventions for efficiency while maintaining efficacy. AS programs have metrics to describe antimicrobial consumption to measure over time, yet we lack any standardized way of tracking program efficiency and, arguably, efficacy. Bypassing the AS team and providing alerts directly to prescribers can theoretically improve efficiency and efficacy and is a promising future direction for AS programs [33]. Yet, ineffectiveness of prescriber-driven antibiotic timeout and concerns for provider alert fatigue dampen this paradigm shift in workflow [34, 35]. As homegrown tiering systems, EHR-integrated scoring systems, and increased use of machine learning become more prevalent, AS programs should leverage these opportunities to formally evaluate their impact on not only AS outcomes but also AS workflow.

CONCLUSION

Many AS programs meet the minimal requirements outlined by the CDC core elements, but insufficient resources or competing demands preclude the optimal operations of many programs in the United States. Prioritization tools are available with the hope that AS programs will use them to improve productivity and overall impact while resources are limited or stretched. Enhancing the efficiency of AS actions to augment the overall impact of AS initiatives is achievable and worthwhile.

Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

Acknowledgments. We acknowledge Kenneth Klinker, PharmD, for his development of and contributions to the original Antimicrobial Stewardship Initiative Prioritization Tool.

Potential conflicts of interest. J. J. receives payment for lectures from bioMérieux and Spero Therapeutics and participates in Merck, Entasis Therapeutics, Shionogi, and Gilead Sciences advisory boards. E. L. H. receives consulting fees from Wolters-Kluwer/Lexi-Comp. J. T. B. reports no potential conflicts.

Patient consent statement. This review article is not human subjects research that would require direct oversight by the institutional internal review board or patient consent.

References

1. Barlam TF, Cosgrove SE, Abbo LM, et al. Implementing an antibiotic stewardship program: guidelines by the Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America. Clin Infect Dis **2016**; 62:e51–77.
2. Centers for Disease Control and Prevention. Core elements of outpatient antibiotic stewardship. January 17, **2019**. Available at: https://www.cdc.gov/antibiotic-use/community/improving-prescribing/core-elements/core-outpatient-stewardship.html. Accessed 28 April 2019.
3. Centers for Disease Control and Prevention. Core elements of antibiotic stewardship for nursing homes. August 20, **2021**. Available at: https://www.cdc.gov/antibiotic-use/core-elements/nursing-homes.html. Accessed 28 May 2023.
4. Centers for Disease Control and Prevention. Core elements of hospital antibiotic stewardship programs. January 16, **2019**. Available at: https://www.cdc.gov/antibiotic-use/healthcare/implementation/core-elements.html. Accessed 24 February 2019.
5. Vaughn VM, Dunn GE, Horowitz JK, McLaughlin ES, Gandhi TN. Duties, resources, and burnout of antibiotic stewards during the coronavirus disease 2019 (COVID-19) pandemic. Antimicrob Steward Healthc Epidemiol **2021**; 1:e39.
6. Nori P, Stevens MP, Patel PK. Rising from the pandemic ashes: reflections on burnout and resiliency from the infection prevention and antimicrobial stewardship workforce. Antimicrob Steward Healthc Epidemiol **2022**; 2:e101.
7. Szymczak J, Saine E, Chiotos K, et al. Prevalence and drivers of burnout among antimicrobial stewardship personnel in the United States: a cross-sectional study. Abstract 965. Open Forum Infect Dis **2022**; 9:ofac492.808.
8. Doernberg SB, Abbo LM, Burdette SD, et al. Essential resources and strategies for antibiotic stewardship programs in the acute care setting. Clin Infect Dis **2018**; 67:1168–74.
9. Greene MH, Nesbitt WJ, Nelson GE. Antimicrobial stewardship staffing: how much is enough? Infect Control Hosp Epidemiol **2020**; 41:102–12.
10. Dellit TH, Owens RC, McGowan JE, et al. Infectious Diseases Society of America and the Society for Healthcare Epidemiology of America guidelines for developing an institutional program to enhance antimicrobial stewardship. Clin Infect Dis **2007**; 44:159–77.
11. Anderson DJ, Watson S, Moehring RW, et al. Feasibility of core antimicrobial stewardship interventions in community hospitals. JAMA Netw Open **2019**; 2:e199369.
12. Mehta JM, Haynes K, Wileyto EP, et al. Comparison of prior authorization and prospective audit with feedback for antimicrobial stewardship. Infect Control Hosp Epidemiol **2014**; 35:1092–9.
13. Smith JD, Nguyen LH, Krekel T, et al. Evaluation of a hybrid antimicrobial restriction process at a large academic medical center. Antimicrob Steward Healthc Epidemiol **2021**; 1:e34.
14. Livorsi DJ, Suda KJ, Cunningham Goedken C, et al. The feasibility of implementing antibiotic restrictions for fluoroquinolones and cephalosporins: a mixed-methods study across 15 Veterans Health Administration hospitals. J Antimicrob Chemother **2021**; 76:2195–203.
15. Szymczak JE, Kitt E, Hayes M, et al. Threatened efficiency not autonomy: prescriber perceptions of an established pediatric antimicrobial stewardship program. Infect Control Hosp Epidemiol **2019**; 40:522–7.
16. Tamma PD, Avdic E, Keenan JF, et al. What is the more effective antibiotic stewardship intervention: preprescription authorization or postprescription review with feedback? Clin Infect Dis **2017**; 64:537–43.
17. Tamma PD, Miller MA, Cosgrove SE. Rethinking how antibiotics are prescribed: incorporating the 4 moments of antibiotic decision making into clinical practice. JAMA **2019**; 321:139–40.
18. Pettit NN, Han Z, Nguyen CT, et al. Antimicrobial stewardship review of automated candidemia alerts using the epic stewardship module improves bundle-of-care adherence. Open Forum Infect Dis **2019**; 6:ofz412.
19. Claeys KC, Schlaffer KE, Heil EL, Leekha S, Johnson JK. Validation of an antimicrobial stewardship-driven Verigene blood-culture gram-negative treatment algorithm to improve appropriateness of antibiotics. Open Forum Infect Dis **2018**; 5:ofy233.
20. Shea KM, Hobbs ALV, Jaso TC, et al. Effect of a health care system respiratory fluoroquinolone restriction program to alter utilization and impact rates of *Clostridium difficile* infection. Antimicrob Agents Chemother **2017**; 61:e00125-17.
21. Elligsen M, Walker SAN, Pinto R, et al. Audit and feedback to reduce broad-spectrum antibiotic use among intensive care unit patients: a controlled interrupted time series analysis. Infect Control Hosp Epidemiol **2012**; 33:354–61.

22. Timbrook TT, Morton JB, McConeghy KW, Caffrey AR, Mylonakis E, LaPlante KL. The effect of molecular rapid diagnostic testing on clinical outcomes in bloodstream infections: a systematic review and meta-analysis. Clin Infect Dis **2017**; 64:15–23.
23. Ghamrawi RJ, Kantorovich A, Bauer SR, et al. Evaluation of antimicrobial stewardship-related alerts using a clinical decision support system. Hosp Pharm **2017**; 52:679–84.
24. Antibiotic Resistance and Patient Safety Portal. Inpatient antibiotic use. Available at: https://arpsp.cdc.gov/profile/inpatient-antibiotic-use/all. Accessed 28 May 2023.
25. Dzintars K, Fabre VM, Avdic E, et al. Development of an antimicrobial stewardship module in an electronic health record: options to enhance daily antimicrobial stewardship activities. Am J Health Syst Pharm **2021**; 78:1968–76.
26. Goodman KE, Heil EL, Claeys KC, Banoub M, Bork JT. Real-world antimicrobial stewardship experience in a large academic medical center: using statistical and machine learning approaches to identify intervention "hotspots" in an antibiotic audit and feedback program. Open Forum Infect Dis **2022**; 9:ofac289.
27. Beaudoin M, Kabanza F, Nault V, Valiquette L. Evaluation of a machine learning capability for a clinical decision support system to enhance antimicrobial stewardship programs. Artif Intell Med **2016**; 68:29–36.
28. Moehring RW, Phelan M, Lofgren E, et al. Development of a machine learning model using electronic health record data to identify antibiotic use among hospitalized patients. JAMA Netw Open **2021**; 4:e213460.
29. Bystritsky RJ, Beltran A, Young AT, Wong A, Hu X, Doernberg SB. Machine learning for the prediction of antimicrobial stewardship intervention in hospitalized patients receiving broad-spectrum agents. Infect Control Hosp Epidemiol **2020**; 41:1022–7.
30. Moran E, Robinson E, Green C, Keeling M, Collyer B. Towards personalized guidelines: using machine-learning algorithms to guide antimicrobial selection. J Antimicrob Chemother **2020**; 75:2677–80.
31. Sakagianni A, Koufopoulou C, Feretzakis G, et al. Using machine learning to predict antimicrobial resistance—a literature review. Antibiotics (Basel) **2023**; 12:452.
32. Wenzler E, Wang F, Goff DA, et al. An automated, pharmacist-driven initiative improves quality of care for *Staphylococcus aureus* bacteremia. Clin Infect Dis **2017**; 65:194–200.
33. Jenkins TC, Tamma PD. Thinking beyond the "core" antibiotic stewardship interventions: shifting the onus for appropriate antibiotic use from stewardship teams to prescribing clinicians. Clin Infect Dis **2021**; 72:1457–62.
34. Thom KA, Tamma PD, Harris AD, et al. Impact of a prescriber-driven antibiotic time-out on antibiotic use in hospitalized patients. Clin Infect Dis **2019**; 68:1581–4.
35. Ash JS, Sittig DF, Campbell EM, Guappone KP, Dykstra RH. Some unintended consequences of clinical decision support systems. AMIA Annu Symp Proc **2007**; 2007:26–30.