Proceedings of the 2018 Winter Simulation Conference
M. Rabe, A.A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, eds.

SIMULATION TOOL TO EVALUATE ELECTRONIC CONSULTATIONS IN RHEUMATOLOGY

Breanna Swan
Chloe Shevlin

Edward P. Fitts Department of Industrial and Systems Engineering
North Carolina State University
Raleigh, NC, 27695, USA

Alex Cho
Donna Phinney

Duke Telehealth Office
Duke University Health System
3100 Tower Blvd
Durham, NC, 27707, USA

ABSTRACT

Complex patients, limited specialists, and high demand create long referral queues ill-equipped to deliver timely quality care. One approach to reduce queue length is for specialists to review referrals through an electronic consultation (e-consult) and determine if 1) the patient requires a specialty appointment or 2) the primary care physician can continue care with the specialist's recommendations. As inappropriate patients are removed from specialty queues, it is hypothesized that lead times will decrease and the system will be more efficient at delivering the right care to the right patient at the right time. A discrete-event simulation was built to estimate the impact e-consults have on Rheumatology clinics at Duke Health; specifically considering lead time, queue length, and specialists' workload. This is an adaptable tool with visualizations for which any specialty clinic, each with its own complex challenges, could estimate the impact e-consults have on delivering quality care to referred patients.

1 INTRODUCTION

As health systems increasingly rely on technology to improve care and efficiency, processes must adapt to best serve the patient. Duke Health is pushing this initiative by streamlining physician to physician communication through the introduction of electronic consultations (e-consults). E-consults serve as a medium for primary care physicians (PCPs) to refer a patient and for specialists to review each patient case and give care recommendations. E-consults have the potential to generate more efficient care coordination, reduce costs by avoiding unneeded specialty care, and increase the effectiveness of specialty appointments (Chen et al. 2013).

Referrals are generated by PCPs when their patient needs advanced care. PCPs expect timely quality care for their patient. Delivery of quality specialty care in a *timely* manner is challenging; on average, referred Duke Health patients wait over 80 days to see a rheumatology specialist. Layers of complexity contribute to these long lead times including an unclear 'best' care path for referred patients, limited resources in specialty care clinics (i.e. physical layout, clinicians, staff), and convoluted communication channels between specialists, PCPs, and schedulers. In the current state, PCPs unsure if their patient needs specialty care contact specialists in a medium outside of the EHR (i.e. phone or email) which requires synchronous communication, is not captured in the patient's record, and can result in a specialist bypassing the scheduler to make appointments. E-consults are a method for specialists, PCPs, and schedulers to work as a team to identify the best care path, efficiently use limited resources, and streamline communication. To reduce lead time, the Duke Telehealth department proposed implementing e-consults, performed by specialists, to ensure the right patients are receiving care from the right specialty at the right time.

To test Duke Telehealth's proposal for improving care for referred patients, a discrete-event simulation was developed to estimate the impact of e-consults on lead time, physician workload, scheduling and appointment queues, and avoided appointments. The model was built such that inputs can be adjusted to any Duke Health specialty interested in implementing e-consults. Here, the tool is applied to Rheumatology where an e-consult project was recently piloted. A combination of historical referral and pilot project data was used to validate the nine-month simulation, specifically looking at patients' lead time, specialty queue length, specialists' e-consult workload, and the total number of referrals completed. Sensitivity of the model was analyzed by varying the proportion of all incoming referrals receiving e-consults and by varying the result of the e-consult (i.e. patient either requires or does not require a specialty appointment). Out of scope of this project were the current scheduling algorithm and the economic impact of e-consults. Currently, referred patients are scheduled through a general hub but each specialty department could have their own in-house scheduler in the future, thus, it was not practical to model the current scheduling algorithm. The economic impact of e-consults has been studied in conjunction with this project by a Duke University MD/MBA student. The goals of this project are to assess whether e-consults significantly impact referral appointment lead time and to quantify the additional workload e-consults have on specialists.

The implementation of e-consults and the potential to improve patient care and experience support Duke Health's core mission of improving care coordination and ensuring each patient sees the right clinician at the right time. It is hypothesized that as more e-consults are performed, the rheumatology referral lead times and demand on the specialty referral queue decreases. Additionally, specialists' time will be maximized by avoiding unnecessary appointments, thus, opening their schedule to timely care for patients with advanced care needs. Beyond patient care, clinic workload capacity for performing the e-consults can be estimated such that feasible results are presented. While the results of this report are specifically for Rheumatology, this simulation can ultimately evolve to model the effect of a full-scale e-consult program for any and all specialties at Duke Health.

2 RELEVANT LITERATURE

2.1 E-Consults in Other Health Systems

Implementation, monetary compensation, workload requirement, and success measures for e-consult programs vary across health systems. As Duke Health and other health systems consider e-consult programs, the variability in implementation prove the importance of considering feasibility factors beyond the potential improvements to patient care.

Three major systems publishing data on their e-consult programs, San Francisco General Hospital (SFGH), Veterans Affairs Medical Centers (VAMCs), and the Mayo Health System, are compared here. At SFGH, a designated reviewer is assigned for each specialty, the VAMC integrates e-consults into the EHR for autonomous and open PCP-specialist communication for all clinicians, and Mayo Clinic uses specialty-unique templates to streamline PCP-specialist communication. Monetary compensation ranged from salary support (SFGH), giving one of three workload credits for specialist's time (VAMC), and receiving visit credit for the e-consult (Mayo Clinic). Convenience and improved access to specialty input, among other reasons, contributed to the 75-90% of PCPs being satisfied with e-consults. Specialists' satisfaction varied from system to system with just 52% of VAMC specialists being satisfied with e-consults. Specialist satisfaction could be due to the estimated 27% of e-consults requiring significant additional workload (i.e. consulting on new patients which would not have occurred prior to e-consults) and concerns over legal protection, time constraints, and monetary compensation (Tuot et al. 2015; Vimalananda et al. 2015). More satisfied specialists reported fewer unproductive and more efficient appointments, reduced interruptions in their day, and perceived shorter wait times to see a patient whereas less satisfied specialists were more likely to convert an e-consult into an in-person appointment.

Reduction in lead time, avoided inappropriate appointments, and saved transportation costs for patients are a few of the effects e-consult programs can have on specialty care. E-consults provide an opportunity for specialists to give care recommendations to the PCP, thus, avoiding an unnecessary in-person appointment which saves travel and time for the patient and opens appointment slots for specialists. At SFGH, wait times for non-urgent specialty appointments decreased by up to 90% with about half of all incoming referrals determined to be inappropriate (Chen et al. 2010). The proportion of avoided appointments ranged from 25% in rheumatology to 85% in cardiology (Wasfy et al. 2014; Scheibe et al. 2015). In Alaska, where patients may have to travel far for specialty care, a five-year study of electronic otolaryngologist consultations resulted in 85% of patients requiring zero travel for their care and over $490,000 in avoided costs (National Quality Forum, 2017). Even with the high percentage of avoided appointments, longitudinal studies showed, in reviewing cases after 6-months, there were zero clinically adverse events for e-consult patients and over 75% did not return for follow-up care (Wasfy et al. 2016).

While it has been determined that e-consults reduced 50% of referred patients for specialties such as hematology, endocrinology, and dermatology (Vimalananda et al. 2015), it has not yet been determined if e-consults reduced *overall* visits to the healthcare system or if lead times for specialty appointments are reduced. Thus, more research is needed into the lead time and system-wide effects of e-consult programs.

2.2 Metrics

The National Quality Forum published a report proposing metrics of success for Telehealth programs: access to care, financial impact, experience of patients, care team, and effectiveness of the system (National Quality Forum, 2017). Access to care can be measured by both duration of an appointment after using Telehealth and the miles or hours avoided by a patient when Telehealth determined an in-person appointment was not needed. Researchers at the University of California Davis found that specialty patients using Telehealth avoided, on average, 278 miles per patient. Timeliness of care can be measured in the time between a patient's test and their diagnosis; ideally decreasing with Telehealth, thus, decreasing time to care intervention. Care coordination measures include the overall number of multidisciplinary visits and improved quality of life due to receiving care at home rather than at a specialty clinic. VAMCs utilize telehealth to efficiently coordinate care for traumatic brain injury; requiring coordination of tests, at-home caregivers, care interventions, and remote monitoring services. More examples of the proposed success measures for any telehealth program can be found in the National Quality Forum Final Report 2017.

Clearly defining metrics for Duke Health's proposed e-consult program was vital as this project has the potential to be adapted for many specialties. Success measures of an e-consult program at Duke Health were narrowed down to three domains: demand, appropriateness, and timeliness. Each domain is illustrated in the results of Section 5 and include the number of referred patients in the queue, number of avoided inappropriate appointments, lead time, and specialist workload (hours spent on e-consults). As the e-consult program is further developed; the metrics of avoided patient travel and number of overall multidisciplinary visits could also be measured at Duke Health.

3 SIMULATION LOGIC

In the current referral process, referrals originate from one of 33 Duke Primary Care (DPC) clinics, a scheduler from Duke Health's general scheduling hub contacts the patient who then schedules the patient for a rheumatology appointment at one of three clinics (Duke University Hospital (DUH), Brier Creek, or Kernodle). Figure 1 visualizes the process for a referral order.

The decision initiating the referral process is whether or not a patient needs specialty care. When this referral decision is unclear, 'undocumented' communication can occur between PCPs and specialists; highlighted in red in Figure 1. If the PCP wants specialist insight into whether they should refer a patient for advanced rheumatology care, the current practice is for the PCP to contact a specialist via phone or email. This practice requires synchronous communication which does not use the providers' time most efficiently, disrupts a specialist's workflow, and can be inconvenient for the PCP. Additionally, no data is recorded on the decision making process; data which could be used to inform the rheumatologist once the patient has an appointment.

The second influential decision in the referral process is whether the patient schedules an appointment with Duke Health. It has been hypothesized by Duke Health that a reason patients choose advanced care outside of Duke Health is the long lead times for referral appointments. The long lead times is part of the motivation behind this project; specifically focusing on rheumatology. The two wait times of most interest, which combine to create the lead time, are the time from referral generation to a scheduler talking with the patient *("scheduler wait time")* and the time from a scheduler talking with the patient to their appointment date *("appointment wait time")*. The blue sections in Figure 1 show the interactions between patient and scheduler; highlighting the point that the scheduler has a significant impact on referral lead times. As discussed in the Introduction, this project will not analyze or improve the scheduling process but it is clear that the blue processes in Figure 1 have a significant impact on the referral process at Duke Health.

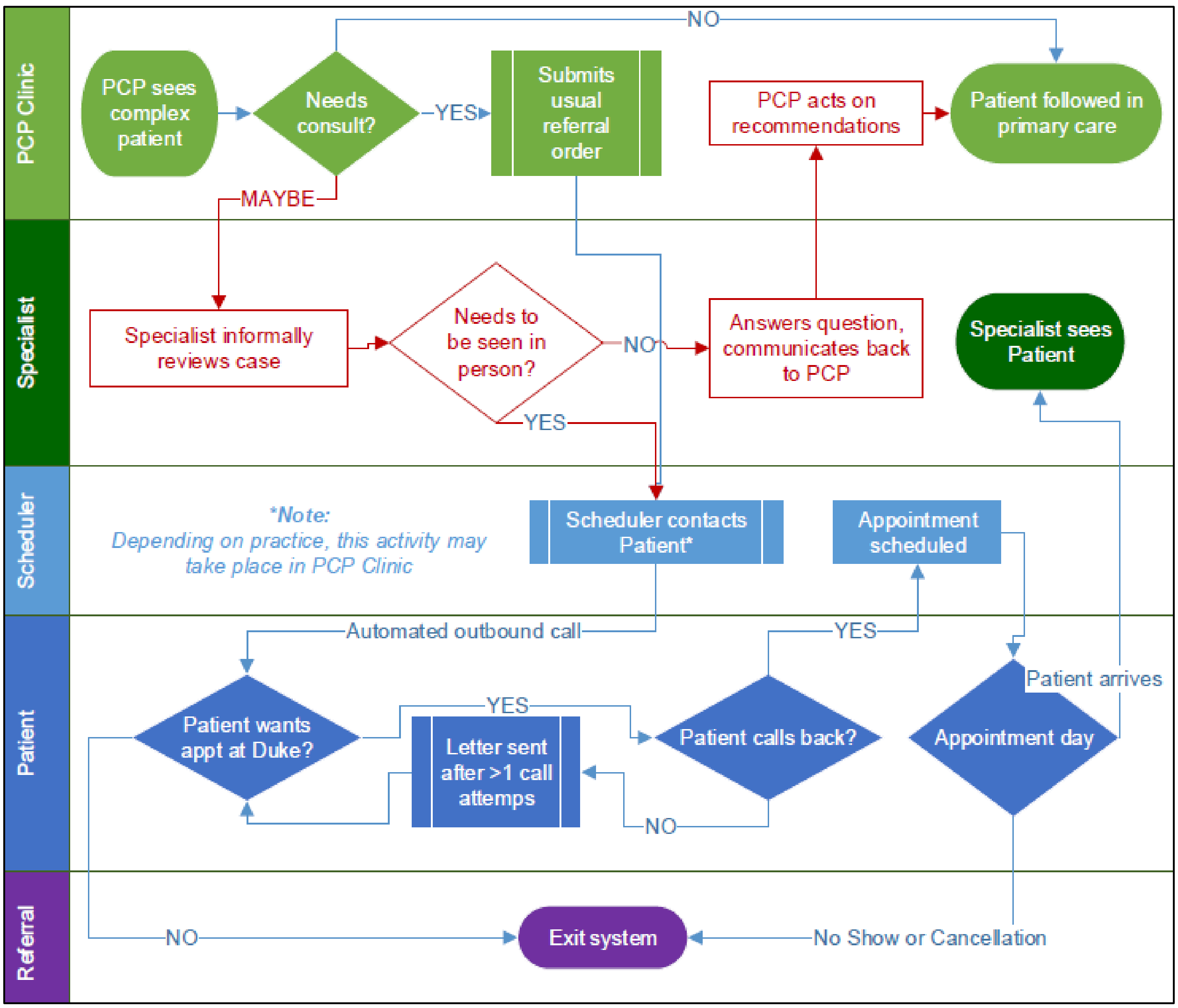

Figure 1: Referral Flow Chart (current process). Highlighted in red is "undocumented" communication occurring between providers. Blue communication flows represent processes out of scope for this project (i.e. scheduling algorithms are assumed to stay the same).

The added event of an e-consult directly affects the workflow for the PCP and specialist and, in essence, replaces the 'undocumented' communication in red from Figure 1. If the PCP is not sure that a patient needs advanced care, they submit an e-consult requesting the specialist to review the patient's case. Once a specialist receives the e-consult from the PCP, they review the patient's case and decides if 1) the patient requires an in-person specialty appointment, thus, sending a schedule request to the scheduler or 2) the patient does not need an in-person specialty appointment, thus, sending care recommendations back to the PCP. The e-consult process should eliminate the need for 'undocumented' communication by creating an official communication stream within Duke Health's EHR.

4 SIMULATION

4.1 Data Description

The simulation tool was created in the free software program R using historical data of 1,445 DPC referrals to rheumatology occurring between July 1, 2016 and April 30, 2017. Each referral has 67 fields containing data on the referral origination, scheduling, and appointment. DPC referrals represent 60-70% of the total incoming rheumatology referrals for Duke Health and have an average lead time of 81 days and a median lead time of 61 days. Data from a Rheumatology e-consult pilot project, containing 94 e-consults with 13 fields occurring between August 31, 2017 and March 13, 2018, was used to accurately simulate the added event of an e-consult.

4.2 Model Structure

Three progressions of the simulation were created; a current state model prior to e-consults, a pilot project model with e-consults, and a full-scale projection of the impact of e-consults on Rheumatology. The simulation tool was built in R with the built-in program 'ggplot2' used to create figures of the results. The model is validated by comparing summary statistics of time distributions (interarrival rate, wait time for scheduler, appointment lead time) and parameters (total number of referrals, proportion going to each clinic) from the simulation outputs to the original raw data. A three-month ramp-up period was used to establish a steady state of incoming referrals, scheduler's queue, and appointment availability. After the ramp-up period, data was collected for a nine-month period in order to calculate and visualize results.

There are two events that can occur in the model, either an arrival of a referral from the PCP or a scheduler talking with the patient to schedule the specialist appointment. When a referral arrives, it is assigned a priority level (routine, urgent, or emergency) and a receiving rheumatology clinic (DUH, Brier Creek, or Kernodle) then enters the queue to wait for a scheduler's call. A pre-set probability determines if the referral will receive an e-consult (see section 4.6); if performed, the outcome of the e-consult determines if the referral is appropriate and stays in the queue or is not appropriate and removed from the system (see sections 4.5, 4.6). The duration of the e-consult by the specialist is recorded (section 4.5). If the referral stays in the scheduler's queue, a wait time is generated (section 4.3) and the queue length increases by one.

When it is time for the scheduler to contact the referred patient, a scheduling status determines whether the referral balks the system or not (i.e. the scheduler cannot get in contact with patient, the patient decides to receive care outside of Duke Health) and the queue length decreases by one. If the referred patient stays in the system, an appointment date (section 4.4) and an appointment status (completed, cancelled, or no show) are assigned.

Each 12-month simulation (3-month ramp-up period and 9-month simulation) was replicated 20 times. Parameters in the simulation such as volume and proportion of referrals for each of the three rheumatology clinics, priority level, balking proportion, appointment status, mean and median wait time for scheduler, mean and median lead time, and completion time of e-consults were validated by confirming the true values fell within the 95% confidence interval of the 20 replications of the simulation.

4.3 Time Distributions

The interarrival time of referrals (time between referrals generated by PCPs) and the length of time patients are in the schedulers' queue (time from referral generation to day appointment is scheduled) are both stochastic processes. This model assumes all referrals coming from the 33 distinct DPC clinics are pooled to have one interarrival rate.

The r-package ‘fitdistrplus’ is used to identify distributions of the data (Arnold and Emerson 2011) . A skewness-kurtosis plot and an unbiased summary was created to identify candidates to fit to the data. Goodness-of-fit tests (Kolmogrov-Smirnov, Cramer-Von Mises, and Anderson-Darling) and fit criterions (Akaike information and Bayesian information) were applied to choose the best fit, and subsequent parameters, for each time distribution. The interarrival rate best fit a Weibull distribution while the scheduler wait time best fit a gamma distribution.

Before assigning a scheduler wait time for a referral, an additional adjustment is made since it was determined that both referral priority and receiving specialist clinic significantly affect the wait. The randomly generated scheduler wait time mentioned above is adjusted based on referrals’ attributes (priority and clinic). The discounting factor is determined by a ratio of the median wait time for each of the nine attribute categories (three priorities by three clinics) to the overall median wait and are truncated by the category’s maximum wait time.

4.4 Scheduling an Appointment

Once it is determined that a patient remains in the system for their referral appointment, the next available appointment is identified by the scheduler. Historical referral data was used to quantify the capacity for each of the three specialty clinics. Using the specialists’ schedule templates to determine capacity was not yet feasible due to undefined ratios between referrals generated from DPC clinics and each specialist’s appointment capacity.

It is assumed appointments are uniformly distributed throughout the business days of each month and that this distribution is approximately stable. In this way, the total number of available slots for referral patients *per day* and *per clinic* are estimated. Appointment slots for Duke Health rheumatology last on average 25 minutes but could last up to 60 minutes depending on the subspecialty and requirements of each unique patient. When an appointment needs to be assigned, the simulation looks ahead at the available slots for the specific clinic assigned to that referral and chooses the first day with an available slot for the appointment. It is assumed that patient preferences reflected in the historical data remains relatively stable. As mentioned above, the appointment scheduling algorithm is not studied here and it is assumed the scheduling methods remain relatively stable. With the introduction of e-consults, appointment scheduling could move from the general hub into each specialty clinic so it was not sensible to study the current scheduling algorithm; this must be considered when interpreting the results.

There are three possible outcomes for each appointment; completed, cancelled, and no show. If the patient cancels their appointment ahead of time, the slot is added back to the specialist’s schedule as an available appointment.

4.5 Adding an E-Consult Event

Three PCP clinics, Sutton Station, Galloway Ridge, and Triangle Family Practice, and two specialty clinics, DUH and Brier Creek, participated in the e-consult pilot project in rheumatology during which the rheumatology specialists performed 90 e-consults between August 31, 2017 and March 3, 2018. In the simulation, if an e-consult is performed, the specialist decides if the patient needs an appointment or not. If the result of the e-consult is “yes, patient needs appointment”, the referral moves to the scheduler, if the result is “no, patient does not need appointment”, then the referral exits the system.

One metric of interest is the added workload of e-consults for specialists. Time spent on each e-consult was tracked in the pilot project for rheumatology and is summarized in Table 1.

Table 1: Estimated minutes per e-consult from the rheumatology pilot project, out of 90 total e-consults.

Statistic	Minimum	25th Quartile	Median	Mean	75th Quartile	Max
E-consult time (minutes)	1	5	9	11.93	14	90

The pilot project showed that 75% of e-consults took less than 15 minutes and, following the methods from section 4.3, time per e-consult best fit an exponential distribution. For each e-consult in the simulation, a randomly generated completion time was assigned so workload could be estimated.

4.6 Sensitivity Analyses

Sensitivity of the model to the proportion of e-consults performed and the outcome of each e-consult were analyzed. The proportion of incoming referrals receiving e-consults varied from 0% to 100% in 10% increments. The outcome of the e-consult, interpreted as a ratio of "no appointment needed" to "appointment recommended" varied between 25% to 75%, 50% to 50%, and 75% to 25%; reflecting results from literature (Wasfy et al. 2014, Scheibe et al. 2015) and the Duke Health pilot project in rheumatology which, for the 90 e-consults, had a ratio of 45% to 55%.

5 SIMULATION RESULTS

After both the simulation based on historical data (prior to e-consults) and based on the pilot project (with e-consult) were validated, the effects of a full-scale e-consult program were estimated. The results displayed in Figures 2-5 are over a 9-month period and analyze the sensitivity of the results to the proportion of referrals receiving e-consults and the outcome of each e-consult.

First, the effect of e-consults on the scheduler's demand is analyzed. The total volume of rheumatology referral requests, volume of e-consults performed, and demand for schedulers are displayed in Figure 2.

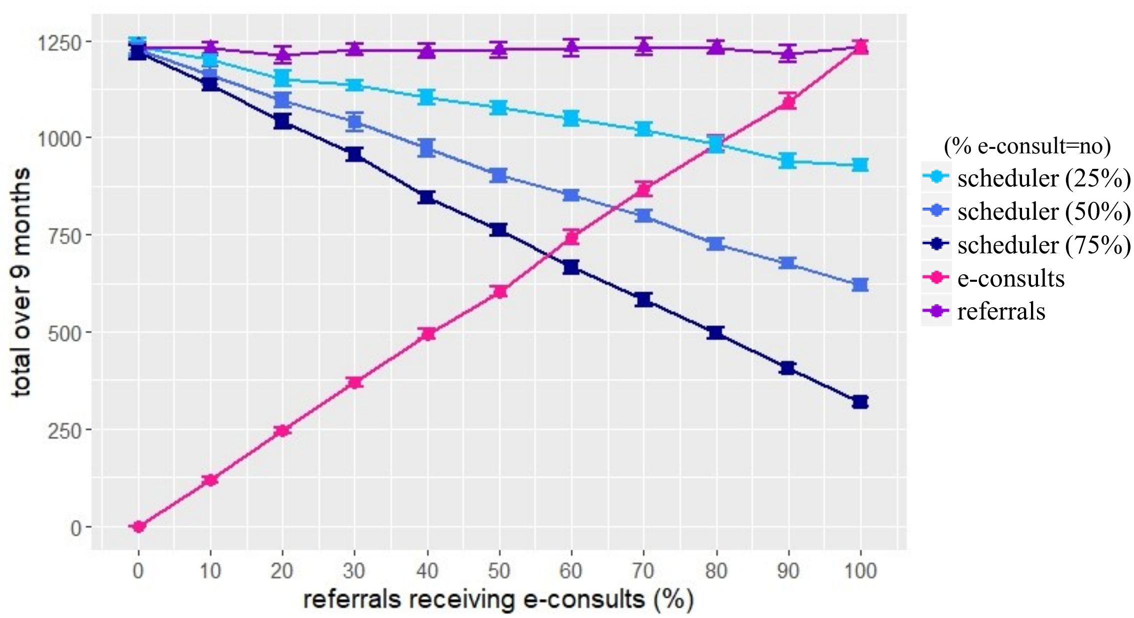

Figure 2: Average total referrals (purple), total e-consults (pink), and total scheduling demand (blue) for 9 months, across 20 replications, as the proportion of referrals receiving e-consults increases across the x-axis and the e-consult outcome varies by percentage of 'no appointment needed': light blue 25%, medium blue 50%, dark blue 75%. Error bars for the 95% confidence interval are shown.

As expected, as the proportion of referrals receiving e-consults increases, the total demand of referrals needing to be scheduled decreases. This effect on the schedulers' queue is amplified as the proportion of e-consults resulting in "no appointment" increases from 25% to 75%. Next, appointment efficiency was analyzed by estimating how many 'inappropriate' appointments were avoided through the implementation of e-consults. By reviewing patient cases and removing those who do not need specialist care, Figure 4 estimates the average number of appointments e-consults helped make available for those patients who truly need the advanced rheumatology care.

Figure 3 shows that if, for example, 80% of all referrals receive an e-consult and 50% result in "no appointment", 500 inappropriate appointments are avoided over a 9-month period.

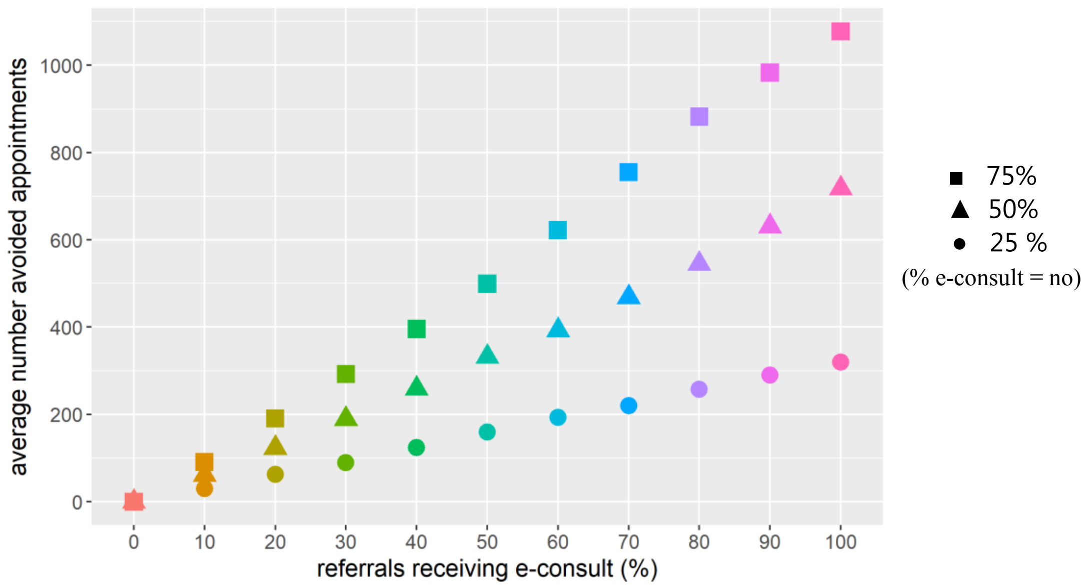

Figure 3: Average number of referrals removed from the system via an e-consult, over 9 months, as the proportion of referrals receiving e-consults increase across the x-axis and the outcome of the e-consult varies by percentage of 'no appointment needed': circle 25%, triangle 50%, square 75%.

Long lead times for specialty clinics is a primary concern at Duke Health. The estimated effect of e-consults on the median lead time for referrals to the DUH clinic is displayed in Figure 4; here assuming just 25% of e-consults result in 'no appointment needed'.

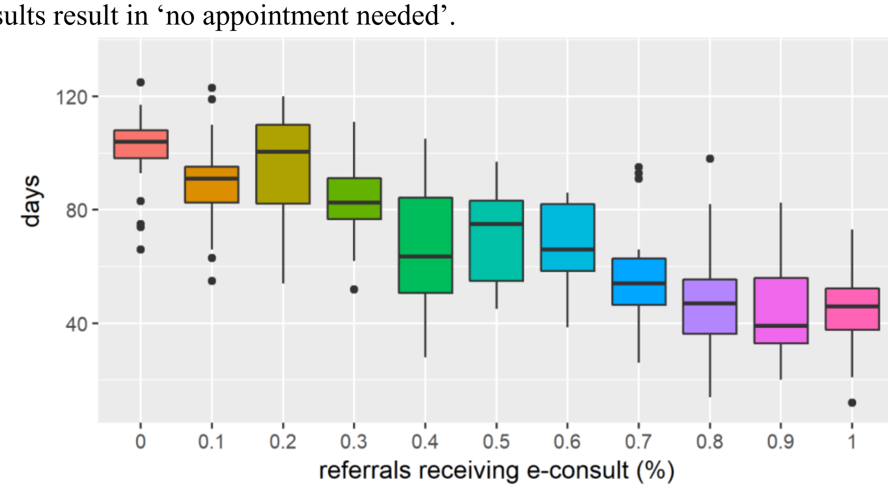

Figure 4: Median lead time (days) for referrals to the DUH rheumatology clinic, over 9 months, as the percentage of referrals receiving e-consults increases across the x-axis. The proportion of outcomes for each e-consult is 25% no appointment to 75% appointment. The boxplots summarize the median lead times for each of the 20 replications with dots representing values outside of 1.5 times the interquartile range.

Without e-consults, referred patients wait on average over 100 days for a rheumatology appointment. Figure 4 shows, with 100% of referrals receiving an e-consult, at least half of patients will have a rheumatology appointment within 55 days.

The previous figures show e-consults can reduce the total referral demand for rheumatology and reduces the median lead time for referred patients. The capacity for specialists to perform these e-consults is evaluated in Figure 5. The total number of e-consults performed over the 9-month simulation period was assumed to be uniformly distributed over each week.

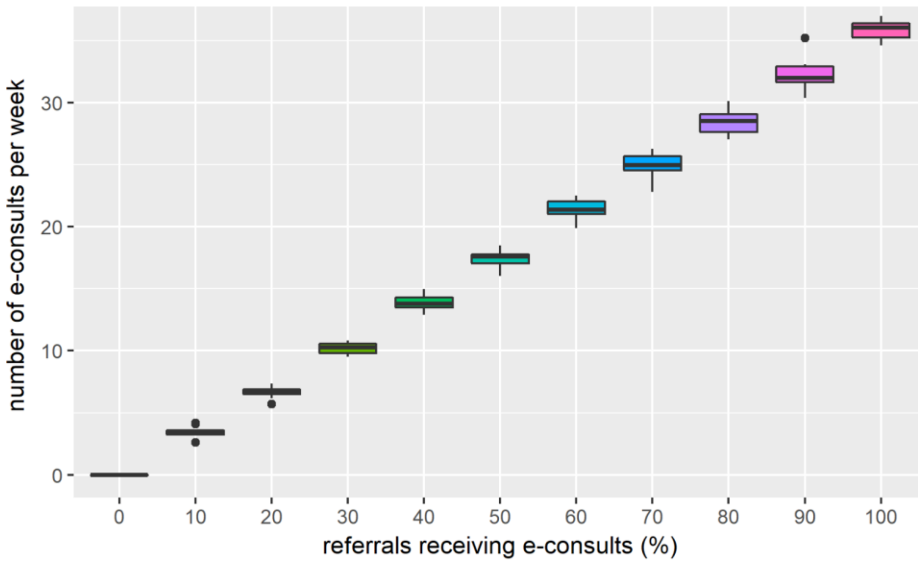

Figure 5: Estimated number of rheumatology e-consults that must be performed each week as the proportion of referrals receiving e-consults increases across the x-axis. The boxplots summarize the total e-consults across replications with dots representing a maximum value outside of 1.5 times the interquartile range.

The added workload for a full-scale e-consult program in rheumatology is, on average, over 35 e-consults per week. Table 1 shows the average time an e-consult requires is 12 minutes; thus, if 100% of all referrals receive an e-consult, this program would require 7 hours each week to be distributed amongst all rheumatology specialists.

6 DISCUSSION AND CONCLUSION

E-consults are a way for specialists to remove 'inappropriate' patients, or patients who do not need to see a specialist, from their schedule. This is beneficial not only for specialty clinics in which limited resources require specialists' schedules to be as efficient as possible but also for patients who can avoid the travel costs and wasted time of seeking unnecessary advanced care.

In this research, a discrete-event simulation tool was successfully built to evaluate the effects of a full-scale e-consult program on specialty clinics at Duke Health. The inserted event of an e-consult, its effects on patient care and physician workflow, was studied specifically for a Rheumatology clinic. In the current state lead times are too long. As stated in Section 4.1, the data used here is from DPC clinics which represents 60-70% of total referral demand with rheumatology referrals to the Duke Hospital clinic averaging a lead time of over 100 days. The simulation estimates that full implementation of e-consults reduces lead time to less than 55 days for half of referred patients; a conservative estimate assuming just 25% of e-consults result in "no appointment needed". This reduction in lead time is a result of over 300 patients being removed from the queue over a 9-month period. The capacity for performing e-consults was also quantified; assuming a goal of 70% of referrals receive an e-consult, rheumatology clinicians, as a unit, will spend approximately 5 hours performing e-consults each week.

In addition to estimating the effects of an e-consult program in rheumatology, this project demonstrates the feasibility of evolving the model so that e-consults could be evaluated in any individual specialty or across multiple specialties at Duke Health. This simulation tool was built in R such that all parameters, outputs, and, if needed, logic could be manipulated and interpreted uniquely to any specialty.

Beyond understanding the effects of an e-consult program on lead time, goals for specialty clinics could be formulated using this simulation tool. The sensitivity analysis on the proportion of referrals receiving e-consults, combined with the workload quantification, informs clinics of their unique capacity constraint. For example, using assumptions from the rheumatology clinic data, if a clinic can only dedicate two hours each week to e-consults then they should expect to complete around ten e-consults per week. This corresponds to approximately 30% of all DPC referrals receiving an e-consult (Figure 5) and a removal of 100-300 inappropriate referrals, depending on the e-consult outcomes (Figure 3). In this way, e-consult goals can be set based on the complex challenges associated with each individual clinic (workload, demand, or lead time).

Future improvements so this tool more accurately reflects the real world include relaxing assumptions of the model, expanding the data beyond DPC referrals to include *all* referrals received by Duke Health, and analyzing the scheduling algorithm. Deeper analysis into how the referral origination clinic and referring physician affect priority level and lead times could highlight trends and inform decisions for reducing referral lead time even without the implementation of e-consults. Adding a queue-length-dependent function describing how patients balk the system and a lead time-dependent function describing why patients cancel or no-show for their appointment could further amplify the effects e-consults have on patient care coordination. Additionally, the results presented here only represent the effects on referrals originating from DPC clinics; a fraction of the total referral demand that is yet undefined. Defining this fraction for each individual clinic would help identify the 'impactable' portion of referrals, or, what fraction of referral demand could be affected by an e-consult program. As this project is further developed, diagnosis, a complete patient care path, and more patient attributes can be added to the model and interpreted for unique specialties.

Further analyses of interest include economic impacts and the longitudinal effects on patient care. The economic impact of e-consults, taking into consideration more efficient specialty schedules, additional workload for specialists, and patient savings found by avoiding unnecessary care, is being pursued by a collaborating Duke MD/MBA student. Determining if e-consults can reduce the overall number of visits a patient makes to any specialty clinic at Duke Health has also been discussed as a next step in this research.

Delivering timely quality care across Duke Health was the motivation behind this research. This simulation tool is successful in estimating the effects an e-consult program will have on referral lead time, referral demand, and additional workload for specialists. For Rheumatology, e-consults significantly reduce the number of inappropriate referral appointments, thus, maximizing efficiency of specialist's time. This work and the simulation tool that has been created demonstrates the positive impact e-consults can have on referral queues at Duke Health.

AKNOWLEDGEMENTS

This work was supported by the Health Systems Engineering Certificate program at North Carolina State University and Duke Health. Specifically, the authors would like to thank Dr. Julie Ivy, NC State University, for her expertise and advising on the simulation tool development. We would also like to thank Kevin Shah and Simon Curtis, Duke Health; without their expertise this project would not have been possible.

REFERENCES

Arnold, T. B., and J. W. Emerson. 2011. "Nonparametric Goodness-of-fit Tests for Discrete Null Distributions". *The R Journal* 3(2):802-826.

Chen, A. H., M. B. Kushel, K. Grumbach, and H. F. Yee. 2010. "A Safety-net System Gains Efficiencies through 'eReferrals' to Specialists". *Health Affairs* 29(5):969-971.

Chen, A. H., E. J. Murphy, J. Yee, and F. Hal. 2013. "eReferral--A New Model for Integrated Care". *The New England Journal of Medicine* 368(26): 2450-2453.

National Quality Forum. 2017. "Creating a Framework to Support Measure Development for Telehealth, Final Report". Washington DC, Department of Health and Human Services.

Scheibe, M. M., J. B. Imboden, G. Schmajuk, M. Margaretten, J. D. Graf, A. H. Chen, E. H. Yelin, and J. Yazdany. 2015. "Efficiency Gains for Rheumatology Consultation using a Novel Electronic Referral System in a Safety-Net Health Setting". *Arthritis Care and Research* 67(8):1158-1163.

Tuot, D. S., K. Leeds, E. J. Murphy, U. Sarkar, C.R. Lyles, T. Mekonnen, and A. H. M. Chen. 2015. "Facilitators and Barriers to Implementing Electronic Referral and/or Consultation Systems: A Qualitative Study of 16 Health Organizations". *BMC Health Services Research* 15(1):568-578.

Vimalananda, V. G., G. Gupte, S. M. Seraj, J. Orlander, D. Berlowitz, B. G. Fincke, and S. R. Simon. 2015. "Electronic Consultations (e-consults) to Improve Access to Specialty Care: A Systematic Review and Narrative Synthesis". *Journal of Telemedicine and Telecare* 21(6):323-330.

Wasfy, J. H., S. K. Rao, N. Kalwani, M. D. Chittle, C. A. Richardson, K. M. Gallen, E. M. Isselbacher, A. B. Kimball, and T. G. Ferris. 2016. "Longer-Term Impact of Cardiology E-Consults". *American Heart Journal* 173(1):86-93.

Wasfy, J. H., K. R. Sandhya, M. D. Chittle, K. M. Gallen, E. M. Isselbacher, and T. G. Ferris. 2014. "Initial Results of a Cardiac E-Consult Pilot Program". *Journal of the American College of Cardiology* 64(24):2706-2707.

AUTHOR BIOGRAPHIES

BREANNA SWAN is a PhD student in the Edward P. Fitts Department of Industrial and Systems Engineering at North Carolina State University. She holds a B.S. in Mathematical Physics and a Master's degree in Mathematics from the University of Wisconsin – Milwaukee. Her research interests are in the development of efficient healthcare systems, from more accurate diagnoses to optimized care coordination. Her email address is bpswan@ncsu.edu.

CHLOE SHEVLIN is a recent graduate of the Edward P. Fitts Department of Industrial and Systems Engineering undergraduate program at North Carolina State University. Her career begins as a Management Engineer at Duke Health. Her research interests include optimized health care delivery and public health policy-making. Her email address is clshevli@ncsu.edu.

ALEX CHO, MD, MBA is a general internist and clinical lead for the Duke Telehealth Office of the Duke University Health System (DUHS). Dr. Cho is also an attending physician at the Duke Outpatient Clinic, the largest adult medicine safety-net clinic in the Duke system, where he leads clinic-based innovation efforts; in addition, he is a provider in the emergency department at the Durham VA. He is also part of the leadership team for the Duke primary care research network. He received his MBA from Duke University, and completed his residency training at New York University and medical school at University of Minnesota, Twin Cities. His email address is alex.cho@duke.edu.

DONNA PHINNEY is Associate Director for the Duke Telehealth Office at Duke University Health System. She received her MSN from East Carolina University, and her BSN from Gardner Webb University. Her research interest includes using telehealth tools to redesign healthcare to improve access, efficiency, clinical outcomes, and patient/provider satisfaction. Her email address is donna.phinney@duke.edu.