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Simulating Effects of COVID-19 Constraints on Reception Day Process Flow at the United States Military Academy

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Abstract: Every year on Reception Day at the United States Military Academy, over 1,200 cadet candidates join the ranks of the Corps of Cadets. Reception Day, or R-Day, is a process flow wonder as each of the 1,200 cadet candidates must complete a litany of administrative and military tasks prior to being admitted into summer training. Through years of observation and improvement, R-Day became an extremely efficient system. However, in the COVID-19 environment, R-Day 2020 looked nothing like it had in previous years. Social distancing and COVID screening requirements forced operational planners to construct a completely new Reception Day experience. In addition to new requirements, the locations of activities along with sequence and timing of these activities changed. To aid decision makers and provide some predictions for this unique and untested system, the research team developed a series of discrete event simulations. Through historical data and stakeholder engagement, baseline models enabled decision makers to visualize their plan. The research team then simulated alternatives to the baseline concept that offered improvements to critical measures of performance. The model analysis shows that adjusting cadet candidate report times, reducing the number of samples collected at once, and re-allocating resources to more time consuming activities will reduce the average cadet candidate time in the Reception Day system, reduce the total time to complete all Reception Day tasks, and increase utilization of critical resources. If used across the academy and the army, these simple and versatile modeling methods may provide predictability and flexibility for decision makers on a larger scale.

Keywords: Discrete-Event Simulation, Kanban, Process Improvement, COVID-19 Constraints, Queuing

1. Introduction

Every year, approximately 1200 civilian cadet candidates (USMA OIR, 2018) enter the United States Military Academy (USMA) gates to start their experience as a cadet. Before earning this distinction however, cadet candidates must graduate from Cadet Basic Training (CBT). The first requirement of CBT is Reception Day, an arduous and challenging experience that takes cadet candidates and transforms them to new cadets. Numerous tasks are required of every cadet candidate on Reception Day including military, administrative, and medical tasks. At the end of Reception Day, cadet candidates, who entered as civilians with little to no military training, will finish as new cadets able to march in formation and primed for future military life. There are over 20 tasks (J. Schlegel, personal communication, June 15, 2020) that a cadet candidate must accomplish on Reception Day and because of the requirement to process the entire class through every task quickly, there is little room for error in the execution. For the class of 2024 who conducted Reception Day in July 2020, the experience was different than that of their predecessors. New challenges and constraints brought about by the coronavirus disease 2019 (COVID-19) pandemic required USMA planners to adjust tried and true methods of process flow on Reception Day. Virus testing and disease spread prevention measures such as social distancing forced an abrupt change. Decision makers were forced to develop a Reception Day plan with little understanding of the interdependencies between tasks in the new environment. This unique situation presented an opportunity to benefit from the versatility and predictability of simulation methods. The research team explored ways to simulate Reception Day processing in its new form and optimize process flow, all without being able to observe the true system in motion. The intent of this research is to provide decision makers with concrete numerical predictions for critical performance measures for both the proposed "baseline" plan as well as for developed alternative solutions that will improve process flow and resource allocation.

2. Background

2.1 Overview and Importance of Reception Day at USMA

The original Reception Day process begins at Eisenhower Hall, West Point's largest auditorium and event venue. From there, cadet candidates are transported to Thayer Hall. During the academic year, Thayer Hall serves as the largest academic space at the academy and is filled with classrooms and auditorium space. Because of its layout, Thayer Hall is the perfect location for the sequential process system that is required on Reception Day. As such, Thayer Hall is the epicenter of all Reception Day operations. Over the decades that Thayer Hall has been used for this purpose, the process flow has been optimized through trial and error. If a bottleneck is identified at a station one year, the bottleneck is alleviated through either a location change or through supplementation of resources. Additionally in 2005, a simulation project team constructed a model using ProModel simulation software and found very specific ways to optimize process flow while keeping key metrics, such as average time a cadet candidate spends in the building, within acceptable ranges (Fuller, et al.). In general, the process runs very smoothly with very few unexpected events occurring or issues that have not been previously identified.

However, under COVID-19 constraints, Thayer Hall will no longer be the only location for Reception Day processing. The nature of military training and barracks living necessitates additional requirements to screen cadet candidates prior to completing Reception Day tasks. All cadet candidates must be tested for the virus prior to gaining access to Thayer Hall and the remainder of Cadet Basic Training. This creates a new screening location which will be conducted at the United States Military Academy Preparatory School (USMAPS) on West Point grounds. However, before cadet candidates may be screened, some tasks that would have been completed in Thayer Hall such as issuance of an ID card and mandatory briefings must now be completed at the screening location. Additionally, Reception Day planners must account for the logistics of cadet candidates who test positive and cannot proceed to Thayer Hall. Finally, cadet candidates, cadet leadership, and other Reception Day staff must abide by social distancing measures at all locations. As such, the process flow can no longer remain identical to previous years. Additionally, because of the new time requirements, Reception Day for each cadet candidate will occur on one of three dedicated Reception Days. Because of these vast differences, stakeholder confidence that R-Day will run smoothly and efficiently is greatly reduced. This confidence in the plan is further eroded by the fact that a full-scale rehearsal cannot be executed as has been done in previous years. Uncertainty in the plan coupled with an already uncertain environment necessitate the use of a tool to aid decision makers in planning.

2.2 Advantages of Simulating Reception Day Process

The previously mentioned areas of concern open opportunities for use of simulation methods. Although a simulated model will not be a perfect representation of the future system, it will provide decision makers with insight into some of the more critical areas of the plan. It may shed some light on the testing operation at USMAPS and how, numerically, key metrics will be affected by changes to the original process flow. Because of the versatility of simulation, multiple alternatives can be generated quickly to provide stakeholders with timely analysis of possible courses of action. Furthermore, because the plan is newly developed, the optimal solution that a simulation could provide may be implemented more easily as it does not run counter to the status quo.

To achieve these benefits, the simulation team took advantage of relationships with key Reception Day planners, decision makers, and subject matter experts. These relationships enabled the simulation team to ensure model verification throughout the construction process. Furthermore, it helped provide decision makers with critical information as it became available rather than at the completion of the simulation study. This enabled the team to continue to refine their plan in the rapidly evolving environment. Lastly, the simulation team used ProModel simulation software for the benefits it provides in visualizing the system that is being modeled.

3. Model Development

The entirety of Reception Day occurs at three distinct locations, USMAPS, Thayer Hall, and the Cadet Area. Each of these locations is associated with a unique list of tasks to accomplish. Tasks at each location are specific to that location and cannot be completed at any others. Additionally, cadet candidates must be processed through the locations in the same sequence, and they cannot go to a previous location. There is no interaction between locations, except for the ability for decision makers to dynamically move personnel from one location to another if demand necessitates it. Because there is no backtracking between locations, the simulation team built separate and distinct models that can be used in conjunction with each other, rather than one large simulation that modeled all Reception Day locations. The first model constructed was of

USMAPS as it is the first location. Thayer Hall was simulated next using simulated data from the USMAPS model. Process flow for the baseline simulation in each model was determined through concepts developed by the Reception Day planning team. Figure 1 below shows the entire model construct with critical components and activities being simulated.

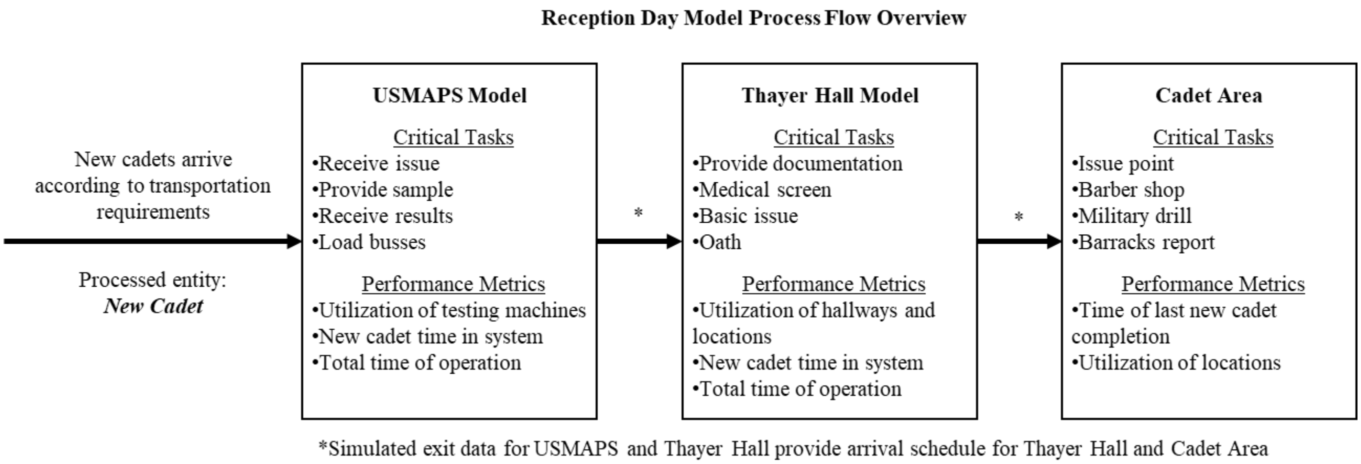

Figure 1. Reception Day Model Process Flow Overview

3.1 Model Overview- USMAPS

In the USMAPS and Thayer Hall models, cadet candidates are the primary system entity. They enter the Reception Day system through the USMAPS sub-system according to an arrival schedule developed to maintain integrity of the groups that each cadet candidate will belong to during CBT. The arrival schedule is also built around transportation requirements for those that are travelling by personally owned vehicle, by air travel, or through other means. Upon arriving at a holding area, cadet candidates are provided a mask and sanitation kit and are sent through the security checkpoint. From there, they move to the testing location where they receive a scanning card for use in future stations.

Because the hospital testing center machines have a capacity of 16 samples, cadet candidates are consolidated into groups of 16 according to a first come first serve basis and are then provided with an initial brief. As a group, they move to the COVID-19 sampling area. Each cadet candidate provides a sample, and when all 16 are provided, the batch of samples is bundled and sent by vehicle to the hospital laboratory about ten minutes away. At the lab, batches of 16 samples are prepared together and placed individually into the testing machine. Once the results are produced by the machine, a lab technician inputs the results into a networked system that can be accessed by personnel at the USMAPS sampling site. When results are put in the system, they are immediately received by the sampling site. Once all 16 samples are received, cadet candidates are notified of their results. Cadet candidates who receive a negative test pick up their bags, place them in a baggage truck, and move to the bus to Thayer Hall. Cadet candidates who receive a positive test pick up their bags and proceed to the positive van which takes the cadet candidates to the quarantine location.

Because of the critical nature of the COVID-19 testing machines, they are modeled as resources to allow for flexibility in adjusting the number available to account for malfunctions or down time. When a batch of samples arrives at the lab, it "uses" the machine resource for the prescribed amount of time. To account for social distancing measures, special attention was devoted to the capacities at each location. The sampling location has the physical space for the entire cohort of cadet candidates, but with 6 feet of separation, the true capacity of the locations is greatly reduced. In the USMAPS model, the capacity of each location is reduced to account for social distancing constraints. A restriction on capacity is also placed on the busses that transport cadet candidates from USMAPS to Thayer Hall to account for social distancing precautions.

3.2 Model Overview- Thayer Hall

Upon arrival at Thayer Hall, cadet candidates receive a short brief and are immediately ushered through a series of "stations" including document completion, medical screening, issue of basic items, and administration of the Oath of Office. Thayer Hall procedures are controlled through personnel and physical boundaries that force cadet candidates through the proper sequence. As such, there is very little chance that a cadet candidate could get lost or backtrack in the process. In the model it is assumed that all cadet candidates proceed station to station as prescribed and that every station will be completed properly the first time.

Although process flow is very straightforward, there is variation in the process due to certain characteristics of each cadet candidate. One of these variations is in the gender of the cadet candidate. Female and male service times are different in some cases as in the height and weight and tattoo check stations. Other variations in processing are found in the medical status of each cadet candidate. Cadet candidates with pre-existing medical conditions are more likely to take more time at the medical station. To account for the variation in service times and process flow, each cadet candidate is given a list of attributes upon arrival to the Thayer Hall system. These attributes are unique to each entity and can be called on at any time in the model to direct flow or determine service rates. Upon completion of all activities in Thayer Hall, cadet candidates are sent to the holding areas where they await their company cadre who will escort them to the cadet area.

Unique characteristics of the model to account for COVID-19 precautions include reducing capacity in each classroom to account for social distancing. A room that could hold 18 cadet candidates under normal circumstances is only able to hold 8 with social distancing measures. Separation in the hallways was also considered. Thayer Hall consists of two main parallel halls with intermittent connecting halls. To account for social distancing in the hallways, conveyors were used instead of standard queues. Cadet candidates travelled along conveyors in the same way a vehicle would on an assembly line. To enforce social distancing, each cadet candidate was modeled as a 6-foot x 6-foot box. These boxes can stand right next to each other in the conveyors, yet their size ensures spacing is maintained and that cadet candidates cannot enter a hallway if there is no space for them. Modelling flow between stations in this way provides excellent visual feedback for how congested hallways can become at peak times prior to bottleneck stations.

3.3 Data Collection and Methodology

Some Reception Day data is collected every year for real-time analysis, but it does not have the fidelity needed for simulation purposes. Specifically, current data represents chunks of time within the Thayer Hall system including movement time and service times for multiple stations. Because individual service time data at each station does not exist, the research team made assumptions about the distributions for service rates. In many cases where subject matter experts could provide minimum, maximum, and most common service times, the triangular distribution was used as it is used frequently in cases with similar constraints (Harrell, et al., 2000). In cases where an average service rate could be determined from subject matter expertise or through historical data and where it could be assumed that service rates have a strong tendency around the average, the exponential distribution was used (Harrell, et al., 2000). The uniform distribution was also used yet less frequently as it does not have a central tendency. The uniform distribution was used when no historical data was available and when subject matter experts could only provide a window of time for service. Lastly, there are some cases, such as in machine testing time, when service times held a deterministic value.

Inter-arrival times were deterministic for both the USMAPS and the Thayer Hall simulations. In the USMAPS simulation, arrivals occurred according to the report times given to cadet candidates. A predetermined number of civilians are required to report at staggered times throughout the morning. These were provided by the Reception Day planners and, as will be explained later, alternative simulations were developed to find ideal arrival times for cadet candidates. As cadet candidates complete their requirements in the USMAPS model, they are transported to Thayer Hall. As such, the exit process at USMAPS became the arrival process at Thayer Hall. The USMAPS simulation was run multiple times and the average exit time for each group was used as the arrival time in the Thayer Hall system. For the quantity of cadet candidates that arrive at these times, it is assumed that 16 of 16 cadet candidates in a testing group would test negative. This ensures the model simulates the maximum amount of stress that could be placed on the Thayer Hall system.

3.4 Verification and Validation

The baseline model was developed according to the Reception Day planning team's concept. Due to the constantly changing COVID environment, the concept and the baseline model were modified frequently. As the baseline model changed, the research team continued to modify the alternative experiments for each simulation. This provided some predictability for decision makers helping them weigh their course of action modification appropriately. For each iteration of the planned concept, the USMAPS and Thayer Hall baseline models were verified through the Reception Day planning team for accuracy.

Validation occurred primarily through subject matter expertise and historical data (Sargent, 2013). Because the USMAPS system is unique, historical data for the entire process did not exist for comparison. Therefore, components of the model were validated individually. For instance, the time to test a group of cadet candidates in the simulation was compared to the actual time that a previous cohort of upper-class cadets took to be tested and receive their results. Additionally, the average time a cadet candidate spends in the USMAPS stations, assuming no blockages, was compared to the estimates of subject matter experts given experience in similar scenarios. In both cases, the results were similar. The Thayer Hall model was validated using the average time in the system results from previous years. Although the process flow in Thayer Hall changed, the stations by type saw little change. As such, it was assumed that the average time in the system for the simulation should be like that of previous years, as is the case.

4. Results and Analysis

To aid decision makers, the research team developed simple models that could be adapted freely to simulate numerous potential scenarios. Experimentation through modification in process flow was conducted in two ways, specific requests from decision makers, and gradual modifications through three steps of the Kanban Method: visualize flow, limit work in progress, and manage flow (Anderson, et al., 2016). Visualizing flow was achieved through simulation software as well as through the quantification of key performance measures in each simulation. Limiting work in progress was addressed where bottlenecks in the system were identified. Last, managing flow was achieved through development of multiple experiments that targeted key performance measures and bottlenecks. This method was executed for both the USMAPS and the Thayer Hall baseline simulations. Experiments and process improvements were conducted for the USMAPS simulation first as the Thayer Hall model is dependent on its performance.

4.1 USMAPS Simulation Experimentation

Because of their limited quantity and low sample capacity (16 samples per machine), COVID-19 testing machines produce the most considerable bottleneck in the USMAPS system. These machines are the limiting factor for the USMAPS systems and, by dependence, the Thayer Hall system as well. Therefore, the goal is always to operate these machines as close to 100 percent utilization as possible. Utilization of testing machines is the primary performance measure of the USMAPS system. Secondary performance measures, which also enable visualization of flow, are minimize total operation time at USMAPS (time from first cadet candidate arrival to last cadet candidate exit) and minimize average time a cadet candidate spends in the USMAPS system. To achieve these objectives, experiments were designed through iterative bottleneck analysis.

To address the primary objective of maximizing testing machine utilization, experiments were designed to ensure work in progress in the testing machines was as close as possible to the machine capacity. To achieve this, samples must be gathered quickly, and work in progress at all stations prior to the testing station should be minimized. Through small improvements to the baseline simulation, it was determined that arrivals into the USMAPS system had the greatest effect on testing machine utilization. The original baseline model dictated arrival times and arrival quantities based on the cadet candidate reporting schedule. Because of gaps in the arrival process, cadet candidates in the initial arrival filled testing machines as quickly as possible. However, after testing was complete on the first group of cadet candidate arrivals, testing machines were left idle while cadet candidates trickled into the USMAPS system, received their in-processing requirements, and provided their COVID samples. Simulation experiments showed that upstream processes such as the initial brief and holding area and sampling had the capacity to service more new cadets than were needed through the original arrival plan. To address this gap, the first experiment adjusted inter-arrival times from one hour to 30 minutes for the first three new cadet arrival groups. This adjustment increased utilization of the testing machines by reducing the time testing machines waited on samples.

Although decreasing inter-arrival times at USMA showed an improvement in utilization and total operation time, a bottleneck was still identified at the test sample grouping station. The baseline plan called for sending samples to the hospital laboratory in groups of 32 as this was the total number of samples that could be tested at a time with two machines. However, by imposing this restriction, gathered and prepared samples which could be sent to the laboratory were forced to wait on cadet candidates to enter the sampling station and provide samples. This resulted in testing machines sitting idle. Through experimentation it was determined that sending test samples in groups of 16 instead of 32 increased utilization of testing machines and reduced the bottleneck at the test sample grouping location. A final experiment combined both experiments to produce the recommended alternative which decreases inter-arrival times for cadet candidates and decreases the sample collection groups from 32 to 16.

It is important to note that the ideal inter-arrival time of 30 minutes was not feasible for Reception Day planners to execute. Because of transportation limitations, arrivals had to maintain their separation and could not be arranged optimally. However, through this analysis, arrivals were adjusted as much as possible with the goal of maximizing utilization of the testing machines. The final cadet candidate arrival schedule did in fact result in an increase in machine utilization and decrease in total operation time from the baseline. The research team's other recommendation, to decrease sample grouping size, also gave flexibility to the planners and decision makers. During the planning process, more testing machines became available which eliminated the logic of testing in groups of 32. By reducing the quantity of the sample group, testing became less reliant on upstream variability and ensured that each machine could be filled as quickly as possible regardless of the number of machines available.

4.2 Thayer Hall Simulation Experimentation

The cadet candidate exit process at USMAPS is the Thayer Hall arrival process. Pictured below is the exit process for one run of the USMAPS simulation. Each spike represents a group of 16 cadet candidates entering the Thayer Hall system. These spikes serve as the arrival times for Thayer Hall and the starting point for analysis and experimentation.

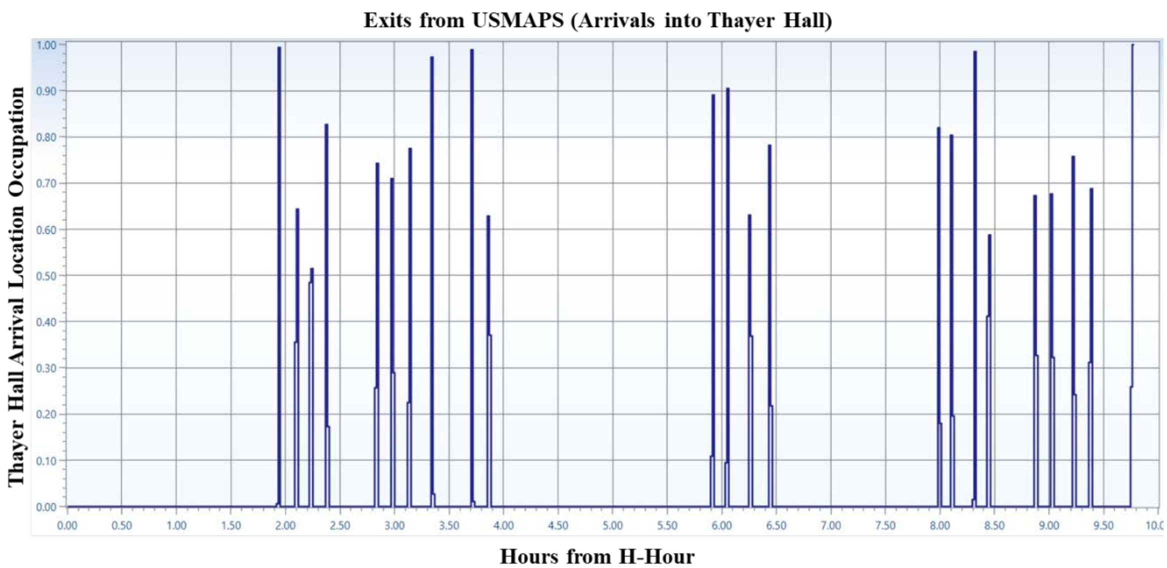

Figure 2. Arrival Process at Thayer Hall

Because of constraints on arrivals at USMAPS and resource constraints from testing machines, arrivals into Thayer Hall are spread out and do not surge wildly throughout the day. As a result, all stations within Thayer Hall can catch up fully with one group of cadet candidates before the next group enters the system. Although this is positive news for work in progress and bottlenecks, it could indicate inefficiencies in resourcing if utilization at stations is too low. To search for improvements and visualize the system, two measures of effectiveness were used: utilization of bottleneck locations and average cadet candidate time in the system.

Although all stations within Thayer Hall can complete one group of cadet candidates before the next group arrives, bottlenecks still exist in the baseline model. These bottlenecks were identified through observing the simulation as well as through analyzing the utilization of each station across the operating period. The goal for each station is to maximize utilization without reaching 100%. It was recommended that workers serving stations with low utilization should move to stations where utilization was at or nearing 100%. One example of this is in the Basic Issue Items station. In this station, utilization was greater than 100%; however adjacent stations with interchangeable workers had utilization less than 100%. By reallocating servers to the Basic Issue Items station, utilization at this station dropped below 100%.

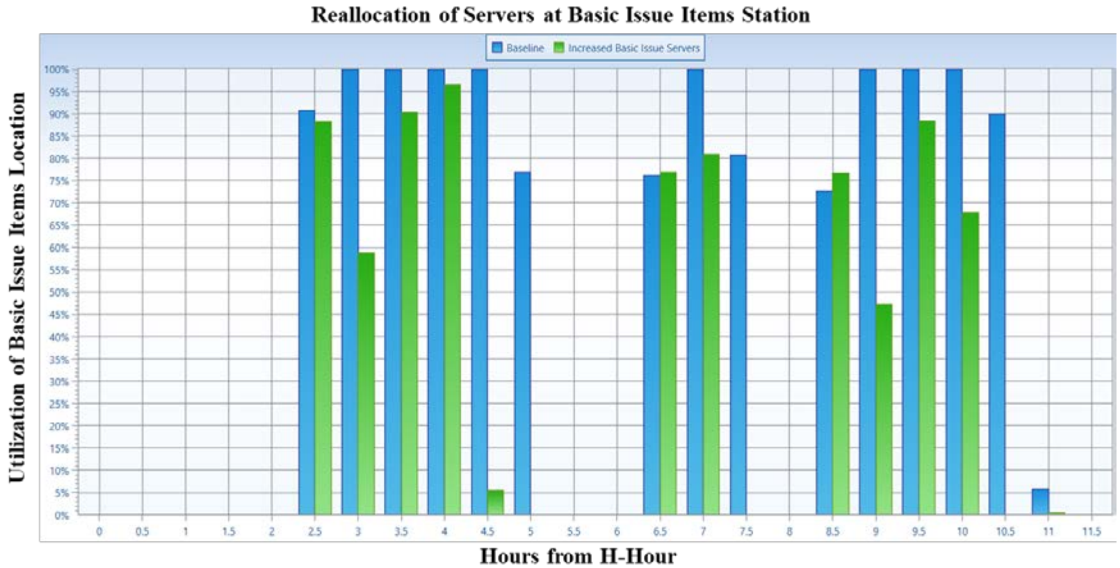

Figure 3. Decrease in Utilization to Acceptable Values with Reallocation of Resources

Bottlenecks in Thayer Hall have a compounding effect because of social distancing requirements. For stations that create queues, it is important to allocate enough hallway or classroom space prior to the station. This is difficult in many cases as stations are normally very close to each other. The simulation identified a congestion and social distancing violation prior to and within the Basic Issue Items station. Cadet candidates waiting to receive their basic issue items were filling the queue space prior to the station and were blocking movement into the Tailor Station prior to the Basic Issue Items station. To remedy this, an additional hallway was added to the Basic Issue Items station's queue space to provide room for cadet candidates waiting to be serviced at this station. Reallocating underutilized workers to the Basic Issue Items station and increasing the station queue length decreased the 95% confidence interval for cadet candidate time in the system from between 73.21 minutes and 75.35 minutes to between 64.66 minutes and 66.71 minutes.

An additional benefit of visualizing the system and conducting bottleneck analysis is in identifying the ability to create worker shifts. In general, the utilization of all stations during the entire operating period (even during active processing) was well below 100%. Because it is so low, workers are only occupied a portion of the day. By reducing the number of workers on shift, an additional worker shift can be created from those workers who were removed from the original shift with no increase to average cadet candidate time in the system. Through the creation of shifts, total operation time in Thayer Hall could be extended to allow for the entire cadet candidate cohort to flow through without requiring workers to remain on shift for the entire period.

4.3 Recommendations

Throughout the Reception Day planning and modeling, the understanding was that there would be two testing machines available. Thus, determining the optimal feasible alternatives was initially based on a two-machine concept. From analysis of experiments in each model, it is predicted that the optimal feasible alternative can be achieved by:

- Reducing the time between arrivals at USMAPS to thirty-minute intervals for the first three groups
- Reducing the grouping of cadet candidate testing from 32 to 16.

By implementing these two changes, the initial two machine model predicts the following improvements in critical metrics from the baseline:

Table 1. Critical Metrics Comparison of Baseline and Two Machines

	2 Testing Machines	
	Baseline Model	**Recommendation**
Cadet Candidate arrivals	Every hour	Reduced arrival times
Batch size	32	16
Testing machine utilization	66.4%	85.7%
Overall operation time	12hr 2min	9hr 18min
Time of day last group departs USMAPS	1732	1448

Enacting these changes increased the testing machine utilization by 19.3% and significantly reduced the time of day that the final group departs for Thayer Hall. After realizing the improved utilization and decrease in overall operation time, the Reception Day planners concurred with the proposed recommendations. Shortly afterward, the planners learned that a third and possible fourth testing machine would be available on Reception Day. Using the same recommendations, the model was adjusted to include the addition of the third and fourth machines. The models predict the following improvements in critical metrics:

Table 2. Critical Metrics Comparison with Three and Four Testing Machines

	3 Testing Machines	**4 Testing Machines**
Cadet Candidate arrivals	Reduced arrival times	Reduced arrival times
Batch size	16	16
Testing machine utilization	77.2%	65.5%
Overall operation time	6hr 48min	6hr 4min
Time of day last group departs USMAPS	1218	1134

In this situation, making the recommended changes provides a savings of approximately five hours. However, the improved flow into Thayer Hall results in several bottlenecks at stations within Thayer Hall, the effects of which are compounded because of social distancing requirements. By reallocating underutilized servers to the bottleneck locations in Thayer Hall, the model was able to decrease queue length and overall time the cadet candidates spent in the system.

5. Conclusion

This research analyzes a complex system, models the system using a discrete-event simulation, and identifies opportunities to increase system efficiency. The power of using simulation to aid decision makers lies in the fact that it is not only formal and predictive but is capable of accurately predicting performance of a system as complex as Reception Day (Harrell, et al., 2000). Simulations also gave the Reception Day planners the ability to visualize the system and view concrete metrics allowing them to make informed decisions. Analysis of the USMAPS model reveals that maximizing the utilization of the COVID testing machine significantly reduces the overall time spent at USMAPS testing station. Specifically, reducing the arrival times from every hour to every half hour and decreasing the batch sample size from 32 to 16 increases testing machine utilization by 19.3%. More importantly, this results in a 25% reduction in time spent at the USMAPS testing station before proceeding to Thayer Hall. Analysis of the Thayer Hall model identified social distancing violations caused by queuing from successive bottlenecks. These were remedied by reallocating underutilized servers resulting in decreased queue length and overall time spent within Thayer Hall. The discrete-event simulation models can be adjusted, with minor modifications, to replicate other systems requiring COVID testing, providing a means to analyze and improve processes and procedures.

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