MSTC Discrete System Simulation

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ABSTRACT

The Army's Medical Simulation Training Centers (MSTCs) consist of a series of eighteen training sites located worldwide. The mission of the MSTCs is to train military medics and combat lifesavers (CLS) medical skills that are necessary to save lives on the battlefield. With increasing numbers of students attending the MSTCs the challenge to train students effectively and efficiently is a topic of interest. This paper discusses the discrete simulation system flow of combat lifesaver students through the individual skills stations under the constraints of the average number of stations, students and number of instructors at a typical MSTC. Using a queuing system with a class of thirty students, groups of students will rotate through three different skills stations A through C (bag packing with two substations, hemorrhage control with two substations and application of tourniquets). After successful completion of their station, the students rotate to the next station until all three stations have been completed by each student. It is desired that this simulation identifies areas where additional training assets would have the greatest effect. A secondary goal is identification of time slots where additional learning could occur via instructor led or instructorless training, in lieu of idle time waiting for a station.

ABOUT THE AUTHORS

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INTRODUCTION

The Army's Medical Simulation Training Centers (MSTCs) train military medics and combat lifesavers (CLS) the critical medical skills that are necessary to save lives on the battlefield. In recent years, demand for battlefield care givers has increased significantly while resources at the MSTCs have remained the same. In 2009, the MSTCs trained over 122,000 Soldiers (Ariza, 2010).

BACKGROUND

System Background

The increase in student throughput has placed significant strain on the resources of the MSTCs. As a first step in optimizing resources, this study will examine the flow of combat lifesaver students though the individual skills stations under the constraints of limited numbers of stations and instructors at a typical MSTC. A simulation analysis tool called Arena by Rockwell Software was used to model the training system and alternative designs (Arena, 2010). The model will allow the analysis of the base system and alternatives without interfering with training or incurring additional training site set-up costs. This exercise will identify areas where additional training assets would have the greatest effect especially with increased student enrollment. It will also identify wait time where additional learning could occur.

System Locations

The Army has fielded eighteen MSTCs worldwide including Asia, and the Middle East (Team Orlando). Initial data collection for this project consisted of phone interviews and surveys that were given to three MSTCs located in the continental United States. Onsite observation and data collection was done at the MSTC in Fort Lewis, Washington.

Service Rates of Systems

The number and frequency of CLS classes was determined through the interviews and surveys mentioned above. Even though MSTCs have a mission to standardize training, variations in both class size and frequency of classes occur among the sites. The survey also documented the number and types of simulation stations, the typical number of students per class and exercise group, and the staffing levels required to conduct the simulation exercises.

SYSTEM DESCRIPTION

Initial System Description

The CLS course is a five-day advanced first aid course provided to non-medic Soldiers. On the battlefield, a CLS provides a higher level of care than the Soldier who is only trained to provide self aid and buddy aid. Each CLS is trained to act both independently and under the direction of a medic. A typical course consists of three days of lecture and two days of practical skills. The first day of practical skills instruction is taught as individual skills at learning stations. The second day of practical skills instruction is taught in simulated combat environments where students must combine individual skills to provide total patient care.

This simulation analyzes the student flow during the first day of practical skills instruction. The class is divided into groups that proceed to different skill stations; A, B, C, etc. Typical skills taught at these stations include hemorrhage control, airway management, IV therapy, needle decompression of tension pneumothoraces, and bandaging. After successful completion of a training station, the students move to the next station until all stations have been completed by each student. Training failures are not simulated because students are coached until they successfully complete each station. Due to this coaching and the inherent variability of student and instructor performance, station completion times vary causing waiting at some stations. Each station is equipped with a queue for students to wait their turn. Since this is a military exercise, a first-in-first-out queuing discipline is followed and skipping stations, balking and cutting in line are not allowed. The number of stations is limited by the number of instructors and the number of simulators.

The initial model concept was designed based on previous experiences at the MSTCs where the typical class size was 30 students. Because of the increase in student throughput, the size of the classes has increased and in some cases doubled. Coincidentally, the observed class at Fort Lewis had 30 students, but discussions with the instructors revealed that the classes typically hold 60 or more students.

Observed System Description

Based on observations at Fort Lewis the number of stations was changed from five to three, with two of the stations having two training sub-sections as shown in Figure 1. Figure 1 illustrates the three stations. Station A, bag packing consisting of two substations, station B, hemorrhage control consisting of two substations and station C, tourniquet application consisting of one station. Students were divided into groups of ten. Group time at each station was limited to 45 minute (2700 second) with a 15 minute (900 second) break between stations. Additional observations resulted in break time being changed from between station waiting to within station waiting. The break time is also used by the instructors to reset the simulations. Because all students enter the training system at once, the pre-waiting and post-waiting queues have been eliminated and queues are within station A and B and outside of station C. This system provides the potential for increased student training with less wait time.

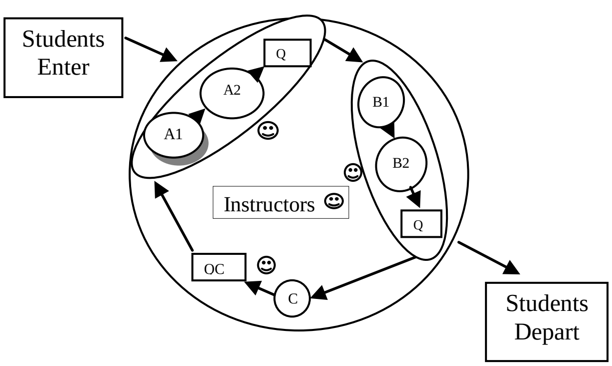

Figure 1: Observed MSTC Training Configuration

Problem Description

Earlier observations indicated a significant amount of time students wait. Optimizing student throughput to minimize wait time should save significant time and resources. The time savings and instructor resources could be used to maximize the delivery of training material and simulations to improve student performance and retention, or the time could simply be used to shorten the course and allow the Soldiers to return to their job of defending the country.

OBJECTIVES

There are three primary objectives of this research. The first objective is to establish a baseline for the total amount of wait and exercise time each class experiences in a typical CLS practical skills lab. The second objective is to measure the impact to both measures if the number of students doubles but the number of stations and instructors remains the same. The third objective is to analyze the impact on both measures if the number of students and the number of station are doubled with the number of instructors staying the same.

The following specific questions that this study addressed include:

- What is the wait time for each CLS practical skills lab class?
- What is the total time required for each CLS practical skills lab class?
- Will additional students impact the student wait time?
- Will additional stations impact the student wait time?
- What is the impact of both additional students and stations upon the student wait time?
- If wait time is affected how will this affect the overall training scheduling costs?

EVALUATION METHODS

Performance Measures to Be Evaluated

This project will measure wait time and overall exercise time of students, in seconds, over three different configurations of CLS skills labs. By documenting these measures, resource recommendations can be made that will increase efficiency and improve throughput.

Input Data, Data Sources and Data Collection Methods

The results of the surveys in terms of number of stations, range of time to complete each station, number of available instructors and typical class size are shown in Table 1.

Table 1: Typical MSTC Configurations

Facility	Number of Stations	Number of Students	Instructor to Student Ratio	Time to Complete Station (minutes)
Fort Lewis	4	30-60	1:10	45
Fort Bragg	5	60	1:2	120
Camp Shelby	4	20-25	1:6	25-30

Input Variables

Table 2 defines the data needed to develop the model in Arena. A stop watch was used to measure the time as students entered and departed each of the five stations at Fort Lewis. Overall start and end times for the entire exercise were also recorded.

Table 2: Data and Definition

Data (Seconds)	Definition
Station arrival time – start	Arrival to one of the stations, A, B, or C
Station end time	Time student completes one of the stations A, B, or C
Exercise start time	Time that students leave classroom to begin pre-exercise (total scenario begin)
Exercise end time	Time that all students complete all stations (total scenario timing)

Data Constraints and Assumptions

Data constraints were identified and confirmed from the surveys distributed to three MSTCs. The following is assumed:

- No balking or reneging.
- Students will wait in line and follow station flow.
- Skill failures do not occur. In other words, coaching occurs until task is completed.

DATA COLLECTION

The model was populated with data collected from the Fort Lewis MSTC on 24 March 2010. The team expected to collect 60 to 70 data points at each of the training stations, but only 30 students attended class on this particular day. The students were divided into three groups of ten, so a project team member went to each training station. General observations were made and specific time data was recorded at each station.

At Station A, the bag-packing station, the exercise was divided into two mini-stations. In station A-1 each individual student had to inventory against a checklist and obtain any supplies that were missing. The students were then required to pack their CLS bag properly. Students were given the freedom to decide how to pack their bags but organizing supplies into treatment packages such as hemorrhage control was highly recommended. The second part of the bag packing station, A-2, consisted of a verbal quiz for the entire group. The instructor called for specific items prompting the student to quickly locate and remove that item from their bag. The students would then perform buddy aid on each other as the instructor called out differing scenarios. The purpose for this was to stress the importance of knowing the location of the supplies and how to use them. A photo of a typical CLS bag and its contents is shown in Figure 2.

Figure 2: Typical CLS Bag and its Contents

Station B taught hemorrhage control of non-compressible injuries (those not treatable with tourniquets). This station consisted of two mini-stations, B-1 and B-2. At station B-1 the trainees teamed up with a buddy to practice direct pressure dressing of penetrating injuries under the arm. These types of injuries are not uncommon as enemies are taught to aim for the arm holes of the Soldier's body armor. Each trainee applied a dressing to their buddy and then switched places. Station B-2 consisted of a bleeding mannequin with non-compressible injuries under each arm and on each side of the groin. Four students approached the patient; each managing a single wound. The students packed the wounds with gauze and applied direct pressure until the bleeding stopped. Once the bleeding was stopped, the students backed away and the next group prepared for their turn. The bleeding mannequin is shown in Figure 3.

Figure 3: Bleeding Mannequin

Station C taught how to best use eight different types of tourniquets; Rag with a windless, Soldiers belt with a windless, Soft-T, Ranger Ratchet, Ratchet, Early war tourniquet, Rag with a slipknot, and a Cravat with windless and zip ties. A photo of a typical tourniquet is shown in Figure 4. Approximately two thirds of the time was spent on basic orientation with these devices and the remaining time allowed the students to familiarize themselves with the basic use of the devices by applying them to themselves and to their fellow Soldiers. This station was very self-paced and relied on the Soldiers self-motivation and interest in tourniquet application. During breaks between groups, the instructor reset all the tourniquets.

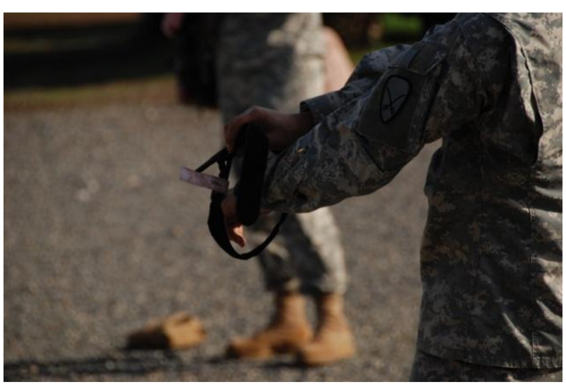

Figure 4: Typical Tourniquet Device

Input Data Analysis

The Input Data Analysis for the samples was done separately for each station and sub-station and is summarized in Table 3. The level significance used in the Arena Simulation is .05 or 95%. Station A-1 shows a triangular distribution. Station A-2 shows a normal distribution. Station B-1 shows a normal distribution. Station B-2 shows a uniform distribution.

Table 3: Input Variables

Stat	Dist	Min	Max	xbar	S^2	Most Likely
A-1	TRIA	435	1345	800	295	525
A-2	NORM	600	1020	780	216	N/A
B-1	NORM	63	277	153	48	107
B-2	UNIF	29	79	52	14	74
C	NORM	N/A	N/A	2187 2640 1800	N/A	N/A

Station C was unique in that all students entered and left at the same time and the time spent engaged in instruction and training appeared to be dependent on external motivating factors, such as proximity to break-time. The average training time for the first 10 was 2187 seconds. The second 10 students, where the students seemed to be most engaged had an average of 2640 seconds. The third group of 10 students went through right before the lunch break and had an average time of 1800 seconds.

MODELING AND ANALYSIS

Initially, three models were built to analyze student throughput. A fourth model was added after analysis showed a significant bottleneck at the tourniquet station. The baseline simulation was built using the observed training structure of 30 students. Three alternative Arena simulations were then constructed and analyzed. In the first alternative design, the class size was doubled to 60 but the configuration of instructors and simulations remained the same. A student population of 60 is much more typical and allowed the team to baseline the impact of greater student throughput without additional instructors or equipment. The second alternative design doubled the number of simulation stations, kept the student load at 60 and kept the number of instructors the same. Observations at the training site indicated that instructors have a minimal impact on completion time of the students at stations A and B. At station C instructors have a large impact since the training is primarily lecture and discussion. Based on the alternative designs, changes in wait time and throughput were evaluated against the cost of the extra equipment and instructors for the stations. The cost of extra training equipment for a more expensive station is estimated at a maximum of $5,000. The cost of an additional instructor, burdened for one year is estimated at $100,000. The additional stations and instructors serve as independent variables.

Base Model Explanation

Discussions and observations at Fort Lewis confirmed that the final base model is accurate. Fort Lewis normally establishes four training stations as noted in Table 1. Based on observations, the team combined the two hemorrhage control stations into one exercise with two sub-stations. The simulation begins as students arrive for skills training. Ten students proceed as a group to the available three exercises (A, B, and C). At each station, students are tallied and a counter assigned as an attribute to each student is incremented. This counter is used to ensure that each student completes each exercise. The students flow from exercise A to B to C to A to B. At the exit of each exercise a Decision module determines whether the student has completed all exercises and routes them accordingly. If the student has completed all three exercises, he is disposed from the simulation. The simulation ends when all students are disposed.

The base model is designed to address variance reduction. The base model is a terminating simulation. A total of 1000 replications provided the best results and serves as a reduction of variance. The use of the common random number (CRN) technique applied similar experimental conditions across the base model and alternative models. The Arena simulation uses a random input yielding, random output approach. This simulation system randomly generates numbers that are independent and identically distributed or IID. The IID approach helps to reduce the correlation between the random numbers producing a distribution with the same probability.

Base Model Verification and Validation

The base model was verified using the Arena Simulation program, computer debugging, multiple team member review and animation. Varying input parameters (number of students and statistical parameters) were changed to make sure the model reacted in the anticipated manner. Running the model observed bottleneck at station C, a third alternative was constructed with the same resource and student configuration as alternative 2 but with the addition of an additional instructor at station C. From the yielded an accurate representation of what was expected.

The base model was validated using a calibration process where it was compared to the observed training exercise. The model was debugged and modified until it matched what was observed. Input parameters and station distributions were derived from times measured during the training event. These times and distributions were further validated through interviews of site leads at different MSTCs. The base model then underwent an output analysis using Arena. The confidence-interval approach allowed the authors to view the negative changes to the mean that resulted from differences between the base model and alternative models. The confidence intervals were tested and are described in more detail in the Output Analyzer Results section.

Experimental Design

The factorial design of the base model was compared to the three alternative designs for evaluation and recommendations to increase station efficiency. The null hypothesis states that there is no difference in total wait time between base and alternative models. The alternative hypothesis states that there is a difference in total wait time between base and alternative models. The base model serves as the control, while the three alternative designs serve as the experimental groups. This research addressed the main effect of changes to numbers of students and to numbers of stations.

Alternative Design 1

Alternative 1 examines the impact of doubling the student population to 60. The number of instructors and training stations remains the same. This design has three stations and three instructors. The students are grouped into six teams of ten. The additional groups wait in queues at each station until that station's resources become available. All six groups flow through the system until each group completes each station.

Alternative Design 2

Alternative 2 as shown in Figure 5, examined whether additional stations affect wait time and overall efficiency. For this simulation, the number of students is 60 and the number of resources at each station was doubled while maintaining the same three instructors.

Changes in wait time and resource utilization were documented. These changes were compared against resource costs to support recommended changes.

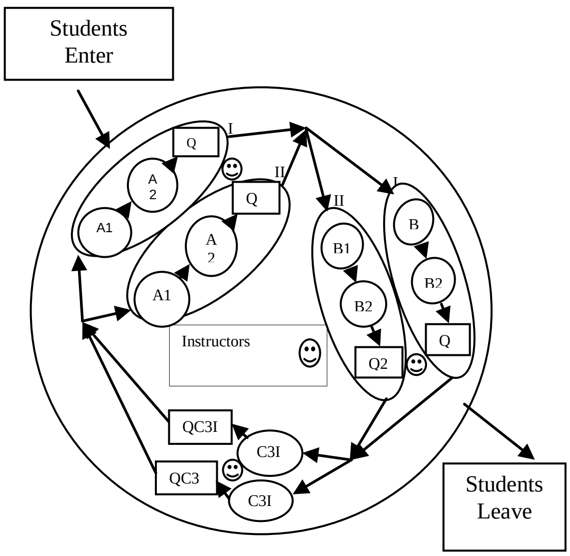

Figure 5: Alternative Design 2

Alternative Design 3

While running alternative design 2, it was noted that a significant amount of time was spent waiting for the single instructor at station C to become available. A third alternative design was developed to see what impact a second instructor at station C would have on the system. The resulting impact was significant but that impact will have to be weighed against the additional cost of hiring another instructor.

DISCUSSION OF RESULTS

As shown in Table 4, alternative model 1, with the addition of 30 students, increased the maximum wait time by a factor of 3.0 when compared to the base model. Alternative model 2, with the addition of station doubling, increases the maximum wait time by a factor of 2.7. In alternative model 3, where the instructors at Station C are doubled, the maximum wait time is only 1.1 times the base model.

Table 4: Overall Wait Time

Model Type	Avg. Wait Time (sec)	Max. Wait Time (sec)	Wait Time Comparison
Base model - 30 students	1135.04	3444.59	N/A
Alternative model 1 - 60 students	4460.90	1032.61	3.0X
Alternative model 2 - 60 students, double stations	4126.59	9245.67	2.7
Alternative model 3 - 60 students, double stations, double instructor station C	1157.14	3718.57	1.1X

The doubling of the instructors and stations in alterative model 3 provides the best mitigation to the forced increase in class size. Alternative model 3 cuts maximum wait time by 2.8 as compared to the alternative model 1 and 2.5 as compared to alternative model 2. When comparing alternative model 3 to the base model, the wait time difference is nominal because the extra instructor relieves a major bottleneck. Alternative model 3 is considered a viable alternative when the student number is 60, while the base model is best with smaller class sizes.

As shown in Table 5, the 60 student class size in alternative model 1 increases the required exercise time by a factor of 1.6. Alternative model 2 increases the required exercise time by 1.**6** indicating that doubling the simulation stations has a minimal impact on this factor. Alternative model 3 increases the overall exercise time by a factor of 1.1 reinforcing the theory that a second instructor at exercise C relieves a significant bottleneck caused by additional students.

Table 5: Overall Exercise Time

Model Type	Avg. Total Time (sec)	Max. Total Time (sec)	Max. Time Comparison
Base model - 30 students	7805.66	10137.26	N/A
Alternative model 1 - 60 students	11033.60	15885.99	1.6X
Alternative model 2 - 60 students, double stations	10613.21	16225.57	1.6X
Alternative model 3 - 60 students, double stations, double instructor station C	7937.72	10812.22	1.1X

Table 6: Resource Instantaneous Utilization

Model Type	Avg. Station A Instructor	Avg. Station B Instructor	Avg. Station C Instructor
Base model - 30 students	.03	N/A	.78
Alternative model 1 - 60 students	.03	N/A	.93
Alternative model 2 - 60 students, double stations	.04	N/A	.93
Alternative model 3 - 60 students, double stations, double instructor station C	.05	N/A	Instructor 1 - .74 Instructor 2 - .78

More evidence supporting the theory that an additional instructor at station C has the greatest positive impact can be derived from Table 6. A single instructor at station C is utilized 93 percent of the time when class sizes grow to 60. High utilization rates are desirable for static resources like simulators but can be overwhelming when applied to human resources. A nearly 100 percent utilization rate of an instructor allows no time for recovery.

Output Analyzer Results

Arena's Output Analyzer was used to compare the means of total wait time and total exercise time. The comparison of the means used a paired t-test. Statistical testing rejected the null hypothesis, at the .05 level of significance, that alternative models were better than the base model. There is a statistical significance as zero falls to the right of the confidence interval. The confidence interval shift to the left of zero is due to the negative difference in means of the base model and alternative models.

From a strict statistical analysis the base model appears to provide the best results. The base model is indeed the best approach when 30 students go through lane training. It is not the best approach when 60 students go through lane training. Alternative model 3 provides the best results when the class size doubles to 60. This conclusion is of practical significance. Although the instructors were not originally part of the performance measures, the authors used Arena's output analyzer to compare the means for the use of additional instructors. The statistical testing noted a failure to reject the null hypothesis at the .05 level of significance. The base model and alternative models 1 and 2 each contained one instructor per group. In alternative model 3, group

C, the instructor was doubled, yielding practical significance as the animation and analysis showed this area was backing up and delaying the entire simulation. When the second instructor was added the instantaneous utilization shifted the load between the two instructors, bottlenecks were reduced and total wait and exercise time were comparable to the base model.

The project team also noted that the Hawthorne effect seemed to have an impact on instructor and student performance (About.com, 2010). Specifically, as participants noted the project team's presence, they were more animated, more focused and more engaged. As they became more involved in their tasks, the observations team's presence seemed to have less effect on performance. There was also a notable fatigue factor with both the students and instructors as the training progressed.

CONCLUSIONS

From the analysis, when class size is increased to from 30 to 60 students, adding an additional instructor to station C (tourniquet application) is the best way to mitigate negative impacts to the simulation. In situations where throughput is closer to 30 students, the base model shows that the MSTCs are properly resourced.

Although not every possible scenario was tested, the comparison of three alternative models to the base model simulated probable changes to the real life system of MSTC lane training. From statistical and practical analysis using Arena's output analyzer, the base model is the best configuration to use when student registration is at 30. Furthermore, the alternative model 3 is the best lane training configuration to use when the student registration is doubled to 60. This configuration has the potential of adding a significant cost; however, discussions with the Ft. Lewis MSTC staff indicated that instructors are occasionally borrowed from other military activities at no additional cost to the MSTC training.

Multiple means of verification and validation confirm that the base model and subsequent alternative models and their functionality are comparable to the actual skill training exercises at the MSTCs. This exercise is the first step in a series of analyses that will be performed to optimize the resourcing of future MSTCs.

RECOMMENDATIONS

Although it was not part of the original study design, the addition of a second instructor at station C became necessary as the data was analyzed. Even though an additional instructor imposes a significantly higher recurring cost, it provides the most effective mitigation to increasing class sizes. Most MSTCs will not hire new instructors but will reassign instructors from other tasks to cope with the student throughput. These observations pointed to the need for more efficient training tools, particularly in the area of tourniquet training. One recommendation the team would make in this area is that MSTC's be equipped with a tourniquet training device, such as the Hap Med arm, that provides some objective measures of tourniquet application. This would benefit both the student and the instructor as they both try to determine whether or not proficiency has been achieved. Also, at the tourniquet station, the team recommends that the instructor direct the students to return the tourniquets to their "unused" condition saving the instructor reset time, especially when there are more students, as described in the Alternative Design 1, 2 and 3 situations.

Additionally, during the built in breaks the project team recommends utilizing some other instructorless training tools such as the newly created Combat Medic Card game. The Combat Medic Card game can be used to reinforce Combat Medic procedures via a flash card or traditional card game format. The portable and inexpensive nature of the game carries a nominal cost to filling wait time with an information rich solution.

FUTURE RESEARCH

One recommendation points to the need to collect data from other MSTC sites. The Army training community needs and deserves this complete analysis to determine the optimum configuration for MSTC locations given the diversity of class sizes, available instructors and training resources. Another recommendation points to the need to collect performance data and its relation to student flow. Future research will include studies at additional testing sites with both the Combat Medic and Combat Lifesaver (CLS) training curriculum and lab stations.

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