Scheduling stored combat load retrieval

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Abstract

Purpose – This paper aims to raise awareness of a potential planning pitfall and provide recommendations on how to assess and improve upon current practices. In potential conflict areas, such as the Korean Theater of Operations (KTO), military forces are required to store a portion of their ammunition combat load within depots and ammunition supply points under the control of a servicing ammunition company. This necessitates a lengthy retrieval process, as the ammunition company does not have enough resources to serve all customers simultaneously.

Design/methodology/approach – The stored combat load (SCL) retrieval process is modeled as a parallel machine scheduling problem and simulated using synthetic requirements. The current system of retrieval is contrasted against a proposed alternate system through a series of simulations scaled across three factors: number of ammunition company Soldiers, number of customer units and number of magazines.

Findings – The proposed alternate system demonstrates a significant potential for reducing the makespan of the SCL retrieval process when more than half of the magazines store SCL for multiple customers and there are more than five customers per Soldier.

Originality/value – Transitioning military units from a peacetime standing to full combat readiness as quickly as possible is of immense value within the KTO and other hostile areas with established troops not actively engaged in combat.

Keywords Ammunition combat load, Korean theater of operations, Parallel machine scheduling, Stored combat load

Paper type Conceptual paper

1. Introduction

1.1 Background

Militaries around the world face the competing demands of keeping ammunition safe, secure and reliable with that of keeping munitions readily available. During times of peace, this is fairly straightforward as there is sufficient time for military units to plan and draw ammunition as required for training. During combat operations, munitions often accompany troops or are readily accessible on combat outposts and forward operating bases. The transition between peace and combat postures can place an extraordinary demand on logistic systems as supplies are transferred from storage to the warfighter on scales much larger than normally experienced. Given enough time and distance, these demands can be managed with relative ease. However, the enemy does not always provide this luxury. The attack on Pearl Harbor is a prime example of

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where this transition came as a surprise. The threat was also faced in Germany along the Fulda Gap during the Cold War. While the situation on the Korean Peninsula may be improving, the remainder of this paper will focus on the Korean Theater of Operations (KTO), as it is the most recent example where Stored Combat Load (SCL) retrieval times play a significant role in operational planning.

For over half a century, tensions between North and South Korea remained high, with each side prepared for an immediate transition to combat operations. In response, the US military has units forward deployed to the Republic of Korea (ROK) to assist in defending our southern ally. US Army units in the ROK face the unique challenge of being ready to "Fight Tonight" if North Korea initiates hostilities towards the south. While combat operations may be imminent, the reality is that military forces are often located in close proximity to heavily populated and peaceful populations, as South Korea has continued to prosper and grow. Long-term storage of large stockpiles of highly explosive munitions on US military outposts would violate ammunition and explosive quantity-distance requirements. Such safety standards are enforced to safeguard military and civilian populations in the event of an inadvertent detonation. Therefore, most of a unit's required Ammunition Combat Load (ACL), necessary for combat operations, is stored on ROK ammunition depots, or supply points, as an SCL and this presents a unique set of challenges.

In 1974, the US and ROK Governments agreed upon the Single Ammunition Logistics System-Korea (SALS-K) to govern ammunition operations in the KTO (Rich, 2016). This led to the US Army relying on Wartime Host Nation Support (WHNS) from the ROK. WHNS consists of the ROK Army storing the majority of US Army ammunition along with providing the bulk of logistic support in the form of personnel and material handling equipment (MHE). As a consequence, US Army ammunition units in the KTO have significantly fewer organic resources than their counterparts elsewhere in the US Army. While this arrangement works well in peacetime, in the event of imminent hostilities, such as those of December 7, 1941, the WHNS resources would most likely be overwhelmed as they support both ROK and US ammunition units. Much of the ammunition transfer would need to occur using limited resources brought by the customer units (such as those found on tactical transports) and manual labor. An efficient system is necessary to quickly process all customer units through the retrieval process while maintaining accountability.

Ideally, this system would minimize the overall time required for all customer units to retrieve their SCL. The system would also allow planners to prioritize those units which may need to become operational sooner than others. The system should also be flexible enough to adapt to changes as they occur, in real time while providing an initial plan that is robust against variability. The current system of SCL retrieval can be modeled as a parallel machine-scheduling (PMS) problem and can benefit from heuristics already defined in current literature. An alternate system, where the ammunition company focuses on processing magazines, has the potential of significantly reducing the makespan of the SCL retrieval process if sufficient magazines store SCL for multiple customers.

1.2 Outline of article

The remainder of the article consists of four additional sections. Section 2 introduces PMS basics in context of the current system of SCL retrieval and describes the proposed alternate system. Section 3 uses synthetic data to compare the performance of the alternate system to that of the current system. Section 4 provides conclusions and areas of future research. Section 5 lists works cited.

2. Methodology and modeling assumptions

2.1 Background

To the best of the author's knowledge, no other researchers have proposed models for this problem. The author's experience as an ammunition company commander in Korea and conversations with leaders recently responsible for the process have provided the inspiration, and validation, for modeling the current retrieval method as a PMS problem. The PMS problem, especially with deterministic job processing times has been thoroughly studied and a brief summary is outlined below. Problems with stochastic processing times have been the subject of research more recently but no prior papers were found that adequately covered the nuances of the SCL scheduling problem where each job's required processing time may be a unique sum of varying distributions.

While the alternate system uses batch processing of customers at magazines to reduce makespans, the process differs from how batch processing is conventionally modeled. In literature, batch processing uses the assumption that once a machine begins processing a particular batch, the jobs cannot depart until the last job is complete. The longest processing time (LPT) in the batch becomes the processing time for all the jobs batched on that machine. This approach is incompatible with the alternate SCL retrieval model which allows for customers to depart an ammunition magazine once they have secured their ammunition, regardless of whether another customer is still retrieving munitions. An inability to find prior research on PMS allowing unequal batch processing sizes with this "early departure" caveat facilitated the need for an initial study. Monte Carlo simulations were used to determine the behavior of the system as the number of customers, Soldiers, and magazines varied.

2.2 Introduction to parallel machine scheduling

The current system of SCL retrieval can be modeled a PMS problem. This structure involves m machines operating in parallel to process n jobs. As this basic structure can be adapted to many systems, it has been a staple of scheduling theory for many years. In the context of the SCL retrieval model, the ammunition company Soldiers are the machines and customer units are the jobs, but more on that later. Michael Pinedo's (2016) textbook, "Scheduling", offers a comprehensive primer on the basics in Chapter 5 for PMS problems with deterministic processing times and Chapter 12 for situations where the times are stochastic. While the makespan, or time the last job leaves the system, is often the objective to minimize, other performance objectives include minimizing average job time in system and sum of completion times. Other variations on the basic concept include jobs with precedence constraints, variations among machine speeds, and batch processing.

PMS problems are often described using a three-field classification system, $(\alpha \mid \beta \mid \gamma)$, as outlined by Graham *et al.* (1979) in their seminal survey on PMS. The first field, α, describes the machine environment, in this case using Pm to denote m parallel machines. The second field, β, denotes job characteristics such as identical processing times or precedence constraints. The final field identifies the performance objective, such as minimizing the maximum job completion time, C_{max} or makespan. If the jobs have individual due dates then minimizing lateness or tardiness can be performance objectives. As an example, $Pm||C_{max}$ represents a PMS problem with m identical machines with no specific job characteristics where the objective is to minimize the makespan.

Even with just two machines, the $P_2||C_{max}$ problem is classified as NP-hard (Pinedo, 2016) as it is equivalent to the NP-hard partitioning problem. Preemption, or the ability to process jobs on more than one machine, simplifies matters significantly and is denoted as *prempt* in the β field when it is allowed. If preemption is allowed, job processing times (p_j)

can be allocated among multiple machines so the workload is balanced and the makespan becomes $\frac{\sum p_j}{m}$, assuming no single job exceeds this value. This provides a lower bound on any makespan as:

$$C_{\max}(\text{OPT}) \geq \max\left\{\max \quad p_j, \quad \sum_{j=1}^{n} \frac{p_j}{m}\right\} = C^*_{\max}$$

As PMS problems can be unique, the bounds on different scheduling methods are given as a ratio with $C^*_{\max}$ as the denominator. If jobs are sequenced according to a predetermined list and are processed via a first-come, first-served (FCFS) policy, the upper bound on the ratio is: $\frac{C_{\max}(\text{LIST})}{C^*_{\max}} \leq 2 - \frac{1}{m}$ (Graham, 1966). A better upper bound can be achieved if the jobs are sequenced with the LPT placed first: $\frac{C_{\max}(\text{LPT})}{C^*_{\max}} \leq \frac{4}{3} - \frac{1}{3m}$ (Graham, 1969). A primitive example with two machines and three jobs can be seen below (Figure 1).

2.3 Current system of stored combat load storage and retrieval

In the KTO, Army in Korea (AK) regulation 700-3 outlines the standards for Army units to store a portion of their ammunition combat load, their SCL, under the custody of their servicing ammunition company when insufficient or inadequate storage facilities are present at the unit's garrison location. The ammunition company coordinates with ROK ammunition depots (AD) and ammunition supply points (ASP) for the long-term storage of the SCL. With few exceptions, the ammunition company stores the customers' SCL throughout the depot to maximize storage capacity in accordance with safety requirements provided in Army Regulation 190-11 and Department of the Army Pamphlet 385-64. Therefore, a customer will likely visit multiple magazines across the AD/ASP in order to retrieve their SCL and multiple customers may visit a single magazine.

Within the KTO, AK 700-3 assigns responsibility for deconflicting SCL retrieval priorities to the area commanders. If a predetermined sequence is not provided, customer units arrive at their servicing ammunition company and are processed for SCL retrieval on an FCFS basis. After in-processing the AD/ASP, the customer is assigned a Soldier from the ammunition company who escorts them throughout the depot as they retrieve munitions from the required magazines. Upon completion, they both return to the ammunition company headquarters for out-processing and the Soldier is released to serve the next customer. This system is easily modeled as a PMS problem with Soldiers as the machines and customers as the jobs. Each customer, j, has an associated processing time requirement,

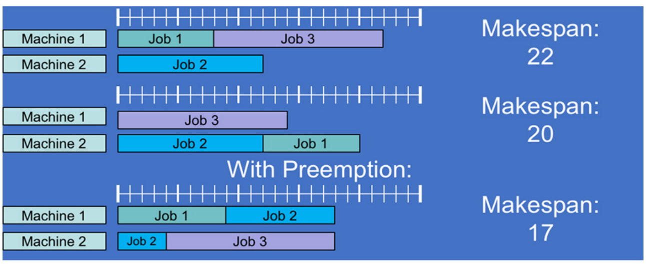

Figure 1. Graphic representation of PMS example

p_j, based upon the ammunition quantity and type they require and the intra-depot travel time incurred between magazines.

2.4 Proposed alternate system of stored combat load retrieval

While lack of MHE hinders the speed of retrieval, the greatest constraint in the current system is the number of ammunition company Soldiers available to escort customers within the AD/ASP. The Soldier escorts are essential in maintaining ammunition accountability and cannot be easily dismissed in favor of opening all magazines, trusting customers to draw the proper lots and quantities associated with their SCL. However, the ammunition company Soldier can potentially maintain accountability among several customers drawing SCL from a single magazine. The initial concern may be that serving multiple customers at a magazine may increase processing times. This would be offset by the ability to empty magazines from front to back, versus working around munition stockpiles of units yet to arrive, while having more labor on hand to assist with retrieval. Changing the focus to processing magazines, versus customers, would allow Soldiers to process multiple customers simultaneously.

While sequencing magazines for processing, versus customers, a few assumptions were made as to the behavior of customers and Soldiers during the retrieval process. Customers move between their required magazines in the order the magazines are sequenced. The Soldiers from the ammunition company remain at a magazine until all SCL has been retrieved. Potentially, a customer could have its required magazines sequenced consecutively so as to maximize the time Soldiers are required to wait before the customer arrives. Clearly, this is not ideal, as minimizing Soldier idle time also minimizes overall makespan. This arrangement also may produce gaps where customers are not actively retrieving ammunition while waiting for a Soldier to arrive at their next required magazine. Thus, the alternate system has the potential to reduce the overall makespan while increasing an individual customer's retrieval time.

2.5 Modeling and example of both systems

The processing time required by customer i at magazine j is represented by $p_{ij} \in \boldsymbol{P}$, where the rows of $\boldsymbol{P}$ represent customers and the columns are magazines. The sum of the columns, by row, represent the total required magazine processing time for a single customer, $p_i \in \boldsymbol{p}$, and is used in the evaluating the current system. The matrices $\boldsymbol{A}$ and $\boldsymbol{D}$ will be used to record the arrival and departure times of each customer at each magazine location and $\boldsymbol{T}$ is a square matrix providing travel times between magazines. For the alternate system, a customer's arrival time to a magazine will be the greater of its departure time from the previous magazine plus travel time and the arrival time of the Soldier processing the magazine.

A Soldier's arrival time to a magazine will be the maximum customer departure time from the previous magazine he/she was at plus travel time. The makespan of the retrieval process will be the maximum customer departure time, max $d_{ij} \in \boldsymbol{D}$.

As a demonstration, consider an example with three customers – {A, B, C} – three magazines – {I, II, III} – and two Soldiers – $\{S_1, S_2\}$. Travel times are excluded from this example for the sake of simplification. The processing times for the three customers are:

$$\boldsymbol{P} = \begin{bmatrix} 5 & 2 & 0 \\ 0 & 1 & 4 \\ 0 & 0 & 3 \end{bmatrix}, \quad \boldsymbol{p} = \begin{bmatrix} 7 \\ 5 \\ 3 \end{bmatrix}$$

As a reminder, the rows represent customers and the columns are magazines. Under the current system, it is clear to see that the optimal makespan is 8 with an optimal allocation being S_1:$\{A\}$, S_2:$\{B, C\}$. Under the alternate system, first consider the magazine sequence I, II, and finally III. Soldier 1, S_1, immediately starts processing Customer A at I while S_2 starts Customer B at II. Solder 2, S_2, is done with B at time 1, but remains at magazine II waiting for A to finish at I. Customer B, being released from II, is free to move to III but cannot start processing until the next Soldier becomes available. Once A is done at I, it moves to II, and S_1 moves to process B and C at magazine III. This process continues until all customers have retrieved munitions from all required magazines and the following arrival and departure matrices demonstrate that the makespan of this magazine sequence, {I, II, III}, is 9. This is worse than the current system due in part to the idle time of Soldier S_2 at magazine II, as he/she waited four units of time for customer A to complete retrieving SCL from the magazine I. Figure 2 shows a graphic depiction of the process with the dashed lines representing the path Soldiers take and solid lines that of the customers. The Soldiers' arrival times at each magazine is also annotated.

$$\boldsymbol{A} = \begin{bmatrix} 0 & 5 & - \\ - & 0 & 5 \\ - & - & 5 \end{bmatrix}, \quad \boldsymbol{D} = \begin{bmatrix} 5 & 7 & - \\ - & 1 & 9 \\ - & - & 8 \end{bmatrix}$$

Next, consider the magazine sequence: {II, III, I}. Soldier 1, S_1, arrives at magazine II and immediately starts processing customers A and B. Solder 2, S_2, arrives at III and starts serving customer C. Customer B finishes II at time 1 and immediately begins retrieving SCL at magazine III since S_2 is already there. Customer A is the last customer to finish II and moves with Soldier S_1 to I to immediately begin retrieving SCL. This arrangement has A being the last customer to depart with an overall makespan of 7 for the magazine sequence which is an improvement over the current system.

$$\boldsymbol{A} = \begin{bmatrix} 2 & 0 & - \\ - & 0 & 1 \\ - & - & 0 \end{bmatrix}, \quad \boldsymbol{D} = \begin{bmatrix} 7 & 2 & - \\ - & 1 & 5 \\ - & - & 3 \end{bmatrix}$$

2.6 Synthetic data

To avoid potential classification issues, actual SCL requirements are not used to demonstrate makespan performance differences between the current and alternate systems (Figure 3). Instead, the analysis makes use of random processing times drawn from distributions based on three classes of customers and three classes of ammunition. The customers are classified as Combat Arms (25 per cent), Combat Support (35 per cent) and Combat Service Support (40 per cent). The required munitions are classified as either Small Arms, Category I and II munitions or Heavy Munitions. Additional variability is introduced

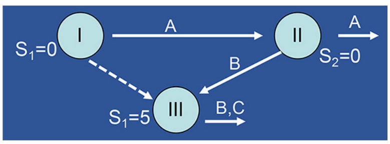

Figure 2.
Depiction of alternate system – magazine sequence {I, II, III}

via the number of magazines each customer requires for each class of munitions. The processing time for each customer/munition pairing is based on continuous triangular distributions. The number of required magazines is uniformly distributed and discrete (Tables I and II).

Travel times within the AD/ASP are modeled using a logarithmic function to populate the matrix $\boldsymbol{T}$ with t_{ij} representing the time to travel from magazine i to magazine j. Using $t_{ij} = 5\log(i - j + 1)$, where $i < j$, produces a travel time of about 28 minutes across an AD/ASP consisting of 300 magazines. An AD/ASP with 1,000 magazines requires less than an hour to traverse. The matrix $\boldsymbol{T}$ is symmetric with $t_{ij} = t_{ji}$ and $t_{ii} = 0$. Assuming that customers and Soldiers will not always take the same time to move between magazines, it is useful to vary the value of t_{ij} slightly in a manner that is proportional to the expected time. In the model, this is done by dividing t_{ij} by a random value drawn from $U(0.8,1)$ every time a value is drawn from $\boldsymbol{T}$. Using this structure, magazine i is closer to $i + 1$ than $i + 2$. The added variability may violate this structure for magazines in close proximity, but the increasing nature of travel times holds true for magazines with greater distances between them.

3. Comparison of system performance using synthetic data

3.1 Design of experiment

To better understand the dynamics of the alternate system compared to that of the current system in place, a series of simulations were conducted drawing from the distributions outlined in the previous section and scaling the number of Soldiers, customers and

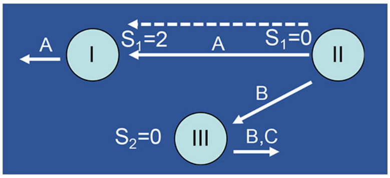

Figure 3.
Depiction of alternate system – magazine sequence {II, III, I}

Table I.
Processing time distribution

	Time at magazine (Min/Mode/Max) in minutes		
	Small arms	Category I and II	Heavy munitions
CA	40/50/60	30/50/60	60/120/240
CS	30/40/50	20/40/50	45/75/120
CSS	20/30/40	10/20/40	

Table II.
Magazine requirements

	Number of magazines to visit		
	Small arms	Category I and II	Heavy munitions
CA	1 to 2	1 to 2	2 to 3
CS	1 to 2	1	1 to 2
CSS	1 to 2	1	

magazines involved in the retrieval process. A full factorial design was used with 50 replications per treatment. There were four levels for each factor: Soldier, customer or magazine. The number of Soldiers were 5, 10, 20 or 40 per treatment. The number of magazines were 50, 100, 200 or 400. The number of magazines within the AD/ASP varied between 150, 300, 600 or 1,200. It is important to note that the customer SCL requirements were not dependent on the number of magazines within the AD/ASP. Fewer magazines resulted in a greater probability of SCL for multiple customers residing within a single magazine.

Each realization of SCL requirements was processed under both the current system where customers were considered the jobs, and the alternate system with magazines as the jobs. Under the current system, customers were sequenced via three methods: a randomly ordered list (LIST), LPT first and a genetic algorithm (GA) with the objective to minimize the makespan. The alternate system sequenced magazines using two methods: a random order (LIST) and a GA again using the minimization of the makespan as the goal. The genetic algorithm used for both systems was based on the methodology presented in Min and Cheng's (1999) article in *Artificial Intelligence in Engineering*. The GA for the current system retained the allocation of customers to Soldiers as the chromosome evaluated and mutated between generations. The alternate system used the sequence of magazines as the chromosome, as Soldier idle time may be induced by magazine sequencing.

3.2 Genetic algorithm

Most GA used for PMS have the chromosome represent the assignment of jobs to machines, each gene is a job with a machine assignment. The advantage of this approach is that as the solution space is often smaller than the intuitive approach of having chromosomes representing sequences; with the genes representing jobs in a given sequence. Once assigned, a particular machine's jobs can usually be rearranged without altering the makespan yet represent a different sequence. Unfortunately, merely assigning magazines to Soldiers in the alternate system is insufficient as the order of magazines can affect how long a Soldier or customer has to wait and therefore affects the makespan. For this reason, the GA developed by Min and Cheng (1999) was modified so the chromosome represented magazine sequences for the alternate system of SCL retrieval.

The GA approach is fairly straightforward. Initially, n random sequences of customers/magazines are generated and makespans determined; the i^{th} sequence's makespan is recorded as m_i. Each sequence is represented as a chromosome with the genes representing jobs in a particular order. While the makespan itself could be used to randomly select sequences to serve as parents, a transformation, or fitness function, was used. This was done to increase the likelihood that sequences with shorter makespans would be chosen randomly via a "roulette wheel" process. As an example, consider two sequences with makespans of 2 and 4 h, respectively. The inverse of each makespan (0.5 and 0.25) is used since shorter makespans are preferred. Then the probability a sequence will be chosen at random would be determined by $p_i = \frac{m_i^{-1}}{\sum m_i^{-1}}, \quad i = 1 \ldots n$. Consequently, the shorter sequence has a 66 per cent chance of being selected and the longer makespan has a 33 per cent chance. By using the fitness function $f_i = \alpha \exp(-\beta m_i)$ greater probability can be assigned to the more favorable sequences. The shaping parameters, α and β, determine how much makespans differ in their fitness values. Using $\alpha = 0.2 \& \beta = 0.8$, the preferred sequence is assigned a fitness value, f_i, of approximately 0.0404 while the 4 hour sequence is assigned a value of 0.0082. Now the probability of being chosen is determined by $p_i = \frac{f_i}{\sum f_i}, \quad i = 1 \ldots n$. In this example, the prefered sequence now a 0.83 probability of being chosen and the less preferred sequence as a 0.17 probability. Finding the proper shaping parameters to accelerate convergence of makespans, through multiple generations, can sometimes be challenging.

For this problem, an initial population of 16 random sequences was generated. The shaping parameters, $\alpha = 0.2$& $\beta = 0.8$, were established after an examination of results using varying values between (0,1) for both; though after 5,000 generations all parameter values tended to converge in makespan for practical purposes. The fittest sequence, max f_i, was selected to be a parent for the next generation. An additional three parents were chosen from among the remaining 15 via a roulette wheel process using the fitness function and probability assignments as previously described. From the individual probabilities a discrete distribution is developed and three random values from a uniform (0,1) distribution are used to select the remaining three parents. If a sequence had already been selected an additional random value will be drawn so that all four parents are unique sequences.

A common practice in GA is to include crossovers between parent chromosomes to generate children. As each parent is a sequence of jobs, a child created by crossover has the potential to contain the same job twice or have jobs missing. To avoid this, an iterative improvement heuristic is used. Viewed as a GA, this heuristic involves only asexual reproduction, with each of the four parents producing three children so that the next generation has sixteen candidates. Two jobs are chosen at random for each parent as bookends for the FLIP, SWAP and SLIDE operations as shown in Figure 4. The resulting population of sixteen move forward to be evaluated and selected as parents for the next generation. This iterative process is run for 5,000 generations and the fittest sequence is selected at the conclusion.

3.3 Makespan trends

The resulting makespans were used to generate boxplots similar to those in Figure 2. As expected, the makespans were inversely proportional to the number of Soldiers available. More importantly, the relative differences in makespans generated by the sequencing methods appear to vary as a function of the ratio of customers to Soldiers. The alternate system tends to perform better than the current system when there are greater than five customers per Soldier. The GA method of sequencing also appears to perform better, in both systems, under similar circumstances. The other trend observed was a decrease in the alternate system's ability to outperform the current system as more magazines were involved in the process. This could be attributed to more magazines storing a single customer's SCL, thus negating any advantage offered by having Soldiers process multiple customers simultaneously. Given enough magazines, it is feasible that each customer's SCL will not be stored with another customer's ammunition (Figures 5 and 6).

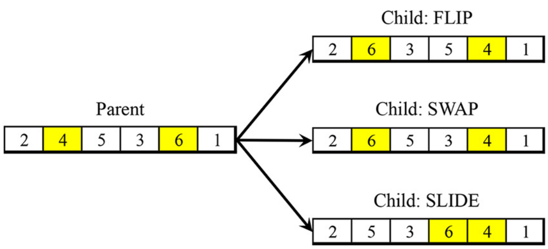

Figure 4.
Asexual reproduction of selected parent chromosome

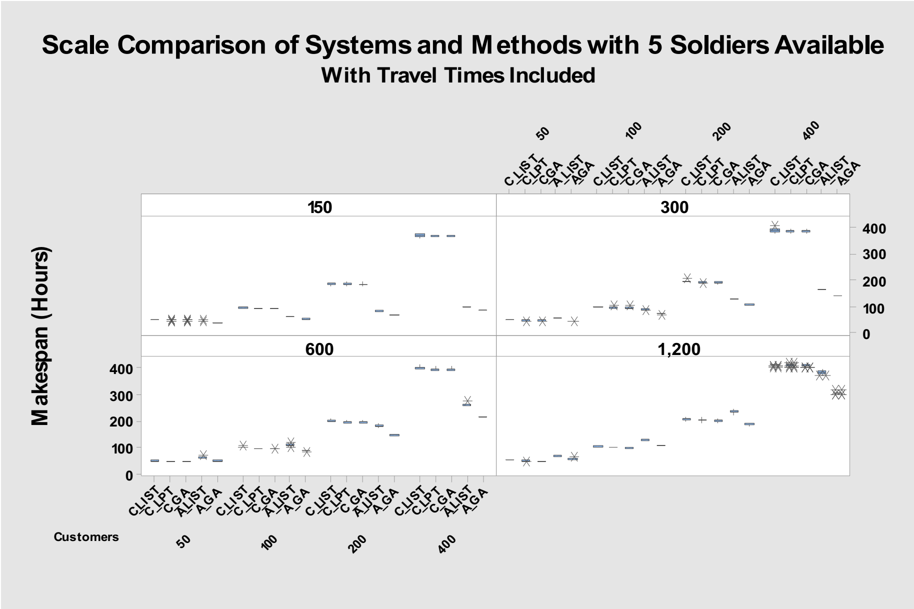

Figure 5.
Boxplots of resulting makespans with 40 Soldiers and as a function of customer and magazine #'s and methods

3.4 Relative differences between sequencing methods and systems of stored combat load retrieval

As synthetic data were used to generate the makespans, it is beneficial to focus upon the relative differences between both the systems of SCL retrieval used and the methods used to

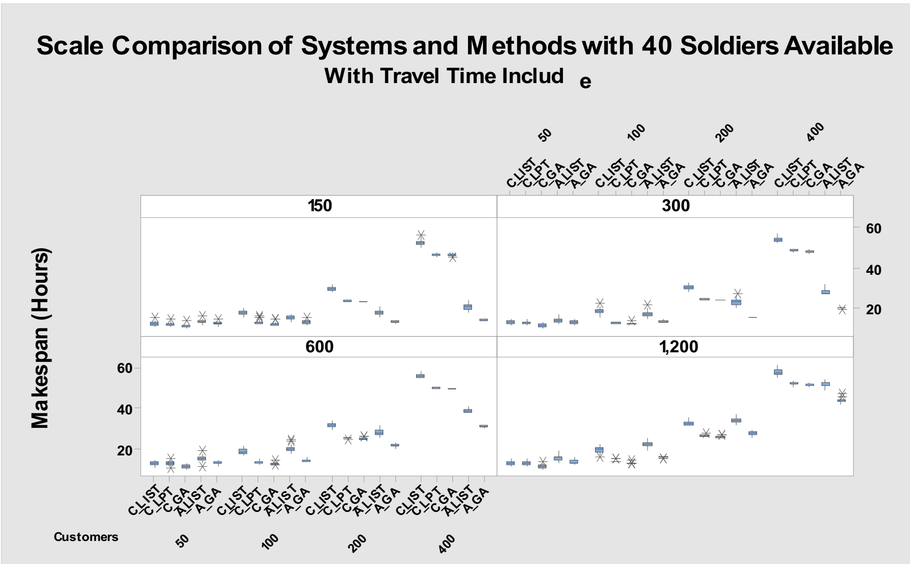

Figure 6.
Boxplots of resulting makespans with 40 Soldiers and as a function of customer and magazine #'s and methods

sequence the jobs. The relative difference, or relative improvement, method 1 over method 2 is defined as $1-\frac{\text{makespan of method1}}{\text{makespan of method2}}$. For example, if method 1 produced a makespan of 60 hours and method 2 produced a makespan of 100 h, method 1 would offer a 40 per cent improvement over method 2. Similarly, if method 1 was 100 h and method 2 was 60 h then method 1 is about 67 per cent worse than method 2.

The trends observed in the boxplots suggest that there are two factors that influence the relative differences. The first is the ratio of customers to Soldier. Using the factor levels in the original simulation, there are seven discrete levels of customers per Soldier: {1.25, 2.5, 5, 10, 20, 40, 80}. However, this grouping of negates the previous balanced design with the ratios potentially having different number of observations. The ratio 1.25 has 200 observations while 10 have 800 observations; in identical order, the observation counts are {200, 400, 600, 800, 600, 400, 200}. The second factor that appears to influence the relative differences between system performance is the ratio of customers per magazine.

The improved performance offered by the alternate system is dependent upon multiple customers storing SCL within the same magazine since it allows for customers sharing a magazine to be processed simultaneously. As the customers per magazine ratio decreases to one, it is expected that the performance of the alternate system will decrease and become similar to the current system. Under the current system, each customer is lead individually to the required magazines, thus the customer per magazine ratio is essentially one. This does not account for the size of the storage facility and subsequent effects on intra-AD/ASP travel times. During the simulations, the percentage of magazines storing a single customer's SCL was captured for each run. This continuous variable was used in lieu of the discrete customer per magazine ratio in evaluating differences between the current and alternate systems of SCL retrieval, though observations were later binned to facilitate ease of analysis and presentation.

Under the current system, Table III provides the differences between using LPT and a GA to sequence customers through the SCL retrieval process. Since customers were processed one at a time, the number of magazines involved had little effect other than affecting intra-AD/ASP travel times. For all customer per Soldier ratios, the genetic algorithm offered an improvement over LPT, with the greatest being an 11.13 per cent reduction in mean makespans compared to sequencing the customers via LPT. The percentage of improvement decreased as the number of customers per Soldier increased but remained statistically significant.

Commanders will need to determine whether the pseudo-optimal sequence generated by the genetic algorithm is conducive to operational requirements and if the effort to run the GA is worth the return on improvement. Everything depends on the composition of the ammunition company and the SCL distribution across the AD/ASP. If simulation show that

GA vs LPT (current system, with travel time)			95% confidence interval	
Ratio of Customers/Soldier	Mean (%)	SD (%)	LB (%)	UB (%)
1.25	11.13	3.12	10.69	11.56
2.5	5.74	1.89	5.55	5.92
5	2.15	0.74	2.09	2.21
10	1.04	0.39	1.01	1.07
20	0.58	0.18	0.56	0.59
40	0.29	0.10	0.28	0.30
80	0.14	0.05	0.14	0.15
Total	2.23	3.05	2.12	2.34

Table III. Current system – genetic algorithm vs LPT customer sequencing a company will require 15 h to distribute the SCL an 11 per cent improvement may not be operationally significant. Likewise, it might be practical to implement a GA sequencing if the process was expected to take several weeks.

When comparing the alternate system to the current system, only the GA methods of sequencing jobs were considered. The relative performance of the alternate system over the current system for each simulation run was grouped according to both the customer per Soldier ratio and the percentage of magazines with only a single customer. Instead of remaining a continuous variable, the latter was placed into ten bins, each representing a 10 per cent spread. Because of the structure of the original DOE, some combinations of customer/Soldier ratio and magazine fill percentages did not have any observed values. Despite this, the resulting data do highlight when the alternate system of SCL retrieval is beneficial and when it might be best to retain the current system.

It is important to note that this analysis represents synthetic data that has been binned for ease of consumption. Additional research is required to determine how sensitive the model is to parameter input and the size of the bins. Furthermore, each Ammunition Company's customer base and storage facility layout is different. With this in mind, Figure 7 is presented to demonstrate when the alternate system may be beneficial and when it may be advantageous to conduct business as usual. It is strongly recommended that planners take actual requirements and run both models to determine what may work best for a specific situation.

The results in Figure 7 are all statistically significant with a significance level of α = 0.05. When more than 90 per cent of the magazines store SCL for multiple customers, and there are more than 5 customers per Soldier, the alternate system of retrieval offers significant time savings over the current system. Most notably, the alternate system offers a 70 per cent reduction in mean makespan when there are 80 customers per Soldier and less than 10 per cent of the magazines storing a single customer's SCL. It is also clear that with 2.5 customers per Soldier or less, the alternate system appears to fair worse than the current system regardless of magazine utilization. The alternate system also becomes less desirable as a greater percentage of magazines store a single customer's SCL. Once 80 per cent or more magazines are allocated to a single customer, it appears that it is better to maintain the current system and process one customer at a time as the mean makespans of the alternate system is greater than the current system.

Without disclosing operational details of the author's experience as a commander for an ammunition company within the KTO, it would be safe to assume that some companies are in the bottom left of the table and gains can be made using the alternate system. It is also safe to assume that some companies are in the top right, where the current system produces better results. Each ammunition company in Korea is unique with respects to their customer base, storage configuration and SCL composition. Additionally, wartime conditions may bring about unexpected changes to the system. Under dire circumstances, commanders may repurpose their civilian workforce to maximize customer throughput. The ROK Army or augmentation from other US Forces may provide additional manpower which can skew the

	Mean Change from Current to Alternate (GA)	Percentage of Magazines with only a Single Customer's SCL										
		<10%	10%-20%	20%-30%	30%-40%	40%-50%	50%-60%	60%-70%	70%-80%	80%-90%	90%-100%	Grand Total
Number of Customers per Soldier	1.25	-	-	-	–10.46%	–10.48%	–11.12%	–12.66%	–13.23%	–16.97%	–18.90%	–14.90%
	2.5	-	–6.77%	–7.09%	-	–7.80%	–6.27%	–8.79%	–10.78%	–20.18%	–28.49%	–13.79%
	5	42.55%	37.31%	36.26%	-	17.19%	15.18%	–0.76%	–3.80%	–16.25%	–22.92%	8.23%
	10	62.56%	40.31%	39.10%	-	18.67%	18.23%	4.88%	0.90%	–10.61%	–17.02%	21.61%
	20	65.59%	42.20%	41.55%	-	20.95%	20.62%	6.57%	4.00%	–6.82%	-	32.21%
	40	66.91%	43.56%	43.33%	-	24.02%	22.55%	8.56%	6.60%	-	-	42.51%
	80	70.17%	45.32%	45.05%	-	25.26%	24.39%	-	-	-	-	52.59%
	Grand Total	64.01%	36.16%	36.74%	–10.46%	15.21%	13.94%	–0.63%	–2.19%	–14.80%	–21.96%	18.93%

Figure 7.
Alternate system vs current system of SCL retrieval (GA sequencing of jobs)

advantage the alternate system provides. It is imperative that planners consider each company as a separate problem to solve and not assume that one solution fits all.

4. Conclusions and future research

Supplying our warfighters with ammunition at the onset of hostilities is far too important to leave to chance. We must be willing to spend the time and energy to design and implement a system which can minimize the time required to complete an immediate call for SCL retrieval. Simulation is a valuable tool that can allow us to not only develop an understanding of how long such a process might take, but also as an aid in making improvements. Furthermore, simulation can assist by producing a timetable for unit arrival so customers are not staged en masse outside of the AD/ASP, denying the enemy a lucrative target. As demonstrated, an alternative method of SCL retrieval exists which can significantly reduce transition time if the right conditions exist.

The number of ammunition company Soldiers available to process customer units is a critical factor in determining the makespan of the process. This is evident by the upper bounds when the current SCL process is modeled as a PMS problem. If the ammunition company Soldiers focused on clearing magazines, allowing them to account for multiple customers retrieving ammunition simultaneously, it may reduce the overall time for the SCL retrieval process. As seen using synthetic data and simulations, this alternate method of retrieval is not beneficial in all scenarios. The alternate system also places more responsibility on customer units to be at the correct magazine at the proper time versus being led around by an escort. Operational planners must consider the SCL requirements of the customer units and the resources available to the servicing ammunition company to determine which system may produce the shorter makespan.

Future research will investigate additional aspects which differentiate system performance and assist planners in developing retrieval plans. By using the lower and upper bounds of the triangular distributions, it is possible to determine the best and worst-case performance for each method with the resulting range of values also being of interest. Planners may wish to assign precedence as some units may require their munitions sooner than others. The effect of precedence can be explored using the weighted sum of completion times, $\Sigma w_j C_j$, for both systems. Furthermore, the stochastic nature of processing times and requirement to determine a customer sequence in advance of combat operations, necessitate developing a method to evaluate the robustness of any given sequence. Finally, the alternate system would benefit from the ability to reschedule customers online, during the SCL retrieval process, as this system requires far more coordination among customers and the ammunition company.

With current peace initiatives, the threat of combat operations on the Korean Peninsula may diminish but it is likely that the US Army will again find itself in a similar situation one day. Forward deployed troops permanently stationed within a host nation will be required to store their ammunition during peacetime. The quantity and type of munitions required for combat operations will necessitate storage on an established ammunition depot, or ammunition supply point, where it will be collocated with munitions allocated to other units. We must develop concise, efficient and tactically sound retrieval schedules for these units to obtain their combat loads as quickly as possible. They can transition to combat on a moment's notice without much of their logistics, trusting it will catch up with them, but they cannot deploy without ammunition. This is the "longest pole in the tent" for forward deployed units attempting to transition from relative peace to active combat operations.

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