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Improving the Efficiency of Military Vehicle Outload and Deployment

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Abstract: The United States military must maintain the ability to rapidly deploy, world-wide, under severe time constraints. As a result, units and organizations have developed standardized, documented processes and procedures to quickly deploy personnel, equipment, and supplies. This research examines a typical military vehicle outload process, models the process with a discrete-event simulation, and identifies opportunities to increase process efficiency. The recommended improvements are incorporated within the simulation to identify the impacts of the changes. Model analysis reveals that an increase in a critical resource (i.e. vehicle inspection teams) can significantly reduce the time required to process a 350-vehicle fleet. Additionally, automating the hazardous material (HAZMAT) documentation and vehicle weight and center of balance computations resulted in time savings, although less significant. It is possible to implement these two automated activities across all installations, further improving deployment operations. With only minor modifications, the presented model can be adjusted to replicate other installation deployment processes and can have significant impacts on how the U.S. Army and U.S. Air Force deploy equipment.

Keywords: Discrete-Event Simulation, HAZMAT, Vehicle Deployment, Process Optimization

1. Introduction

Every day, the United States faces various threats from across the globe. In order to preserve its security, the Department of Defense is given the responsibility of maintaining military units that are postured to deploy forces at any time in order to defeat any threat. In this type of situation, the National Command Authority must have the confidence that troops are ready to deploy, fight, and win as quickly as possible. To achieve this desired confidence level, in 2008, the Department of Defense created a unit whose sole responsibility it is to remain ready-to-deploy at any time (Pernin, 2016). The DoD named this organization the Global Response Force (GRF) and selected an Army Division to supervise its training and preparedness. When called upon, the GRF has just hours to mobilize all soldiers and get its equipment ready to deploy via air, ground convoy, rail, or sea. It remains of utmost importance to conduct these deployment activities as quickly as possible, therefore even minor inefficiencies in the outload process can have strategic impacts or result in U.S. and Allied casualties. To identify capability gaps in their current process, the leadership of the GRF requested an analysis of the overall efficiency of the operation. A team of researchers from the Department of Systems Engineering at the United States Military Academy conducted multiple site visits, observing training exercises where the GRF units conducted mock outloads of soldiers and equipment. Based on data collected, it was evident that the current process used to aerially deploy vehicles had room for improvement. This study specifically examines the GRF's process for deploying vehicles and equipment via cargo aircraft, discusses the means in which the process was simulated, and makes recommendations for how to improve the process in the future.

2. Background

2.1 Overview of the Global Response Force

The Global Response Force (GRF) is composed primarily of active duty Army soldiers and their organic equipment. Most of these forces are permanently stationed at Fort Bragg, North Carolina. The unit leadership maintains a "playbook" of GRF options, varying in size and composition, that can be called upon based on the threat that is faced. These units are dedicated to the GRF mission which is treated as a strategic asset, managed by the Joint Chiefs of Staff and reserved for use in extreme circumstances where power must be projected quickly. While serving on the GRF, soldiers and units are constantly working to decrease the amount of time it takes from notification (N-Hour) to deployment.

At its largest, the GRF can include over 5,000 soldiers, more than 400 pieces of equipment, and hundreds of supply storage containers. The Joint Chiefs of Staff selected Fort Bragg as the location for the GRF, in part, because it is the only aerial port of departure in the continental United States for the U.S. Army (S. Wykel, interview with 46th ASFBN, June 31, 2019). This means that the facilities and personnel located at Fort Bragg can perform all tasks required to deploy soldiers and equipment directly overseas. While this study focuses on the movement of equipment via air, it is important to note that the GRF also has the capability to move equipment via rail or ground convoy, usually to ports where the equipment can then move on a vessel.

The competitive edge that the GRF provides the National Command Authority lies in its speed. The GRF is designed to be anywhere in the world within hours of being notified. Because of this, the infrastructure on Fort Bragg, processes, standard operating procedures, and the robust package of supporting units must all operate in unison to ensure the GRF can deploy on short order.

2.2 Deployment Process

Given that units serving as part of the GRF are always ready to deploy, a standardized sequence of events exists to ensure that units accomplish all required tasks in an organized manner. This sequence, called the "N-Hour" sequence, is used to guide all operations from the time the GRF is notified it will deploy until the time the aircraft take-off from Fort Bragg. A major component of this sequence of events is the preparation of vehicles and trailers that the GRF commander determines are needed to accomplish the impending mission. These vehicles and pieces of equipment are separated into two categories: A-Echelon and B-Echelon. A-Echelon equipment is anything that will be airdropped out of an aircraft just prior to soldiers conducting a parachute assault onto an objective. A-Echelon equipment is usually the most mission critical items that the commander needs to access immediately. This typically includes several trucks with fully automatic and anti-tank weapons systems, command and control vehicles, as well as artillery pieces. The amount of equipment airdropped as part of A-Echelon is traditionally kept to the minimum required to enable the GRF to gain control of an area and prepare an airstrip for secondary forces and equipment to be brought in on aircraft. This secondary load of equipment that is air-landed is called B-Echelon; everything the commander needs to sustain operations over an extended period. The composition of the B-Echelon equipment is mission dependent and can range anywhere from 30 to 400 pieces of equipment.

During the N-Hour sequence, A-Echelon equipment is prioritized to go through all steps necessary to make it ready to load on an aircraft in preparation for an airdrop. Much of this equipment is pre-rigged with parachutes and staged in a facility at Fort Bragg year-round. Because of this, the resources required to prepare A-Echelon equipment is not a significant strain on operations. The B-Echelon equipment, however, is not pre-staged and therefore presents a significant logistical challenge to the GRF. Upon notification, the deploying units from the GRF must begin executing the tasks on the N-Hour sequence to ensure their vehicles are ready to load aircraft in time.

Figure 1 depicts the process that the vehicles must navigate to be certified for loading on Air Force planes. Several factors require deliberate calculations and inspections to ensure that the fully-loaded aircraft are safe to fly. For example, the center of gravity for each vehicle must be calculated and annotated, which then dictates the way it is secured in the aircraft. Historically, miscalculations have led to vehicles coming loose on takeoff; dramatically changing the center of gravity of the aircraft as a whole and leading to a catastrophic crash of the plane (National Transportation Safety Board, 2015). The focus of this research is on the Arrival / Departure Airfield Control Group (A/DACG), the penultimate step before the vehicles are ready to load. Upon arrival at the A/DACG, the vehicles have passed inspection by their respective units and have received their ammunition.

Figure 1. Vehicle Flow During Outload Process

As seen in Figure 2, to be deemed ready to load, a vehicle must pass a pre-joint inspection, determine center-of-balance through measuring dimensions and passing over a scale, and finally, pass joint inspection (JI). The title "joint" is used to describe these inspections since doctrinally whenever two or more components of the Department of Defense work together, it is a joint operation. In this instance, Air Force personnel inspect Army equipment to determine airworthiness on Air Force aircraft.

Important to note is that the pre-JI is conducted by contractors rather than Air Force personnel. These civilian personnel use the same checklist and, if executed correctly, provide the deploying Army unit one last chance to identify issues before the formal JI by Air Force personnel.

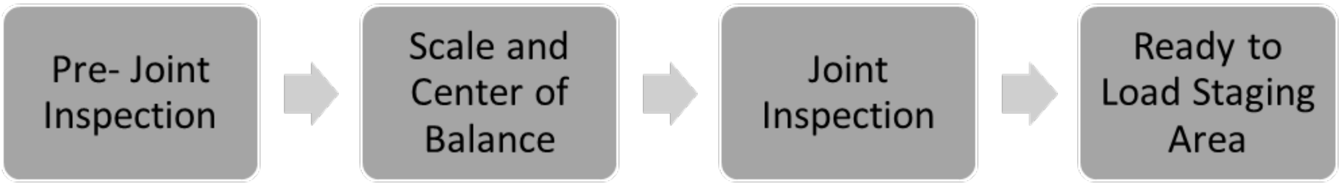


Figure 2. Vehicle Flow During Outload Process

3. Observations and Possible Opportunities for Optimization

3.1 Observations of Current Process

Despite the frequency of the rehearsals done surrounding this process and the complete transparency of the expectations of the inspection teams, the A/DACG process is consistently plagued with bottlenecks with negative impacts on the time required to process an entire vehicle fleet. Observations of several outload exercises, in addition to historical data gathered by the unit from previous exercises, revealed that the largest contributor to excessive vehicle fleet processing time was vehicles failing either the pre-JI, the JI, or both. While some failures were due to maintenance or improper shoring (the process by which wooden bracing is used to further secure loads inside an aircraft), the most common issues were incorrect Shipper's Declaration of Dangerous Goods (SDDG) forms, improper declaration of hazardous materials (HAZMAT), or errant military shipping labels (MSL).

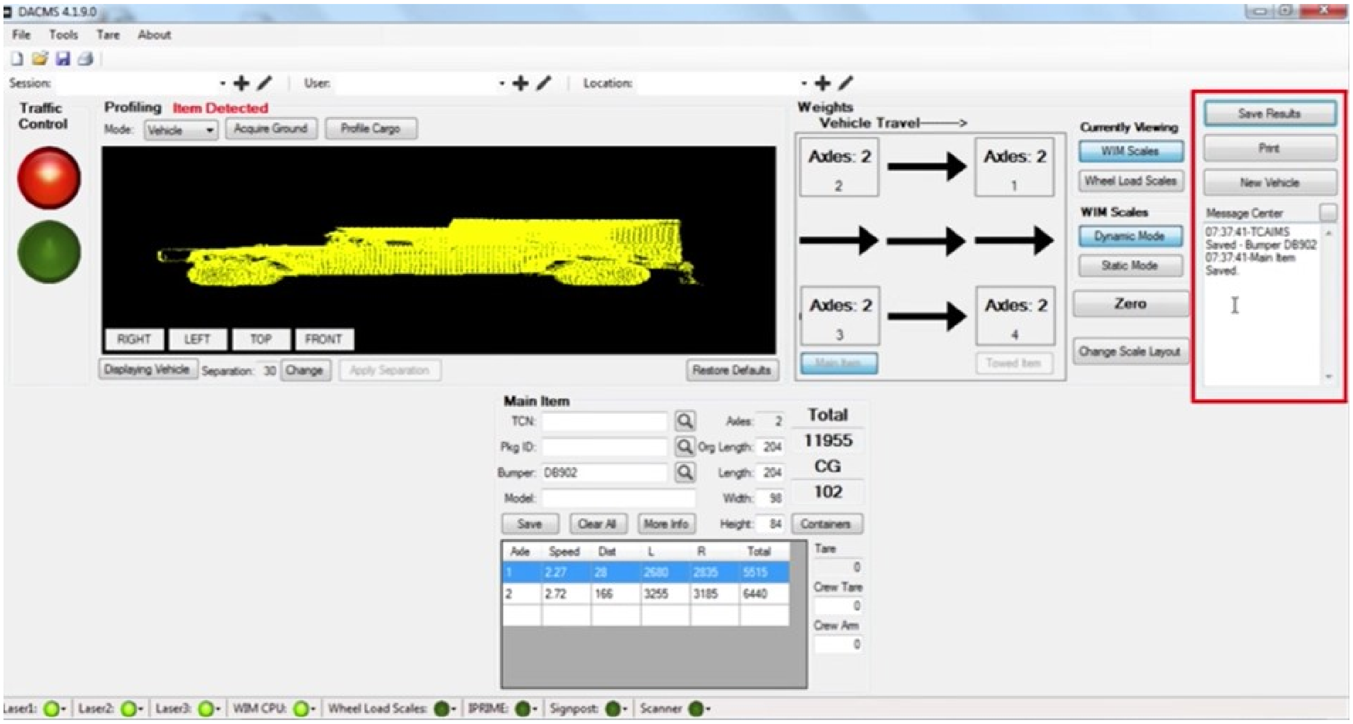
As previously discussed, equipment must be properly labeled and documented to ensure that they are secured in the aircraft appropriately and that incompatible hazardous materials are not stored inside the same aircraft. The issues with the SDDG and Hazardous Declaration (HAZDEC) were often due to information not being correctly filled out or referenced from the governing document (Department of the Air Force, 2018).

An additional inefficiency observed in the process was the calculation of size, weight, and, eventually, center-of-balance of the vehicles. The current process requires a vehicle to drive onto a scale to get its weight and then several individuals capture the dimensional measurements. These measurements are then communicated to a supervisor who manually calculates the center-of-balance for the vehicle. This process is slow, inefficient, and error prone given that technology-based solutions exist or could be quickly generated.

3.2 Possible Opportunities for Optimization

Several opportunities to gain efficiency in the process were observed by the researchers. First, the SDDG, HAZDEC, and MSL all contain overlapping information. By automating the completion of these forms, duplication of effort can be reduced, saving time and reducing the potential for error. Additionally, by text mining the manual governing the information required on the form, auto-population of certain items can save time and reduce the potential for user-generated errors.

Secondly, the measuring and center-of-balance calculation is an opportunity for improvement since there is significant potential for human error and manual calculations result in slow processing times. The Deployable Automated Cargo Measurement System (DACMS), Figure 3, was built exclusively to reduce error and processing time (Larsen, 2013). Several installations are already employing the DACMS with significant time savings and error reduction (Harrower, 2013). Two DACMS already are operational on Ft. Bragg but are not currently located at the A/DACG nor are they utilized during a GRF outload. Both the automation of the forms and leveraging the two DACMS can generate potential time savings and reduce inspection failures.



Mode: Vehicle

Separation: 30

Main Item

TCN:

Pkg ID:

Bumper: DB902

Model:

Axles: 2

Org Length: 204

Length: 204

Width: 98

Height: 84

Total
11955

CG
102

Axle	Speed	Dist	L	R	Total
1	2.27	28	2680	2835	5515
2	2.72	166	3255	3185	6440

Tare: 0

Crew Tare: 0

Crew Arm: 0

```
07:37:41-TCAIMS
Saved - Bumper DB902
07:37:41-Main Item
Saved.
```

Figure 3. DACMS Display (Intercomp, 2016)

Finally, the actual time to move vehicles from their stored location, process them through required stations, and stage them at the airfield is another opportunity to gain efficiency. Currently, all vehicles must travel with the other vehicles which will be on the same plane for deployment (a chalk). Thus, if at any point in the process one vehicle breaks down or is frustrated with a deficiency, all other vehicles in that chalk cease making progress. This problem compounds when subsequent issues continually halt the progression of the group. In the model presented in the next section, multiple other business practices were tested to determine if there is a more efficient way to process the vehicles that can save time in the aggregate.

4. Model Development

During observations of several loadout exercises, potential opportunities to gain efficiencies were noted and were described in the previous section. However, since each loadout exercise is slightly different, is performed by a different unit, and has other competing training objectives, it is difficult to test the potential time reduction techniques on subsequent exercises. Therefore, the process outlined in Figure 2 above was modeled as a discrete-event simulation using Pro-Model. The model allows for the analysis of bottlenecks in the existing system flow, opportunities to optimize the mobilization process, and observe the effects of modifying resource allocations. Since the process is gated, where steps must be completed in a sequential order, bottlenecks naturally occur; as such, the model provides insight into where they occur and quantifies the impact of allocating resources to alleviate that delay.

4.1 Model Overview

Figure 4 displays the overall architecture of the model. The model receives inputs from a Microsoft Excel file that is intentionally editable by any user. The Excel workbook is divided into tabs, with the first tab containing the vehicle list which lists each vehicle going through the process as well its vehicle type, bumper number, nomenclature, and the chalk to which it belongs. The second tab contains the chalk movement list, which gives the time that the chalk is expected to depart from the Marshaling and Staging Area (MASA) to subsequent activities. The third tab contains the processing times required at each processing location. These times are defined as uniform distributions, with the inspection and measurement times being a function of the vehicle type. This tab also contains a table that details the probability of an issue occurring during pre-JI and JI (Spivey & Sawicki, 2017).

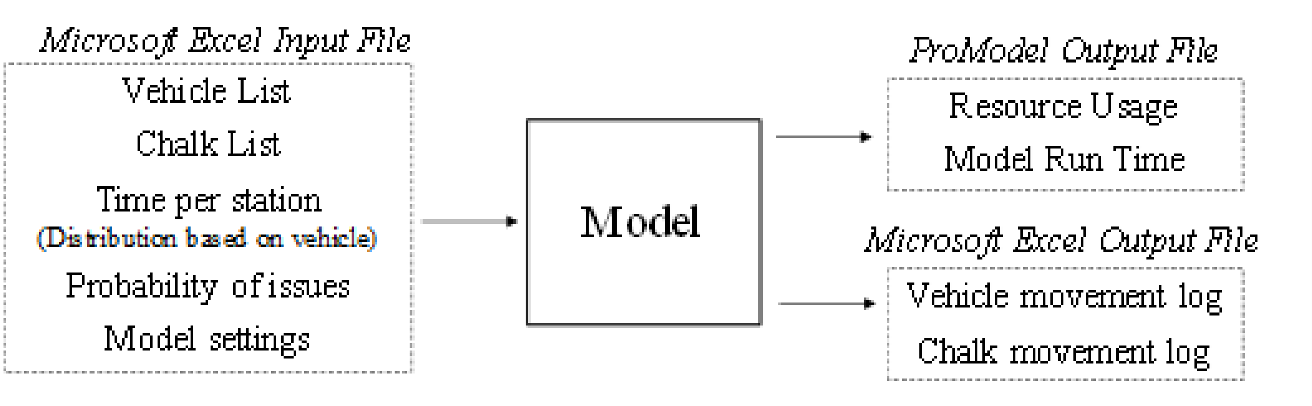


Figure 4. A/DACG Discrete Event Model Architecture

The table also includes the amount of time required to remediate the issue and whether or not the vehicle must go to a frustrated cargo area to resolve it. The final tab provides a series of toggles that a user can modify. These toggles include:

- Vehicles move as chalks or independently
- Automated HAZDEC to reduce probability of human-errors
- Use of DACMS for measurement
- Number of Pre-JI Teams
- Number of JI Teams

The model receives the data included within the workbook and executes the simulation. Figure 5 displays an image of the model running. The gray boxes indicate the chalks or grouping of vehicles and tan boxes indicating the individual vehicles. Since the processing times per station and probability of an issue are stochastic, the model must be run multiple times to ensure an accurate distribution of the output variables. The primary output variable of concern is the total time for a brigade-size element to go from the MASA to the ready-to-load line. To achieve a 95% confidence interval on that variable, the model is run 30 times.

Figure 5. A/DACG Discrete Event Model

ProModel generates an output file that provides analysis into the resource constraints and availability of different stations in the model (Harrell, et al., 2000). It also tabulates the total time required for all the vehicles to move from the MASA to the ready-to-load line. However, the ProModel output viewer does not provide the granularity of vehicle movement times nor does it log vehicle issues. As such, a subroutine was added into the model to log the movement of each individual vehicle and all chalks, in addition to noting if the vehicle experienced any issues. This subroutine outputs the data to a CSV file.

4.2 Model Process Flow

The model consists of the following locations: MASA, Ammunition Issue, AHA, Scales, JI, Frustrated Cargo, and Ready Line (Figure 5). The vehicles are all modeled as individual entities. The chalks are modeled as containers that absorb vehicles, move from one location to the next location, then releases the vehicles into that location. This construct captures the constraint that vehicles cannot move onto the next stage until all vehicles in the chalk are ready to move on.

At the initiation of the model, all units are located at the MASA. Either at a pre-determined time, or when space is available at the subsequent stages, the vehicles are grouped into a chalk and moved to ammunition issue. The chalk spends a certain amount of time at the ammunition issue based upon the number of vehicles in the chalk and a random number based on a uniform distribution defined in the input file.

The chalk then continues to the AHA where it unloads the vehicles so that they can go through pre-JI. Many of the vehicles will experience some sort of issue, with certain issues resulting in the vehicle having to go to the frustrated cargo area to be resolved (other issues are able to be fixed on the spot). Once all the vehicles in a chalk have completed pre-JI and all issues are resolved, the chalk can group the vehicles and move to the measurement station, where the vehicles are then ungrouped. The vehicles move through this station independently. Once all vehicles are measured in a chalk, the chalk groups all the vehicles and moves them forward for JI. The chalk releases the vehicles, and they undergo the JI process which is similar to the pre-JI process. Once all the vehicles in the chalk are complete, they are re-absorbed into the chalk and moved to the Ready Line, at which point they have completed all the steps in the model.

4.3 Verification and Validation

In order to ensure that the ProModel simulation accurately models the A/DACG process, the model is validated and verified (Sargent, 2013). The model was run for a small-scale exercise that only had 6 chalks and 25 vehicles, as opposed to a full brigade which can have upwards of 400 vehicles. The model found results that were similar to the times experienced for that exercise. Additionally, the model predicted a significant choke point at pre-JI, which was observed during these training exercises. Finally, the full brigade-level model was run for selected stakeholders, who identified that the model behaved as they would predict based on experience.

5. Results and Analysis

5.1 Number of Inspectors

The model was run with the standard resource allocations, equipment, and procedures that are currently being used at the A/DACG. Overall, the model predicted that the average time over 30 runs was 54.60 hours to process 397 different vehicles in 44 chalks. This model is based on the number of pre-JI and JI inspection teams that were available for the small-scale exercises. The model showed a large back-up at the AHA that resulted in vehicles being delayed in leaving the MASA. This backup was found to be due to a limited number of pre-JI inspectors and many issues that had to be resolved before the vehicles could move on. Due to the bottleneck at the pre-JI station, the scales and the JI stations did not experience any back-up. However, this bottleneck is related to the number of pre-JI inspectors. In a real-world, brigade deployment, the number of pre-JI inspectors, as well as JI inspectors, could be augmented.

As such, the model was modified to account for the possible addition of pre-JI and JI inspection teams, with the results shown in Figure 6. Since the additional inspectors can be placed at either the pre-JI or JI stage, the model was run with the additional inspector teams being placed at the pre-JI station, the JI station, or at combinations of the two. The results found that placing the new inspectors at only the JI station did not change the model significantly since the model run-times were set by the bottleneck at the pre-JI station. However, placing the additional inspectors only at the pre-JI station resulted in a new bottleneck at the JI station. Therefore, the additional inspectors should be allocated to both stations. Since the JI station only has to handle vehicle and paperwork issues that the pre-JI teams missed, the pre-JI inspection takes longer than the JI inspection. The model found that adding an equal number of pre-JI and JI teams resulted in underutilized JI teams, and that optimally, there should be one or two more pre-JI teams than JI teams.

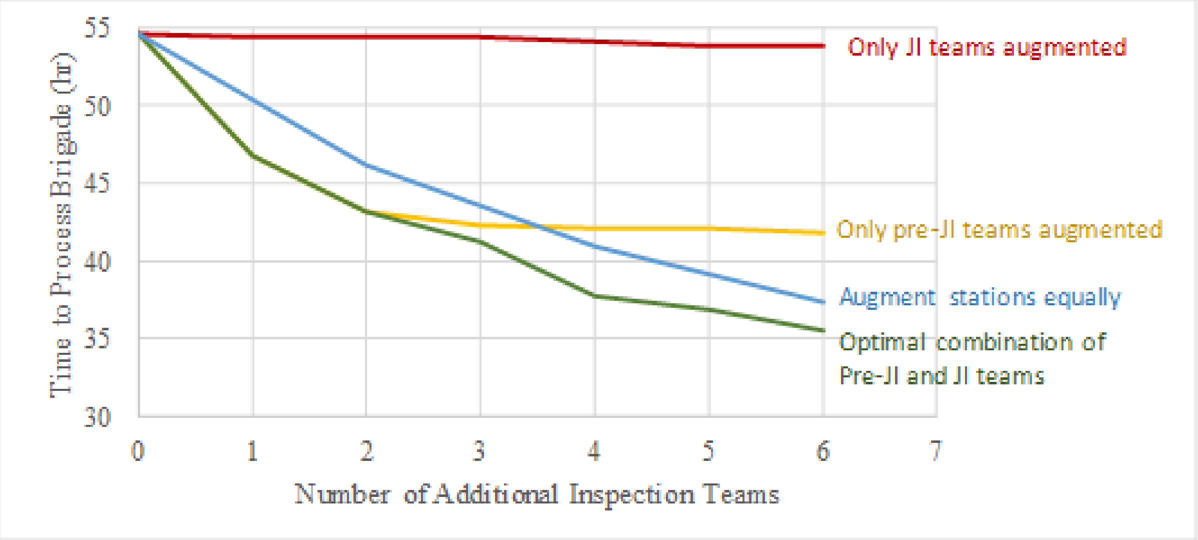


Figure 6. Examination of Model Results when the Number of Pre-JI and JI Teams are Increased

5.2 Changes in the Processes

The overall goal of the model was to identify time improvements that result from changes in the deployment process. Three changes were identified in Section 3.3 - automating the HAZDEC, incorporating the DACMS, and relaxing the chalk integrity requirement. With these three design factors, a 2^k design matrix allows for the assessment of implementing each of these changes. The model was run at each design point for the current number of inspectors, an increase of five inspection teams (i.e. where diminishing returns set-in), and with an unconstrained number of inspectors. The results are shown in Table

1. Each column in the table indicates a different design point. For example, the fifth column indicates the deployment time in hours with a DACMS and automated HAZDEC.

Table 1. Vehicle Fleet Processing Times when Varying Design Factors (DACMS, HAZDEC, Chalk Integrity)

DACMS	-	*X*	-	-	*X*	-	*X*	*X*
Auto HAZDEC	-	-	*X*	-	*X*	*X*	-	*X*
No Chalk Integrity	-	-	-	*X*	-	*X*	*X*	*X*
Base	54.6	53.6	51.0	52.0	50.0	48.9	51.8	48.1
+5 inspection teams	37.4	35.6	35.6	33.9	33.5	32.1	33.7	31.3
Unconstrained	33.7	22.2	33.5	31.0	21.4	30.7	20.6	19.7

Without any additional inspection teams, the implementation of all three changes results in a savings of 6.5 hours. The DACMS does not necessarily provide a significant benefit since the bottleneck at the pre-JI station results in no queues for weight measurements. However, the automating of the HAZDEC and the relaxing of chalk integrity each result in approximately a 3-hour savings for the overall process. As the number of inspectors increases to five, the constraints at the pre-JI and JI stations are alleviated, resulting in a new backup at the scale station. In this instance, the use of the DACMS has a larger impact in reducing the overall model time. Since the bottleneck now exists at the scales, the automated HAZDEC does not provide a significant savings on its own; however, coupled with the DACMS, the two provide a 4-hour savings. Additionally, relaxing chalk integrity further reduces the time in the model, since chalks would not have to wait for all vehicles to be ready to proceed through the measurement station.

In the unconstrained case, where there are enough inspectors at both the pre-JI and JI stations, the DACMS has a very large impact on the model since the largest bottleneck in the process is now the measurement station. Further, by alleviating the requirement for chalk integrity in conjunction with using the DACMS results in a large time savings.

5.3 Recommendations

The model predicts that the processing time for a brigade reduces from 54.6 hours to 19.7 hours by adding a large number of inspectors, automating the HAZDEC, adding the DACMS, and removing the requirement for chalk integrity. However, all of these additions may not be realistic considering resource constraints. For a real-world deployment, the inspection teams can be expected to increase by up to five additional teams that can be split amongst the pre-JI and JI stations.

In that situation, adding the DACMS provides a savings of approximately two hours; however, the addition of the DACMS allows for flexibility and reduces the bottleneck effects at the weighting station if more inspection teams become available. Additionally, automating the HAZDEC provides an additional savings of two hours. Automating the HAZDEC is a low-effort project that will reduce paperwork errors and provide a time savings. Though relaxing chalk integrity could further reduce the mobilization time by two hours, the model was not able to capture the secondary effects of removing chalk integrity. The reduction in command and control could potentially offset any time savings.

Model analysis indicates that the deploying force should ensure that there are multiple pre-JI and JI teams that are on call to augment their teams with a short notification. Additionally, the deploying force should invest in automating the HAZDEC; if funds are available, the implementation of the DACMS would provide additional benefits and flexibility.

6. Conclusion

This research examines a typical military vehicle outload process, models the process with a discrete-event simulation, and identifies opportunities to increase process efficiency. The recommended improvements are incorporated within the simulation to identify the impacts of the changes. Model analysis reveals that an increase in a critical resource (i.e. vehicle inspection teams) can significantly reduce the time required to process a 397-vehicle fleet. Specifically, the addition of five pre-JI teams can reduce processing time by 17.2 hours. Automating the HAZDEC can reduce processing time by approximately 3.6 hours. Utilization of the DACMS to automate vehicle weight and center-of-balance computations can save approximately one hour. More importantly, automating this activity frees up a resource that can be utilized to augment the pre-JI teams; the primary bottleneck in the overall process. When employing these improvements in combination, a time savings of 23.3 hours can be realized. These savings make available valuable time that can be used to conduct planning, mission preparations, or mission rehearsals. Automation of the HAZDEC, vehicle weight and center-of-balance calculations can potentially be implemented across other installations, further improving deployment process efficiency. The discrete-event simulation model presented can be adjusted, with only minor modifications, to replicate other installation's deployment processes, providing a means to analyze and improve processes and procedures.

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