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Simulating Army Rail Yard Operations at the Port of Bremerhaven

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Abstract: To maintain the United States military's capability to deploy rapidly across the globe, logistical planning tools, simulations, and models enhance leaders' decision making abilities. This research develops a discrete event model designed to simulate military operations within a railyard in order to support the Engineer Research and Development Center's (ERDC) Planning Logistics Analysis Network System (PLANS). The research team chose the Port of Bremerhaven, Germany as a case study due to its relevance to current military operations, granting us access to timely data and stakeholders with recent operational experience. The discrete event simulation (DES) utilizes stochastic processes and multiple layouts in order to analyze the amount of time it takes to move varying amounts of cargo and vehicles and identify potential bottlenecks in the operation.

Keywords: Rail, Military, Discrete Event Simulation

1. Introduction

Since there is no sure way of predicting where or when the next military campaign or natural disaster will occur, the United States' military needs to be prepared to deploy at a moment's notice to any area including anti-access/area denial areas (Bednar et al., 2016). In order to improve the deployment process, it is crucial that the U.S. military is able to effectively plan logistics lines of communication. At the Engineer Research and Development Center (ERDC), researchers have started a new initiative, an online program called Planning Logistics Analysis Network System (PLANS). PLANS will be used to analyze a set of early entry alternatives to optimize effectiveness and efficiencies while adapting to environmental conditions, allowing users to compare each alternative (Bednar et al., 2016).

Rail is a crucial logistics method used by the United States Army to move large amounts of equipment, vehicles, and supplies from military installations to points of interest during both peace-time and combat operations via military and commercial railways for four functions: rail operation, maintenance of way, maintenance of equipment, and train control (FM 4-01.41). However, due to the size and nature of rail operations, they quickly become complicated to plan and execute.

By creating a discrete event simulation (DES) model of the rail operations at a commonly used port, future logistics planners will be able to compare port layouts, capacities, and resources prior to deployment. The chronological nature of DES explains future queues well and helps to identify bottlenecks with greater discretion than other simulation methods (Allen, 2011, p. 45). The model will identify bottlenecks in order to maximize efficiency of U.S. Army rail operations and better estimate early on courses of action for rail through its integration with PLANS.

1.1 Background

The U.S. Army is currently deployed around the world. One of the most recent examples of the use of rail operations occurred in the Port of Bremerhaven, Germany which is a large multimodal port. The research team was able to use real world data from a 2017 U.S. Army deployment through Bremerhaven as input data for our model. Many of the units currently deploying into Europe pass through the Port of Bremerhaven, making the data relevant to today's operating environment and an exemplar for future deployments. This research integrates the 2017 deployment data with the actual layout and resources available at the Kaiserhafen terminal of the Port of Bremerhaven. DES allows users to analyze railheads with different layouts and available resources.

1.2 Problem Statement

The goal of this paper is to contribute an analysis of rail capabilities to ERDC's PLANS initiatives. The research team will develop a discrete event model that accurately simulates military operations within a railyard to analyze the amount of time it takes to move varying amounts of cargo and identify potential bottlenecks in the railroad transit system.

2. Methodology

2.1 General Assumptions, Constraints, and Limitations

In order to conduct this research, the research team had to make several assumptions. First, the team assumed the information from stakeholder interviews will provide a more accurate model than taking information from Army Field Manuals. Additionally, the team assumed rail operation procedures are similar across all rail heads. The team is constrained to focusing on Outside Contiguous United States (OCONUS) locations as opposed to Contiguous United States (CONUS) locations. This poses some difficulty because the laws and regulations differ between OCONUS locations, and there is limited information about how operations work at each location. The team is primarily limited by the fact that no one has ever conducted a rail movement operation or witnessed one in person, limiting their knowledge to online videos, interviews, and Army Field Manuals.

2.2 Data Collection

The team began collecting data by conducting multiple interviews with rail subject matter experts including both military personnel and civilians. These interviews were conducted via phone and email. Questions given to experts were separated into three categories: operation, technical, and data. The operational questions were geared towards experts with a top level view of rail operations, the technical questions were geared towards experts with a simulation background, and the data questions were geared towards experts with on-the-ground experience.

The first person the research team approached to gain an understanding of rail operations was a logistics battalion commander within the European Command Area of Responsibility who stated that his movement control teams (MCT) run the staging area in Kaiserhafen and facilitate onward movement (W. Kost, personal communication, Oct 23, 2017). Additionally, he advised the team that we should model a brigade combat team (BCT) since it is the typical size of the unit that has traveled through in the past. The team also gained significant information from company grade officers who have experience in planning and executing rail operations. They provided concepts of operations from past CONUS rail operations and values that could be used to create distributions for input variables; all of which could affect the overall throughput in a railyard. One of the officers highlighted bottlenecks that he noticed during his deployment through Kaiserhafen and helped explain the rail off-loading process (M. Liles, personal communication, Oct 11, 2017).

Alexander King was a civilian that conducted a study called *Rail Development Study – Fort Stewart, Georgia* (King, 2015, p. 30). The study contained a flow chart that provided the team with a greater understanding of how a rail car should be loaded during rail operations. Additionally, a terminal manager at the Port of Bremerhaven, Germany has been crucial for understanding exactly how rail operations are conducted. He provided the team with information about the equipment and estimations that could be used to create distributions for input variables (M. Korn, personal communication, Nov 2, 2017). The terminal manager also provided the team with a rail build sheet that is used by Army units at all echelons deploying through Europe. The rail build sheet contains cargo assignments and train characteristics for each mission. In order to incorporate the rail build sheet, it was modified so that information is directly pulled from the rail build sheet and placed into an input sheet that is read into the model.

2.3 Model Development

The scope and structure of the model is based on the desires and recommendations given to the team by ERDC. They specified that the team was to simulate military rail on-loading processes that can be easily modified to study multiple rail yards. The model begins with the first mission's vehicles and cargo being randomly populated in the various staging areas and ends once the final mission's train has left the yard. Various flow charts were acquired in order to get a better understanding of the actual processes behind rail operations. Figure 1 is a routing table that was adapted from Mr. King's flow chart and validated with the terminal manager at Bremerhaven to ensure the process was consistent with OCONUS operations. Similar to Mr. King's flow chart, the model calls a vehicle to the on-loading ramp which then drives out to the furthest available car to be tied down. The model does not currently have a function to inspect the vehicles for improper tie-downs since it is assumed that tie-downs and inspections occur simultaneously. Once all the vehicles have been loaded and tied down, the train departs the yard.

Off-loading procedures are not accounted for in the model due to time restrictions but can be easily incorporated due to the use of loading statements.

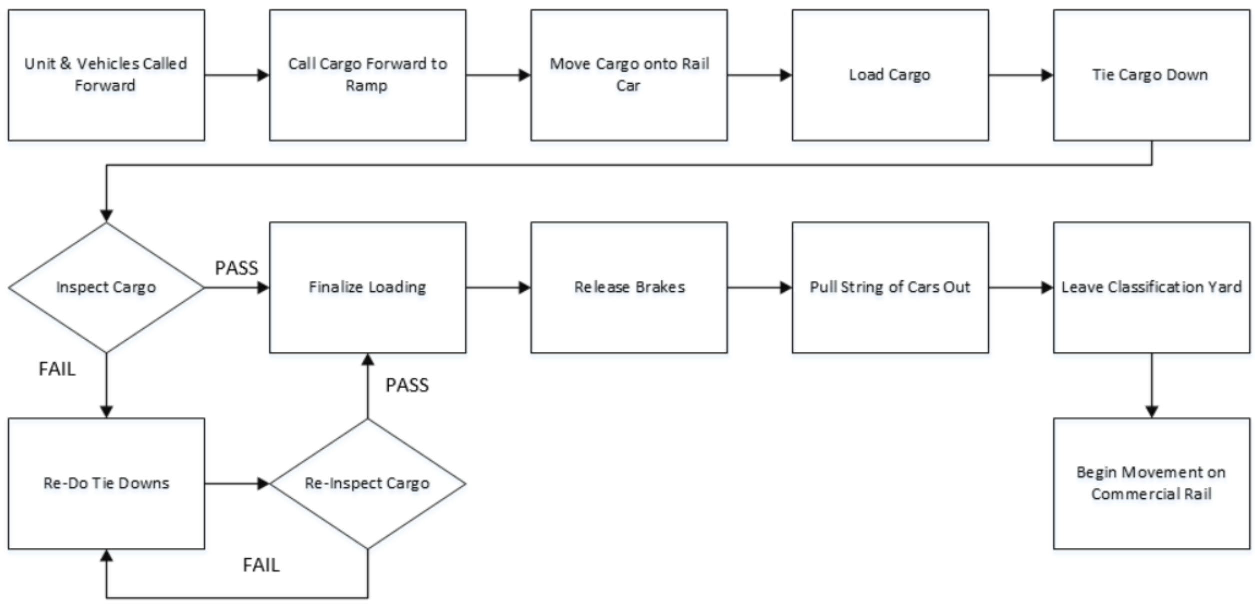

Figure 1. Adaption of a model used by SDDC in a rail deployment study on Fort Stewart, Georgia (King, 2015, p. 30).

2.4 Model Assumptions

In order to create the model, the research team had to make several assumptions. Railcars must be split between operational spurs at the start of the simulation due to the maximum number of track locations per spur (currently 170). Based on stakeholder analysis with a terminal manager at Bremerhaven, trains are normally split between available spurs for the purpose of on-loading. In order to account for this, the model orders 15 railcars to each operational spur at the start of each mission.

The model currently uses a 60 foot railcar for all scenarios. Preliminary experiments showed that differing the size of railcars did not affect the completion time. Common railcars the Army uses vary between 40 and 80 feet. The model assumes a 60 foot railcar provides an accurate estimate.

Based off stakeholder analysis, a certain percentage of vehicles are assumed to be disabled before the simulation starts due to complications arising from batteries being left on during shipping. Currently, 20% of all tracked and 20% of all wheeled vehicles are disabled at the start of the simulation but can be modified in the input sheet.

The model incorporates two vehicle types (wheeled and tracked) and a shipping container object. FM 4-01.41 describes tie-down procedures by vehicle type, but does not provide times. Surface Deployment and Distribution Command (SDDC) guidelines provide tie-down times that are based off a vehicle's size (small, medium, or large). In order to translate the SDDC tie-down times to the Field Manual's vehicle types, the model assumes that containers are small, wheeled vehicles are medium, and tracked vehicles are large.

Finally, scenarios are run under the conditions of a large port where longshoremen are assumed to be trained contractors. Untrained workers normally take 30 to 40% longer to complete tie-downs, however, the model does not account for this condition (King, 2015). It is possible to change the tie-down times in the input sheet to model an untrained worker for future work.

2.5 Explanation of Model

All of the model's inputs come from the input sheet which is derived directly from the rail build sheets. For the purpose of modeling, the number of operational spurs (two to five), workers per track (one to eight), reachstackers (two to ten), vehicle breakdown percentages, and tie-down distribution times for each vehicle can be modified in the input sheet. The model

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currently accommodates both a BCT set up with 28 mission tabs and a BN size element with four mission tabs, but missions can be added or subtracted based on the unit's composition. If this model were to be utilized in the future, there would be a small learning curve since units only have to add in their own mission tabs to the input sheet and change parameters listed above. Theatre support planners, deploying units, and terminal managers could edit their own mission trackers, upload them, and get time predictions on the operation. This allows them to evaluate several courses of action in a short period of time through simulation. The model's main output is the amount of time needed to complete missions because our objective is to identify friction points and bottlenecks in the process. If the research team notices a particular mission takes significantly longer than the rest, we can investigate the reason and make recommendations accordingly. Through those recommendations, the research team can potentially maximize efficiency of U.S. Army rail operations.

Figure 1 serves as the basis for the model's flow. The model uses an array called y_Vehicle_Load_List to import the data from the input sheet. A subroutine called s_Populate_vehicles_to_be_loaded reads through the array's information to determine how many vehicles need to be populated into the model. The vehicles are then sent to staging area 1 or 2 randomly. The vehicles are also assigned a spur using a uniform distribution that accounts for the number of operational spurs. If a vehicle is broken, they require a reachstacker in order to move to one of the outside tracks. Simultaneously, fifteen railcars are ordered to each operational spur. Each railcar knows how many vehicles it will load or if it will be empty. The furthest available railcar calls a vehicle from the ramp to be loaded. Once the vehicle reaches its respective railcar, a worker is called to tie-down the vehicle. In order to incorporate tie-down times a simple relationship was developed that provides the average tie-down time, according to the number of each type of vehicle and their corresponding triangular distribution based off the SDDC tie-down times (King, 2015). Equation 1 below represents this relationship.

$$Average\ Tie\ Down\ Time = \frac{\left((\#\ of\ Wheeled\ Vehicles * T(10,20,30)) + (\#\ of\ Tracked\ Vehicles * T(30,40,50)) + (\#\ of\ Containers * T(10,12,15))\right)}{(Total\ \#\ of\ Vehicles\ and\ Containers)} \quad (1)$$

This equation allows the team to assign a single value to the tie-downs teams operating time, while still accounting for the number of each vehicle type. Currently, tie-downs and inspections occur simultaneously due to the nature of trained contractors. A separate step should be included in future work to account for failed inspections so that a worker can be called to redo the tie-down. Once all vehicles are tied down, the train departs and a time stamp is taken to determine how long it took to finish the mission.

3. Analysis and Results

3.2 Design of Experiments and Results

The research team conducted two 2^k factorial experiments to study effects of three factors on the time required to complete all missions. One experiment was conducted for a Battalion (BN) size element and the other was conducted for a Brigade Combat Team (BCT) size element. The main factors of these experiments included: number of operational tracks, number of reachstackers, and number of workers per track. The research team believed that these factors would have the greatest effect on the time needed to finish loading all missions. Although vehicle breakdown percentages would affect the length of the mission, it is unrealistic that a high percentage of all vehicles would be dead prior to loading operations. The research team conducted 30 replicates of each treatment combination. The observations are assumed independent, normally distributed, with mean 0 and variance σ^2. The null hypothesis for all tests is that changing these factors will not have an effect on the time to complete all missions.

Table 1 shows the average times across the 30 replicates for each scenario. Out of 480 replicates, there were four outliers where the model does not appear to collect an accurate time. The outliers occurred in the scenarios with the lowest possible spurs and workers. This can be attributed to the uniform distribution associated with a vehicle's spur assignment where a high number of vehicles were assigned to one spur.

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Table 1. Average Times to Finish All Missions

Scenario	Average Time for BN (Hours)	Average Time for BCT (Hours)
3 Tracks, 10 Reachstackers, 8 Workers/Track (3)	9.51	95.31
3 Tracks, 2 Reachstackers, 8 Workers/Track (4)	9.54	95.51
5 Tracks, 10 Reachstackers, 8 Workers/Track (2)	10.01	102.09
5 Tracks, 2 Reachstackers, 8 Workers/Track (5)	10.06	102.40
5 Tracks, 10 Reachstackers, 1 Workers/Track (8)	14.79	138.46
5 Tracks, 2 Reachstackers, 1 Workers/Track (6)	14.80	138.54
3 Tracks, 10 Reachstackers, 1 Workers/Track (1)	16.91	146.15
3 Tracks, 2 Reachstackers, 1 Workers/Track (7)	16.92	146.17

3.3 Analysis of Results, Verification, and Validation

The research team conducted a multifactor analysis of variance to analyze the results of the experiments on the time to complete all missions. For the BN size element experiment, the number of operational tracks, number of workers per track, and the interaction between tracks and workers were significant with p-values near zero.

Table 2. Linear Regression for BN size Element

Coefficients	Estimate	Standard Error	t Value	P- Value
(Intercept)	12.8170	0.1165	110.037	< 2e-16
β_1- operational tracks	-0.4030	0.1165	-3.460	0.00064
β_2- workers per track	-3.0395	0.1165	-26.094	< 2e-16
β_3- operational tracks: workers per track	0.6585	0.1165	5.653	4.53e-08

A linear model was constructed based on the main factors and the significant interactions as seen in Table 2. The number of reachstackers was determined to be insignificant in the model because of its high p-value. Additionally, removing the number of reachstackers from the model increased both the multiple and adjusted R^2. The model, shown in Equation (2), has a p-value < 2.2e-16, multiple R^2 of 0.7544, and adjusted R^2 of 0.7513 which accounts for the majority of the variability within the data.

$$Y = 12.82 - 0.40\beta_1 - 3.04\beta_2 + 0.66\beta_3 \tag{2}$$

The same methodology was used for the larger BCT experiment. The number of operational tracks, number of workers per track, and the interaction between tracks and workers were significant with p-values near zero. A linear model was constructed based on the main factors and the significant interactions. The model, shown in Equation (3), has a p-value < 2.2e-16, multiple R^2 of 0.7255, and Adjusted R^2 of 0.7221 which again accounts for the majority of the variability within the data.

$$Y = 120.58 - 0.21\beta_1 - 21.75\beta_2 + 3.62\beta_3 \tag{3}$$

Verification and validation improve the reliability and usefulness of a model. Verification is a technical examination to ensure the model runs correctly. Throughout the creation of the model, we worked with a ProModel consultant to ensure that the code worked as intended. Aside from the four outliers mentioned in Section 3.2, the model behaves as designed. Validation is the process by which a model's results are compared to results from the real world. For validation, the research team plans to consult the original subject matter experts in order to gauge the realism of the completion time for each scenario.

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4. Conclusion and Future Work

The analysis focused on altering the number of operational tracks, number of workers per track, and the number of reachstackers. The regression analysis indicates that the most important factors that affect a mission's completion time are the number of tracks, workers per track, and the interaction between them. Based on the current model, units who are constrained on resources should focus their efforts on acquiring more skilled workers. However, there are several factors that could potentially affect the time to complete a mission to include using trained contractors versus regular Soldiers, the railyard's operating hours, and weather considerations based off geographical location. The input sheet should also be modified to incorporate more types of cargo such as trailers in the case that they are not attached to wheeled vehicles. The input sheet's flexibility allows for these other factors to be considered in future work.

In order to effectively plan rail operations, units need to be able to determine how long it will take to off-load equipment. Although the model only accounts for on-loading procedures, the use of loading statements allows for an off-loading component to be added into the same model. A model with both on-loading and off-loading procedures will provide logisticians with a holistic view of rail operations to help support the Army's operational needs.

Although the Port of Bremerhaven served as the foundation for this research, the model can be adapted for other railyard layouts and resources in conjunction with units' future rail build sheets. The linear model derived from the model output allows quick estimations for mission completion time given the number of operational tracks and the number of workers per track. The combination of the discrete event model and the linear model provides a foundation for planners to analyze rail capabilities and compare different courses of actions.

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