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SIMULATION MODELING AND ANALYSIS IN SUPPORT OF BRIGADE ASSAULT BRIDGING OPERATIONS PLANNING

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ABSTRACT

Simulation models allow us to examine the performance of critical systems variables and provide input into a decision making process. In military operations, the complex interactions of many subsystems necessitates the use of simulation models. The key is scoping the problem at the outset and being flexible enough to add or delete model items, as needed. This paper provides some insight into a quick analysis for the Army of brigade assault river crossing requirements and the use of discrete-event simulations in determining what the "real" requirement should be. Additionally, a spatial and temporal analysis builds on the initial analysis. Both analyses provide critical input to a military commander's decision making process.

1 INTRODUCTION

In military operational planning, commanders (aka: decision makers) must use judgments based on years of experience, as well as input from military staff planners. Quick macro level assumptions and analysis provide the input, but the input is often imprecise and does not allow for complex interactions. A tool that would quickly provide planners more complex analysis would be invaluable. As it is, many assumptions are made and planning factors are used that may not be valid.

An example of this is assault river crossing operations. Combat Engineers perform a map terrain analysis of possible assault river crossing locations and determine the minimum number of bridging sets needed to successfully span the river. This result would hold in an ideal world. However, what if only some (or no) bridging assets are available due to maintenance failures? What if bridges are damaged during emplacement, or worse, destroyed by hostile fires? Accordingly, military planners use a "planning factor" to provide a "better" approximation for the actual number of bridging sets that would be required to successfully complete the river crossing.

Prior to this study, the Combined Forces Command (CFC) in Korea used a planning factor of 1.3, or 30% more assets than calculated as the minimum required. This rigid number represents an "expectation" on the part of the planners, with no assumption as to the level of risk accepted.

The Commander of the Combined Forces Command asked the Center for Army Analysis, to research the current 30% planning factor and validate its use. If this could not be done, he asked the Center for a broader analysis of the assault river crossing operations and development of a more credible planning factor.

2 DEFINING THE PROBLEM

The first step in defining the problem is understanding the problem. Initially, we presumed the planning officers for CFC had lost documentation for the 30% factor. We believed that this would not be a labor intensive project; perhaps a mere literature search and review. This was not the case.

The planning factor is one that takes the possibilities of inoperable bridging assets as a result of maintenance failure, losses to enemy fire and damages resulting during emplacement. Since a maintenance, loss and damage (MLD) planning factor is the result of three different probability distribution interactions, one wonders how 30% average ever came about, with no associated error factor.

In our research, we reviewed over thirty relevant bridging studies, contacted numerous military schools, including the Army's Engineer School, test and evaluation agencies and the Center for Army Lessons Learned. To our surprise, there was a wealth of Operational "How To" data concerning river crossing operations, but no data concerning the associated planning factors. Even the numerous historical military assault river crossings highlighted the operational insights. Even subject matter experts were unable to provide a range of data or concrete information. The only historical record that was available was for the Sava River Crossing in the Bosnia Campaign. In December 1995, the Army Engineers, lead by COL Steven Hawkins, successfully made an assault river crossing of the Sava River to replace the bridge damaged during the war in Bosnia. The after action report of the crossing resulted in a planning factor of 100%, or twice the planned number of bridges that would be needed to accomplish the river crossing. One must also note that this was an unopposed river crossing; hence no losses to enemy fires.

While this was only one observation, it could not be ignored. We notified the CFC staff that we could not validate their planning factor and suggested a planning factor of 2 versus 1.3. We were met with a great deal of skepticism. CFC asked us to develop a model that would provide a more credible planning factor for the CFC.

3 PROBLEM SOLVING METHODOLOGY FOR THE MLD FACTOR

Now that we understood how the planning factor was being used, we had to develop a methodology to generate a credible planning factor. Our client, CFC, was used to rigid numbers being used as a planning factor. Additionally, this number is an approximation for the "expected value" of an MLD distribution generated from the joint probability distribution of equipment maintenance downtimes and frequencies of occurrence, losses from enemy fires, and damage from emplacement of assault river crossing assets. While a single point approximation simplifies planning, it does not allow for risk assessment or sensitivity analysis. It was our goal to provide the decision maker with a more credible tool that would provide a planning factor based on the joint probability distributions and a level of risk acceptable to the commander.

3.1 MLD Factor Generation – The Idea

We knew that if we could model the maintenance, loss, and damage probability distributions using raw data and input data analysis methods, we would be able to generate a credible MLD factor based on the joint probability distribution. The problem was there was little data to conduct an input data analysis. Some data sets could not provide any probability distribution that passed a Kolmogrov-Smirnoff, Andersen-Darling, or Chi-Squared Goodness of Fit test.

This lack of data limited us to three possible modeling methodologies: empirical distribution, uniform distribution and triangular distribution.

The first method would be to use the very limited empirical data sets and repeatedly draw from this set. While this would provide samples similar to actual occurrences, the data was so limited and we had no possibility of any other occurrence. We believe this is too limited.

Our second method would be to use a range of values and weight their probability of occurrence equally, using a uniform distribution. This method is commonly referred to as the "distribution of maximum ignorance."(Banks, p.196)

Our final method option was the use of the Triangular Distribution. We had subject matter experts, such as military officers, planners and commanders that could provide input into the "most likely" occurrence. This equated to the modal parameter of the Triangular Distribution.

There are values that allow us to "anchor" the minimum and maximum values for each triangular distribution. One possibility is using the Army's "Pacing Item" Unit Status Readiness value to model the percentage of bridges that were unavailable due to maintenance. Any value less than 70% for these pacing items equates to a unit that is non-mission capable. The maximum value would be 100% which is rarely, if ever, achieved. The modal value would then be the unit's current reported readiness rate. By sampling a Triangular distribution based on these three values, we can generate an observation of daily operational bridges and, consequently, those not available because of maintenance issues. We used similar procedures to develop Triangular Distributions for Loss and Damage.

Even though the exact form of each probability distribution for maintenance, loss and damage is unknown, using quantile values between 0 and 1 gives a realistic likelihood of events (Banks, p.196). The point estimate of the joint probability distribution modeled allows random occurrences for each variable that then produces a more credible point estimate of the MLD factor. Simulating multiple runs allows independent observations of the MLD factor. By sampling numerous independent replications, we can take advantage of the Central Limit Theorem and the Law of Large Numbers. Produces a better and more credible method than the "expected value" point approximation used by the CFC. This further allows more credible input to a decision making process.

3.2 Modeling the River Crossing System

The area of operations considered in this study is the Korean Peninsula. To maintain an UNCLASSIFIED classification, no other details of the terrain are discussed.

At each river crossing site, the engineer planning officer provides the required number of bridges as an input variable to the simulation model. He also inputs the EXPECTED damage and readiness rate. These values are the modal values for the triangular distributions. For the Loss distribution, initially, we used the CFC planning factor of 30% as a modal value. The model then generates an observation of the number of bridges non-mission capable for maintenance reasons, an expected number of bridges lost due to enemy attack, and an expected number of bridge bays damaged during emplacement. The MLD factor is then calculated as the minimum number of required bridge bays, plus the number of bridge bays down for maintenance, the expected losses and the expected number damaged. This sum is then divided by the minimum required number of bridges, which yields a value between 1 and 2.

3.3 Initial Results of the Model Output

The initial simulation model was modeled using the PROMODEL discrete-event simulation package. It took into account time and distance between the key river crossing sites. One result of the model was the understanding that the major sequential crossings were far enough apart that any bridges damaged, lost to enemy attack, or down for maintenance would be replaced in theater in time for the next major river crossing. This is best illustrated in the charts below. One can see that for the same inputs, for the three river crossing sites, similar MLD factors were achieved. The CDF plot of the MLD factors across 3000 replications is illustrated. If we assume a desired level of success to be 80% probability, the MLD factors for each crossing are 1.59, 1.58 and 1.61.

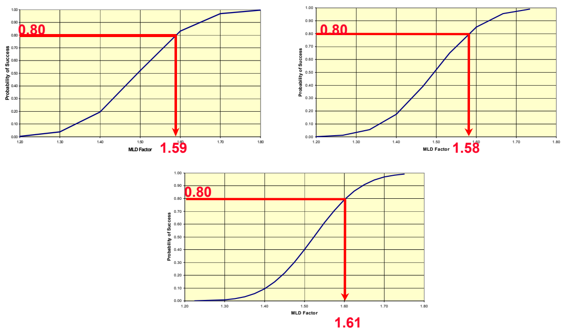

Figure 1: Initial Model Results

From these initial observations, we were able to see that we did not need a time factor for this analysis.

3.4 Feedback and Model Modifications

The initial model output and MLD factors were received favorably by CFC staff officers. They were, however, concerned with the mode value for the loss distribution. They wanted the ability to modify the modal value since we were not able to validate their 30% planning factor (for maintenance, loss and damage). They asked us to generate a different modal value based on a military theater attrition model; Contingency Evaluation Model (CEM). This was not possible, as CEM does not have the level of fidelity that would provide a useful number. Accordingly, we modified the model and automatically varied the modal values. The output was as series of CDF curves based on these values. This allowed CFC to see any significance in the loss modal value.

At the same time we were getting feedback from our client, we realized we could significantly simplify the simulation model. We determined that there was no need to model the individual crossings in one model. Each crossing required its own inputs. To make the model more generic, we modified it to allow analysis of individual crossing sites at separate times. We were able to migrate the model to Microsoft Excel, create a Graphical User Interface (GUI), and automate the output.

3.5 Revision to the Model and the User Interface

The first step was to migrate the model methodology to Microsoft Excel using Visual Basic for Applications. The trickiest area was generating the random observations according to the triangular distributions. We accomplished this by using the appropriate algorithm for random variate generation. (See Law & Kelton)

We designed a custom graphic user interface that allows the user to input the decision variables, run the simulation and view the last saved results. The figures below illustrate the graphic user interface developed.

Figure 2: Graphical User Interface

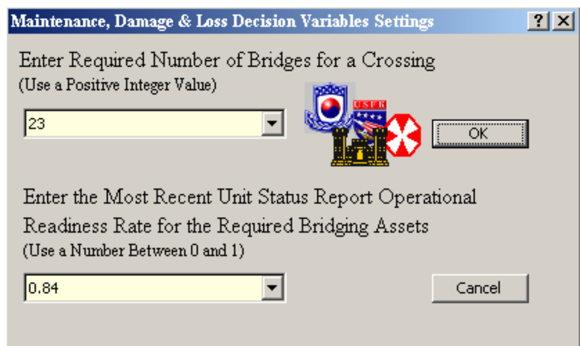

Figure 3: Input Variable User Interface

The automated output provided the user with a series of CDF plots that would allow them to look at several possibilities of MLD factors based on a different loss mode value. In Figure 4, one can see that there is, relatively, little difference in the expected MLD factor, regardless of the mode value.

3.6 Model Basics

Once migrated to Microsoft Excel the basic process was similar to the PROMODEL model. The significant differ-

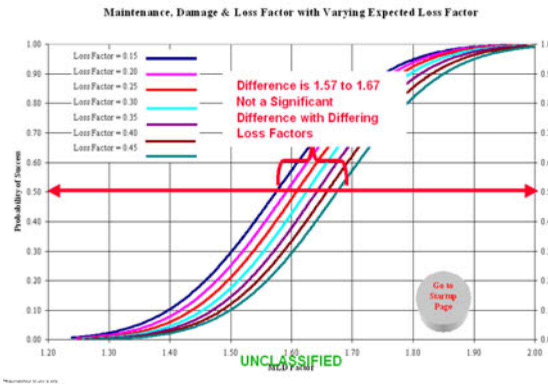

Figure 4: Automated Output

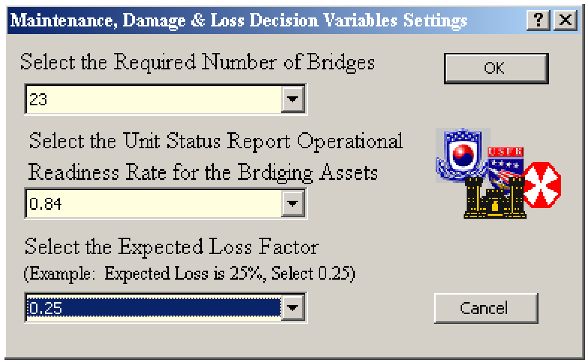

Figure 5: Decision Variable Inputs - Final Version

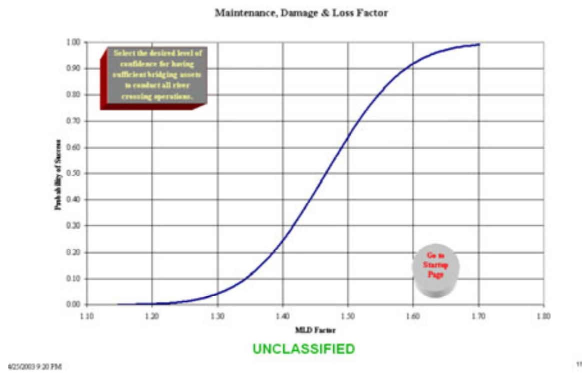

Figure 6: Final Output CDF

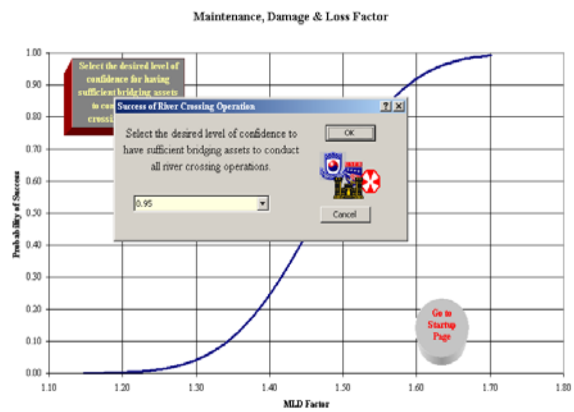

Figure 7: User Input Risk Analysis

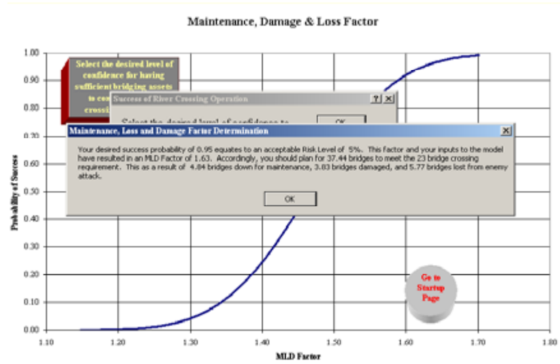

Figure 8: Message to User

ence was there was no need for a simulation clock and event manager. We generated 1000 individual observations of the number bridge bays down for maintenance, the number of damaged bridge bays, the number of bridge bays lost to enemy attack and then calculated the MLD Factor. The data was automatically sorted by MLD Factor. The integrity of the maintenance, damage and loss data was not lost. After 1000 replications, we repeated the experiment 30 times and performed our analysis across the independent experiments. We calculated the Average MLD factor and the values for maintenance, loss and damage. The normally distributed CDF was generated and plotted automatically on a new sheet in the file. The Risk input corresponded to a lookup of the collated data to see corresponding maintenance, loss and damage values. The MLD factors remained consistent at two–digit level of significance, which is more than adequate for planning purposes.

3.7 Final Modifications

Our client responded positively to this version. However, they did not want multiple CDF plots. Accordingly, we modified the graphical user interface to allow the user to input the expected loss (the mode value) and output to one CDF. Additionally, we found that the client wanted a single output number and an explanation of MLD losses.

Our client had trouble interpreting the CDF plots, because it was not intuitive. They desired a point value. However, one must know the commander's acceptable risk to use a single value. This is something that is situation dependent and cannot be assigned an precise value. To accommodate this, we added a button on the output with an assigned macro that allowed the user to input an acceptable risk level.

Figure 6 shows the single output CDF. The rectangular box on the upper left corner allows the user to input the acceptable risk and get a numeric planning factor. Figures 7 and 8 illustrate the Risk Input and Message Output to the User Figures 7 and 8 illustrate the Risk Input and Message Output to the User.

3.8 Model Insights

The original CFC MLD factors did not separate maintenance, loss or damage. Even when modeling each of the elements of the MLD Factor, the generated CFC planning factors showed that the original 1.3 planning factor was not unrealistic; rather, the values were close to values generated by model.

The model still allowed for values to be generated at the "expected" level, but also provides the user with a risk analysis methodology. Finally, the model illustrates most likely problem areas based on Maintenance, Damage and Loss.

The general nature of the model also allows for comprehensive "what-if" sensitivity analysis by the user without having to change simulation code. Some of the parameters one might consider in performing as sensitivity analysis are the Loss Triangular Distribution mode parameter, the Unit Status Operational Readiness Rate and the required number of bridges. Our output is based on these user–selected inputs. The model runs quickly, so planners can look at multiple areas in question.

The CFC planners were pleased, overall, with the model. Their intent had been to have a rigid planning number, but, they felt that the risk analysis methodology provided some further insight.

4 BUILDING ON THE MODEL'S SUCCESS

The scope of the initial study was not spatial or temporal. However, it resulted in a methodology that would allow us to model spatial and temporal requirements, and use the MLD planning tool, too.

This was the case when the Army Vice Chief of Staff asked the Deputy Chief of Staff for Operations and Plans (DCSOPS) to perform a comparative analysis of the Armored Vehicle Launched Bridge (AVLB) and the Wolverine Armored Assault Bridge. DCSOPS asked us to perform an operational comparison to provide input into their overall decision concerning upgrades to the AVLB versus purchase and fielding of the Wolverine. Specifically, we were asked for an operational analysis comparing the number of bridges of each type and their capabilities in a combat scenario. While these bridges were gap spanning bridges as opposed to float ribbon bridges, the same process can be used in developing a model for the analysis. This is how we built on the first study.

5 ADDING TO THE METHODOLOGY

For this project, we had to add the time and distance component of a military operation. To do this, we went back to using the PROMODEL discrete-event simulation software. We were asked to use a Korean Peninsula scenario as this area of military operations would have the greatest need for assault bridging assets. Even though we were able to use our previous work, we still had to begin the process of understanding the task at hand and how we were going to solve this new problem.

This problem was slightly different in that we knew each crossing site required four launched bridges. We could use our earlier model, but we now had to take into account time and operational distance for two different systems.

5.1 Background and Assumptions

The AVLB and Wolverine are mobile armored assault bridges. They are heavy load classification bridges that launch from their carriers and, when emplaced, allow armored vehicles to cross.

The AVLB is vertically launched in an "A" frame style until is opens. It has an M60 tank chassis and can cross a gap of up to 15 meters. There are, currently, 12 AVLB vehicles per brigade combat team.

The Wolverine is a horizontally launched assault bridge. It has a heavier armored launcher than the AVLB and has an M1 Tank chassis, making it faster and more survivable. It has the latest digital communications equipment. It can cross gaps up to 24 meters. However, it is an extremely expensive and heavy piece of equipment. While these factors are worthy of analysis, it was not what we were asked to do. DCSOPS rolled our analysis into its overall analysis that performed a cost-benefit analysis of the weight, dollar cost and other factors we did not consider.

In developing this model, we wanted to include some realistic events that we would expect in military operations; such as vehicles being brought back up from maintenance down time. Accordingly, we recalculated the number of vehicles down for maintenance every 24 hours. Secondly, the bridges were strong enough that we considered a damage assessment only after each 4th assault crossing. Finally, any bridge that was lost due to enemy attack was catastrophic and could not be repaired.

The measure of effectiveness that were essential to our analysis were:

1. how far could a brigade combat team (BCT) travel;
2. how many assault crossings could the BCT make;
3. how long were the assault bridging assets greater than or equal to four (4).

5.2 Input Data Analysis

In developing the probability distribution for the distance between crossing sites, we evaluated corps routes of march and collected distances between bridging sites. We then fitted a continuous distribution to enable true random observations of distances that were not biased with respect to known data and routes. The distances were representative of terrain in Korea. Figure 9 shows the result of the input data analysis.

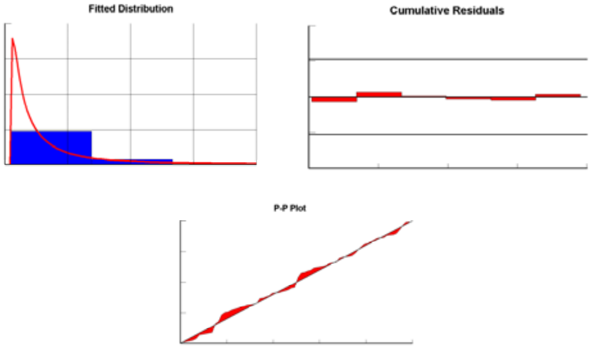

Figure 9: Input Analysis Result

We examined the cumulative residuals and the P-P plot of the theoretical distribution against the actual data to see if they are approximately the same. A 45-dgree straight line in the P-P plot and a flat line in the Cumulative Residuals plot would be an exact match. Both plots show that the fitted distribution is a good model for the actual distances. This distribution was used in the model. The actual distribution and parameters are left off because they were derived from CLASSIFIED data.

5.3 Simulation Model

The simulation model was then built and included the MLD model algorithms. Figure 10 shows the basic process. The first step is to determine the number of operational bridges. We then generate a gap to cross that is based on CFC assumptions for, determine losses due to enemy fires and generate a random distance to the next site. We repeat the process until the Brigade Combat Team has less than four operational bridges. After 1000 replications, we conduct our analysis. We performed this experiment on 18 different courses of action. Our initial model had 12 AVLB bridges per combat team. We evaluated the AVLB from 12 to 4 bridges and then did the same for the Wolverine.

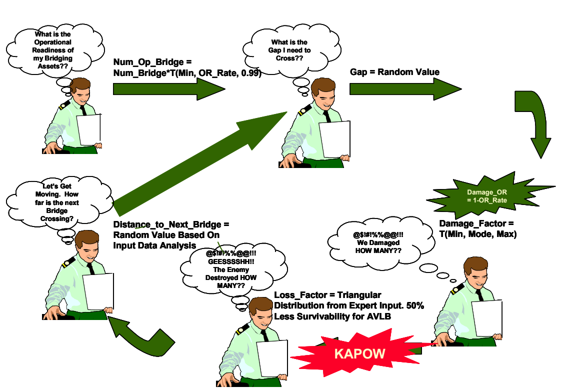

Figure 10: Simulation Model Process

5.4 Output Analysis

Figure 11 illustrates a comparative analysis of the Operational River Crossings for each course of action. The left most set of results is for 12 AVLBs, the current force structure. The dotted lines show that 12 AVLBs are approximately equivalent to a Bridge Combat Team of 9 Wolverines. However, the Operational Time for 12 AVLBs is 22 hours. For the 9 Wolverines, it is about 11.5 hours. Figure 11 illustrates the Operational Distance Traveled by the Brigade Combat Teams with the Bridging Assets.

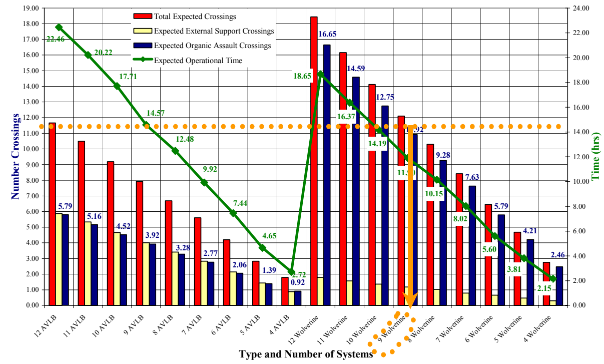

Figure 11: Operation River Crossing Analysis

In Figure 12, we illustrate the distance a brigade combat team can travel with the various number of bridging assets organic to the unit. Once again, we see that the distance a brigade combat team (BCT) can travel with 12 AVLBs is approximately equal to that of an BCT with 9 Wolverines. Also note that it takes almost half as long for the Wolverines to achieve the same operational distance.

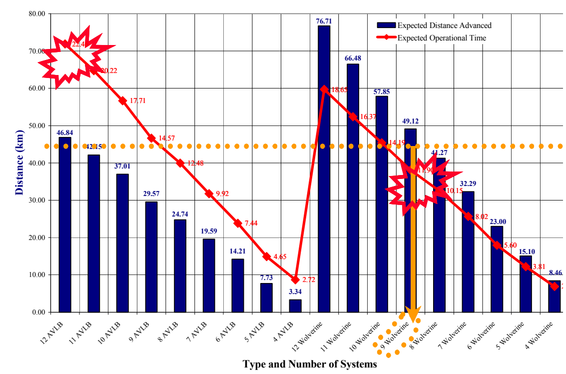

Figure 12: Operational Distance Analysis

In Figure 13, we see why the Wolverine only lasts about half as long as the AVLB. Its sustained rate of march is twice that of the AVLB. What this means is the operation tempo of the Wolverine BCT is higher. The AVLB has to stop and wait for Divisional level bridging assets such as the Bailey Bridge or Medium Girder Bridge to span gaps greater than 15 meters, while the Wolverine

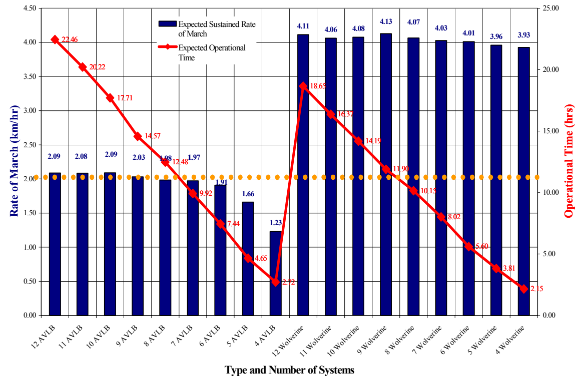

Figure 13: Sustained Rate of March Analysis

can span many of those gaps. This is a significant difference in the operational usage of the two systems

5.5 Sensitivity Analysis

Our sponsors had two concerns. First, the survivability score based on subjective analysis and resulted in a huge difference between systems, with the better score being given to a newer system. Secondly, the Operational Readiness score we associated with the AVLB for maintenance issues was, similarly based on subjective analysis.

Holding the Wolverine parameters constant, we performed a sensitivity analysis by modifying the AVLB parameters from the starting conditions we used above, to those equal to the Wolverine. Figure 14 shows that there was little significant sensitivity as a result of the maintenance parameter

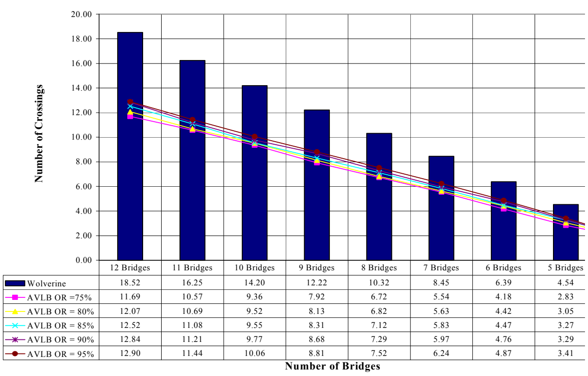

Figure 14: Operational Readiness Sensitivity Analysis

When we modified the Survivability factor associated with the AVLB, we see some significant sensitivity. In Figure 15, we can see that the Operational Distance for 12 AVLBs with a survivability score equal that of the Wolverine is almost 20 km farther, then previously modeled.

However, as we see in Figure 16, the sustained rate of march for the AVLB continues to be half that of the Wolverine. The cost-benefit analysis of the OPTEMPO delays

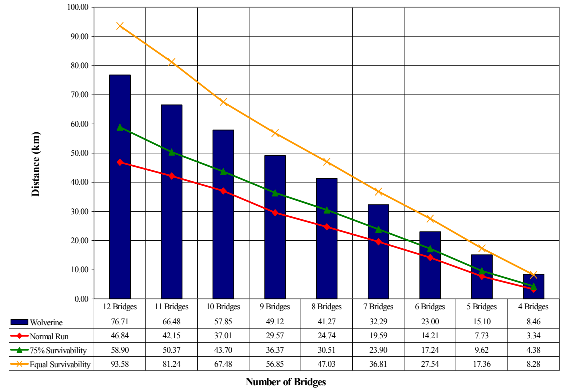

Figure 15: Survivability Sensitivity Analysis

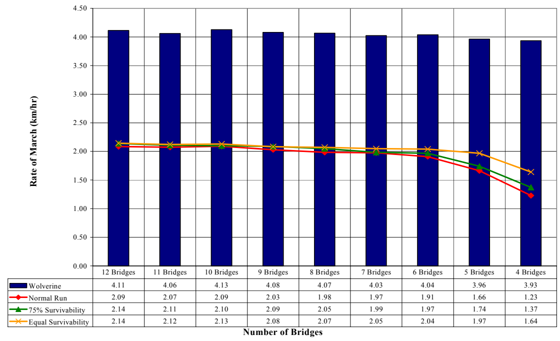

Figure 16: Sustained Rate of March Sensitivity Analysis

associated with the AVLB was not part of our study. Our comparative analysis did show the strengths of the Wolverine in a Korean Peninsula scenario.

5.6 Summary Analysis for the Army

Since we were using stochastic processes in our modeling, we looked at the Cumulative Distributions of our measures of effectiveness. In this way, similar to the MLD factor analysis, we were able to generate a set of curves associated with the different courses of actions, AVLBs versus Wolverines. Figure 17 illustrates this. If a decision maker

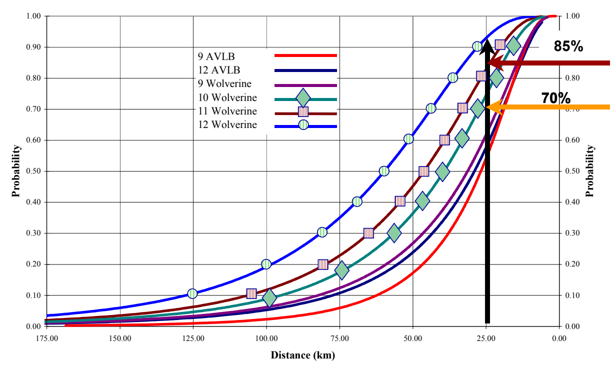

Figure 17: Cumulative Density Function Plots

wants to be 85% confident that there will be enough bridging assets available to travel 25 km in a Korean Peninsula Operation, for instance, then he should ensure there are 12 Wolverines available.

Again, the cost-benefit issues associated with this would be a natural follow-on, but were not part of the scope of this project.

6 SUMMARY

In these two studies we saw the power that discrete-event simulations provided for quick analysis and input to the decision-making process. By scoping one problem and understanding what was really necessary, we were able to create a stand alone quick analysis tool from a macro view of the military planning process. Building on the success of the initial project, we were able to incorporate its strengths into a more complex spatial and temporal analysis, and continue to provide support and information for military decision makers.

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