Computer Simulation of Decontamination Operations

By Captain Ian McCulloh

With potential deployments into areas with a likely threat of chemical warfare, what can a chemical company commander do to improve decontamination operations? How should he augment his decontamination line? Army doctrine provides a guide under ideal conditions, but a decontamination unit in a real-world situation will receive different resources to support the decontamination effort. The efficient use of these resources can greatly increase the speed of a decontamination operation and quickly return units to the field for future combat operations. Simulation scenarios are used to model queues, manpower requirements, and equipment in decontamination operations. An experimental approach is used in conjunction with the simulation to determine the optimum space and manpower requirements. In the same manner, the system can be evaluated for different levels of available resources, such as augmentation with additional personnel.

The essential performance measure of any study of military decontamination operations is to minimize the time to process (decontaminate) a unit. A unit waiting to be decontaminated is vulnerable and is not a combat multiplier. The speed at which it can return to the fight is determined by how quickly decontamination operations are performed. There are three more factors that significantly impact the overall time objective:

- The wait time in the decontamination line.
- The ideal space for queues.
- Optimally allocated manpower resources.

Computer simulation is used to mathematically integrate tactical scenarios with actual decontamination times for each step in the decontamination process. The steps in the process are statistically modeled from actual tests conducted by the US Army Test and Evaluation Command (TECOM). This simulation scenario does not attempt to predict untested human processes. Instead, the known human processes are rearranged from a planner's perspective to improve the overall decontamination process. This approach has been widely implemented in civilian industry with great success, but the simulation study is limited in that tactics, techniques, and procedures (TTP) must be proposed before they can be evaluated. Validation tests have shown that simulation models accurately evaluate new TTP.

System and Simulation Specifications

Simulation models can address scenarios under different decontamination site resource constraints, allowing chemical doctrine writers to better develop TTP. These scenarios may address the—

- Likely bottleneck locations.
- Normal queue space.
- Average time for a military unit to process through a decontamination line.
- Average time spent waiting in the decontamination line.

The different decontamination site resource allocations are evaluated based on the statistics gained from the scenario. The scenario evaluated for this model includes—

- Two doctrinal decontamination lines (according to Chapter 4 of Field Manual 3-5, *NBC Decontamination*).
  - An optimum M12A1 power-driven decontamination apparatus (PDDA) detailed equipment decontamination (DED) setup.
  - An alternate M12A1 PDDA DED setup.
- Several levels of personnel augmentation to evaluate the effects on the decontamination line. (The data gained from this scenario is especially useful for justifying personnel augmentations.)

System Description and Modeling Approach

The main model consists of four sections: unit arrival, detailed troop decontamination (DTD), DED, and unit departure. There are two sources of contaminated units arriving at the decontamination site: dismounted units requiring only DTD processing and combat and support vehicles with crews requiring both DTD and DED processing.

The DTD is a simple doctrinal model that contains eight stations. In this simulation, only seven are modeled. Station 7, mask cleaning, is not performed by soldiers processing through the decontamination area and, therefore, does not affect the planning times. The seven remaining stations are—

- Station 1: Individual-gear decontamination.
- Station 2: Overboot and hood decontamination.
- Station 3: Overgarment removal.
- Station 4: Overboot and glove removal.
- Station 5: Residual-contamination monitoring.
- Station 6: Mask removal.
- Station 8: Reissue point.

The DED is more complex to model due to the driver change at Station 3. The basic model follows Army doctrine:

- Station 1: Initial wash.
- Station 2: Decontaminating Solution Number 2 (DS2) application.
- Station 3: Wait/interior decontamination.
- Station 4: Rinse.
- Station 5: Check.

Station 3 of the DED requires the driver to dismount his vehicle and proceed to the DTD. After 30 minutes, a clean (decontaminated) driver drives the vehicle through the remainder of the DED. The driver change and 30-minute wait at Station 3 is modeled based on the arrival of an available licensed driver. When a driver exits the DTD, he enters a queue, waits to occupy another vehicle at Station 3, and finishes the decontamination process according to Army doctrine. The number of vehicles in the model is based on an average percentage of vehicles in a real-world scenario. As units depart the decontamination site, statistics of interest are tallied for analysis and comparison.

Model Input and Output

There are several key sources of model input. The contaminated unit is the first source of arrival information. This data is obtained from the National Training Center (NTC) at Fort Irwin, California. Predicting unit arrival information depends heavily on the extent of chemical contamination. Real-world data of chemical-weapons exposure was not available for this study. NTC routinely simulates chemical-weapons attacks in their training exercises, and this is the best available source of arrival data. But the NTC arrival data is slightly artificial, as all rotations of contaminated vehicles meet at a staging area before moving to the decontamination site. This is not the optimal method of routing vehicles through a decontamination line, but the model produces data with vehicles entering the site following a uniform distribution with a single arrival time.

The second source of model input is the actual process times for the DED stations. The TECOM provided data from field tests using chemical-agent simulants and the M12A1 PDDA. The US Army Chemical School provided information on tests conducted during the 1960s; this information is the basis for current chemical doctrine. When data were compared, the more recent tests resulted in faster processing times at the DS2 application station. The cause for this has not been determined, but this study uses the more recent data for evaluation. The stations that used an M12A1 PDDA followed a triangular statistical distribution. This makes intuitive sense, based on the similarity of the processes. Station 2 followed a lognormal distribution, and Station 5 followed the Weibull analysis distribution.

The third set of model input is the DTD. An actual chemical unit was tasked to conduct a DTD strictly by the manual. The average process times were recorded for each station. Detail in this area is not extremely important and is difficult to obtain due to recent world events. The key outputs for evaluation were the—

- Time required to decontaminate a unit.
- Average time a unit spends waiting in the system.
- Manpower for operations.
- Space required for each queue.
- Potential bottleneck locations.

Model Formulation

This section details the logic used to formulate the simulation model. The concept is essentially two models in one. *Figure 1* shows the logic diagram for the DTD line submodel. The simulation generates soldiers to arrive from a random exponential distribution. The soldiers then process through the seven stations of the eight-station decontamination line (Station 7 is not included in this simulation). The diamond-shaped decision box at the end sends a clean driver to Station 3 of the DED line to take the vehicle through the rest of the DED. The remaining clean soldiers depart the system. Stations 1 and 5 seize a resource. At Station 1, equipment is required to scrub individual equipment. At Station 5, medical personnel are required to check personnel for symptoms of contamination. All of the process times are set as constants. The purpose of this section of the model is

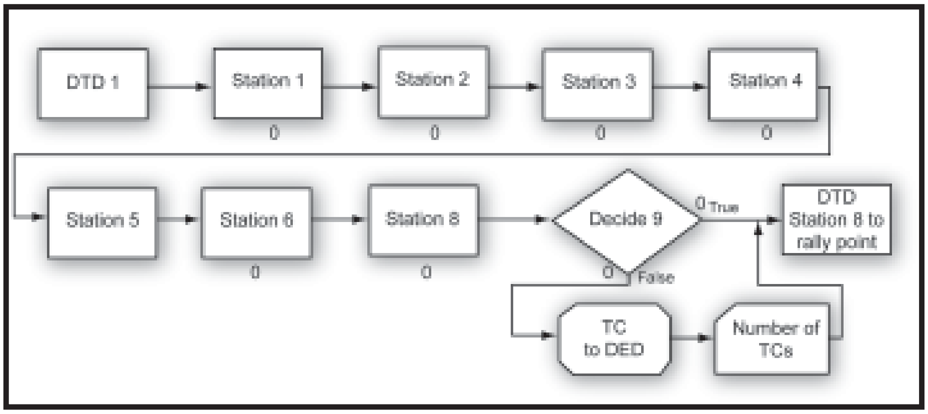

Figure 1. Logic diagram for the DTD line submodel

only to simulate the driver exchange in the DED. The decision module near the end of the logic diagram routes licensed drivers to an assignment module (octagonal box) that increments a global variable modeling a driver waiting in a queue to move a finished vehicle at Station 3 of the DED through the rest of the decontamination line. The record module (dog-eared box) tallies the number of licensed drivers that move through this logic. *Figure 2* shows the logic diagram for the DED.

The simulation then generates vehicles to arrive from a random exponential distribution to process through the DED. The station and route modules are identified on the screen in red. These modules enable the simulation to model the transfer time between decontamination stations. The actual stations of the DED are identified in yellow squares on the screen. There are two assignment modules on either side of Station 3. These assignment modules simulate the driver exchange. The first assignment module increments a global variable that allows a dirty (contaminated) driver to be created for the DTD. The wait station remains on hold for at least 30 minutes or until a clean, licensed driver is ready to drive the vehicle through the remainder of the decontamination line (if longer than 30 minutes). The second assignment module then resets the global variable that sends a clean driver. The diamond-shaped decision box at the end sends vehicles that are still dirty back to Station 2 along the dirty recycle route based on a set probability. The remaining clean vehicles depart the system.

Figure 3, page 18, shows the arrival of soldiers at the DTD. The first module creates dismounted soldiers to enter the DTD. More soldiers will slow down the DTD and impact the ability of the dirty drivers to process vehicles through the DED. The second module creates a dirty driver to go through the DTD. The third module creates crew members on various vehicle systems to process through the DTD. *Figure 4,* page 18, shows the arrival of vehicles at the DED. Three types of vehicles were modeled: tanks; medium trucks; and high-mobility, multipurpose wheeled vehicles (HMMWVs). The type of vehicle affects the process times at various stations throughout the DED. *Figure 5,* page 18, shows the departure of entities from the system. The simulation will organize chemical personnel and augmentees in the areas where they are working. For example, the DED 2 set contains all of the personnel who are working at Station 2 of the DED. Patient decontamination, security, and a clean bypass route are not considered in this simulation.

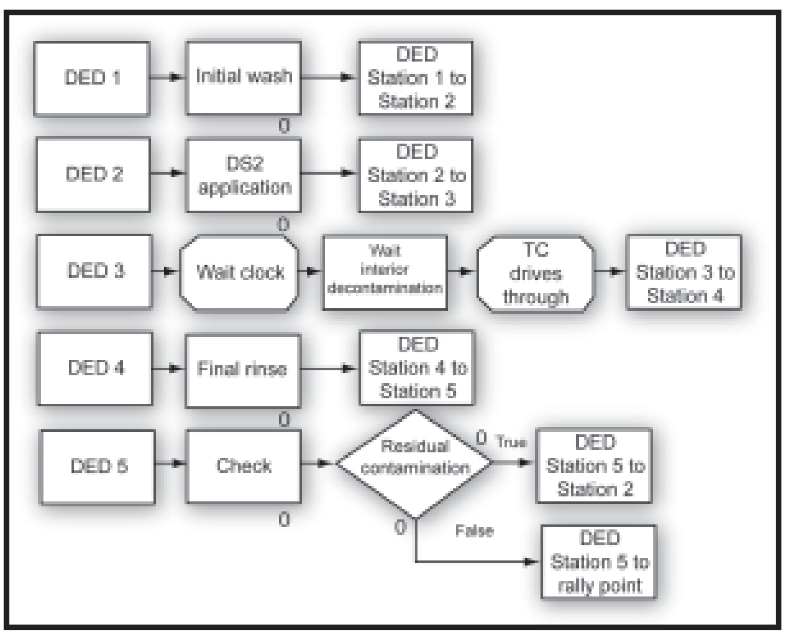

Figure 2. Logic diagram for the DED

Verification and Validation

Model verification was conducted by observing global variables at different points in the simulation, as well as observing the queuing statistics for each station of the system. The data used to create the statistical distributions in the simulation were not used to validate the model. Validation was conducted against established Army doctrine for process times (according to FM 3-5). The simulation model was validated as being faster than the established standards. This is due to the test data for DED Station 2 being faster than the established standard (12 minutes versus 30 minutes). All other process times were within the standard. When the difference in the standard and DED Station 2 was added to the

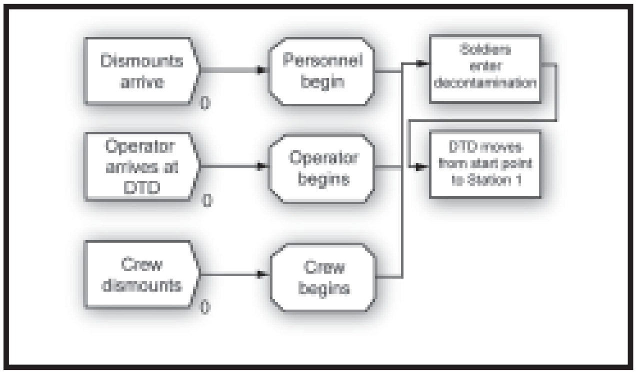

Figure 3. Arrival of soldiers at the DTD

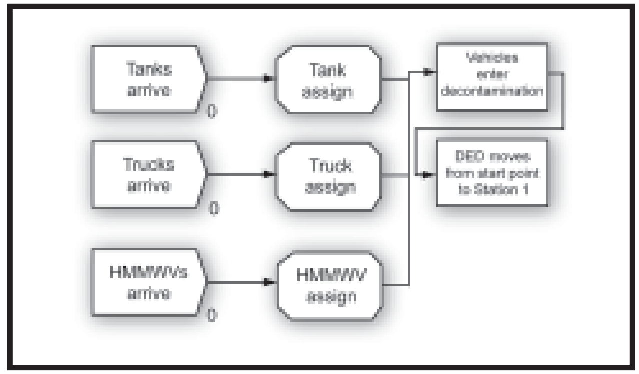

Figure 4. Arrival of vehicles at the DED

average process time for vehicles, the total time met the standard; therefore, this model is valid.

Experiment and Analysis

One benefit of conducting model simulations is the control of normally uncontrollable factors. As a result, analyzing the cause and effect of variability in a system is much simpler. Cause and effect relating to measurement, environment, and material are controlled and are not considered in this simulation. Furthermore, the choice of the decontamination apparatus is controlled and not considered.

Two areas that are considered for experimentation and analysis are manpower and methods. For manpower, there are many factors that influence the performance at the decontamination site. This model only addresses the augmentees. The method also impacts the performance of the decontamination procedures. This model addresses the standard two-lane "optimum layout" operation (according to FM 3-5). In some cases, as the required augmentees are varied, certain stations may behave like a one-lane "alternate layout" operation, but the equipment and resources are always present for a two-lane operation.

Experiment and Factors

Five experimental factors are considered when optimizing the decontamination site. Three of those factors are the augmentees provided at Stations 1, 2, and 4 of the DED. Two levels of factors are set for experimentation. The high level is the number of augmentees required under the doctrinal optimum layout. The low level is the number of augmentees required under the alternate layout. The other two experimental factors relate to the speed at which drivers were processed through the DTD. The first of these factors is "truck commander (TC) priority." The high-level TC priority allows drivers to process vehicles through the DTD ahead of other personnel. A low-level priority allows drivers to process vehicles in the order in which they arrive at the DTD. The second factor is DTD speed. The low-level priority of this factor is the normal DTD speed. The high-level priority is a theoretical setting where the DTD takes no time. Four responses to the experiments are measured. The first response is the total time a vehicle spends at the decontamination site, the second response is the time the vehicle spends waiting, and the third and fourth responses are models for dispersion of the first two responses. The models for dispersion are based on the range between the average maximum values and the average minimum values taken more than 100 experimental runs.

Experiment and Design

The simulation experiment follows a 2^{5-1} resolution-five design. With a resolution-five design, all main effects and two factor interactions are clear of any confusion or aliases. Two center points are used to detect any curvature in the model. Each design point is duplicated 100 times and averaged. This is equivalent to running 1,800 decontamination operations.

Statistical Analysis

The half normal plot in *Figure 6* shows that the TC priority in the decontamination line (B) and the DTD speed (E) are the most significant factors affecting the total time a unit spends at the decontamination site. The graph of the two factor interactions (BE) in *Figure 7* shows

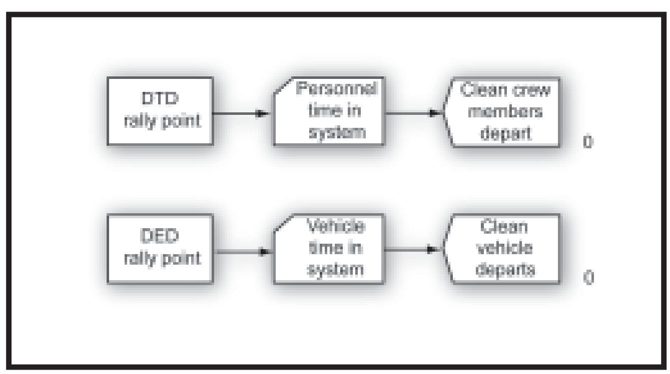

Figure 5. Departure of entities from the system

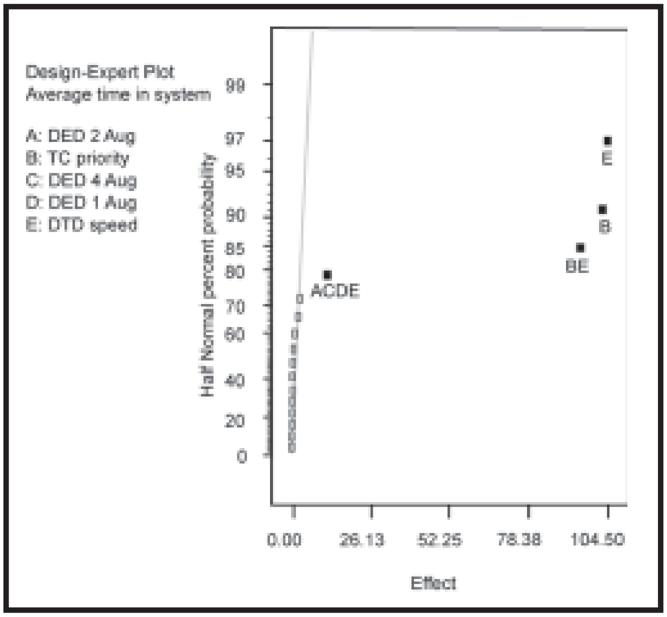

Figure 6. Half normal plot

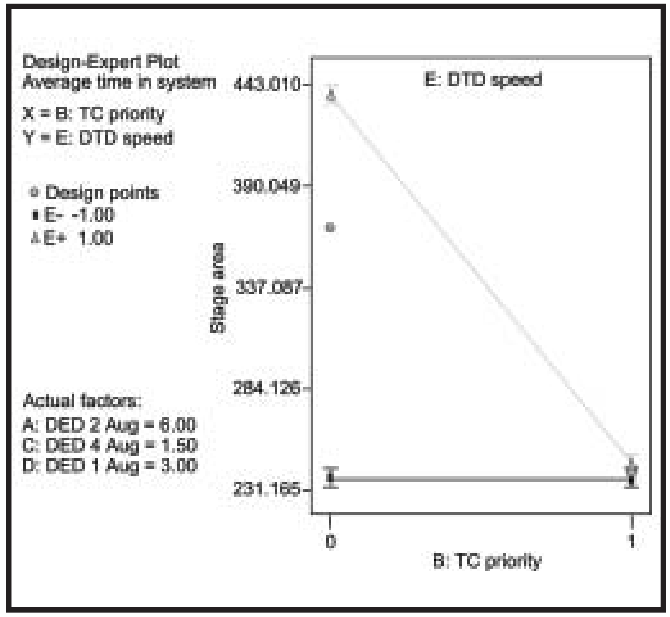

Figure 7. Interaction graph

intuitively obvious results. If the DTD is running slowly, then giving the TC priority in the DTD significantly shortens the time spent in the system. When the DTD takes no time at all, then giving the TC priority has no effect on the time. The analysis of the time spent waiting at the decontamination site yields the same results as the total time in the system. Furthermore, the dispersion models for the time in the system and the waiting time shows that faster DTD processing leads to less variability in the overall system.

Conclusion

The most important requirement to improve doctrinal decontamination operations and reduce the time it takes to decontaminate a unit is to have clean drivers available to drive vehicles from Station 3 of the DED through the rest of the decontamination site. This objective can be met in several ways:

- Prioritize licensed operators in the DTD, serving them ahead of other personnel. In practice, this can be very difficult. In mission-oriented protective posture (MOPP), a soldier will not have access to his military license to prove that he should be prioritized. Many soldiers may claim to have a license to get out of MOPP faster. The careful identification of drivers and TCs at the decontamination site entry point may solve this problem.
- Instruct the contaminated unit to provide additional qualified operators to move the vehicles through the DED after Station 3. This may be resource-intensive for the contaminated unit.
- Instruct conventional units to train multiple DTD teams and establish a multiple-lane DTD to perform decontamination procedures in a shorter amount of time. This would enable more personnel to be decontaminated in the same amount of time. This may also be resource-intensive for the contaminated unit.
- Use a faster method to decontaminate personnel. When used by trained personnel, the Expedient Personnel Decontamination System (EPDS) can fully decontaminate a soldier in less than 2 minutes. Unfortunately, the training costs—which involve cutting the MOPP suit with a handsaw—are high.

Additionally, consider the queue space. Station 3 of the DED must have sufficient parking space for at least three tanks, five 5-ton trucks, and five HMMWVs.

For additional information on using this simulation to evaluate your unit TTP, contact Captain McCulloh at the US Military Academy *<ian.mcculloh@us.army.mil>*.

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