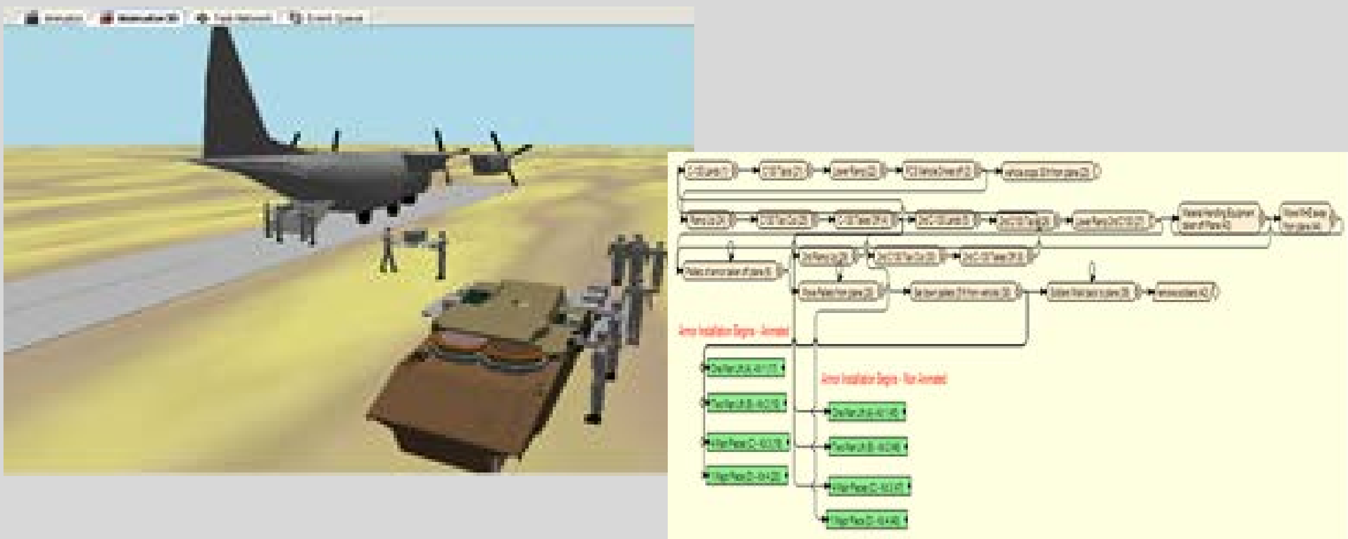
Using Discrete Event Simulation to Assess Human Lifting and Assembly of Vehicle Armor



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Year: 2006

Human Factors and Ergonomics Society Conference

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The Future Combat Systems (FCS) program goal is to develop the next generation of vehicles and networks for the Army. Eight configurations of Manned Ground Vehicles (MGV) are being designed as part of this effort. Requirements state that each MGV must weight less than 20 Tons to be C-130 transportable. To achieve this weight limitation the armor will be removed before flight. The armor will be flown in on a separate aircraft and installed at the destination. A specific challenge for the manufacturer of the MGVs is determining how best to utilize human resources in the installation process. This poster will describe the use of discrete event simulation to develop a human performance model that helps determine an optimal combination of manpower, armor panels, and installation equipment. Four different "up-armor" scenarios were simulated each with different manpower, number of armor pieces, size of armor pieces, and material handling equipment requirements.

SUMMARY

A major armored vehicle manufacturer is developing a series of manufacturing concepts for MGVs. Due to space and weight constraints, they are exploring the installation of the armor at the destination rather than complete assembly at the manufacturing plant. For this project it was assumed that the vehicle base will be flown in on one aircraft and the armor flown in on a second aircraft. There are several different ways that the armor can be designed and installed each with different cost, time, risk, and manpower requirements. To help analyze the question of which combination of armor, manpower, and equipment to use a human performance simulation model was developed to examine a portion of the armor installation process. The model was developed using Micro Saint Sharp as the modeling environment and simulation engine.

The simulation project was broken out into two phases. The first phase was a proof-of-principal step. During Phase I a simulation model of the assembly of the front section of the hull was developed. The Phase I simulation included a basic network model of the process flow and a 3D representation of the process. The second phase was the optimization phase where several scenarios were simulated and executed for comparison.

Results from the human performance simulation model show the number of personnel required, the time to unload the armor, time to assemble the armor, and number of pieces lifted by each person.

PROJECT STEPS

<u>Step 1: Define the scope and scenarios</u>
The goal of this effort was to evaluate alternative strategies for utilizing human resources in placing armor on the chassis and sizing the armor. There are trade-offs associated with each alternative. For example, if the armor pieces are small enough for one person to lift then a benefit is that the extra weight of transporting material handling equipment is not required; however there is a higher chance of injury and the effects of fatigue must be taken into account. If, on the other hand, several large pieces of armor are used, material handling equipment must be transported and the extra weight and space accounted for. Working with the customer it was decided that they wanted to simulate a full range of possible scenarios including one where many small pieces could be handled by one soldier to another that looked at having one large piece that would require material handling equipment.

Using simulation, productivity can be determined easily by measuring the amount of material moved within a certain amount of time. Physiological stress and human performance can also be approximated by incorporating algorithms from the human factors and material handling communities (Snook and Ciriello (1991) Waters, Putz-Anderson, Garg, (1994), Salvendy (1997)). In real life, excessive work stress results in increasing feelings of exhaustion and a decrease in productivity. The work-rest cycle as well as heat and other environmental stressors can contribute to the problem. These considerations were included in the development of the human performance model.

Four different "up-armor" scenarios were defined: 1 man lift/multiple small armor pieces, 2 man lift/larger armor pieces, 4 larger pieces/use of material handling equipment required, and 1 large piece/material handling equipment required.

<u>Step 2: Define the tasks and sequences</u>
Any system or process that can be drawn as a flow chart can be represented as a model in Micro Saint Sharp. This is a useful feature for human factors professionals because the task network diagram mimics the task analysis data collected. A high level sequence of 13 discrete tasks was defined in this

step. For each task, data regarding timing and resource requirements were also defined.

Step 3: Develop the 3D objects for the graphical animation
The vehicle manufacturer provided the necessary 3D armor graphics to animate the simulation. The graphics then had to be manipulated and formatted into the form needed by Micro Saint Sharp. For this effort, we also developed 3D representations of soldiers, a C-130 aircraft, tools (wrenches, drills, hammers, etc.), forklifts, and cranes.

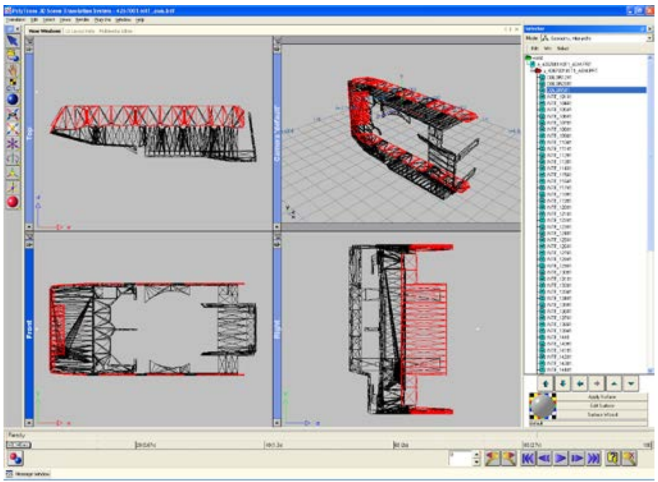

Figure 1 – Development of 3D Objects

Step 4: Develop the simulation model
Micro Saint Sharp uses a methodology known as task network modeling. Activities are represented in a diagram as nodes and the arrows between the nodes represent the sequence in which the activities are performed. This approach allows users to develop models using the same techniques they would use to define a flow diagram of the activity. Each activity, whether it is a human activity or a system activity, is defined using the same method. This forms the "backbone" of the model.

A Micro Saint Sharp model is composed of "networks" which may be a sequence of tasks to be performed by a human or a series of processes that define an organization. Networks are composed of either lower-level networks or "tasks." Tasks represent the lowest level in the model and have specific parameters (timing information, conditions for execution, beginning and ending effects). The degree of model complexity is flexible. A simple, functional model can be built just by drawing a network diagram and filling in the task timing and operator assignment information. Also a more complex model that includes dynamically changing variables, probabilistic and tactical branching logic, sorted queues, conditional task execution, and extensive data collection can be built in Micro Saint Sharp. Micro Saint Sharp includes a fully functional programming language (Microsoft C#). This sophisticated programming language makes it more efficient to write code especially for large, complex models.
The human performance model developed for this effort is shown in Figure 2.

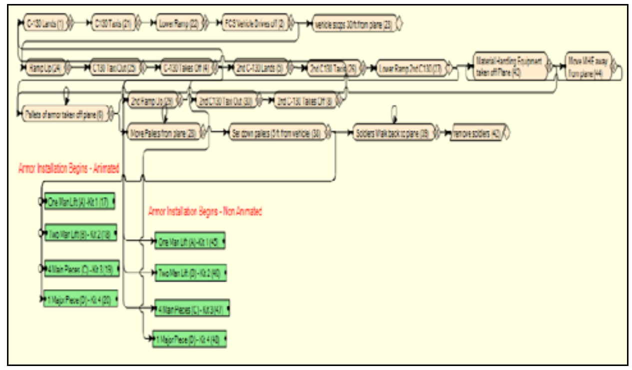

Figure 2 – Micro Saint Sharp Model

Step 5: Develop the 3D graphical animation
Three dimensional graphical animations were developed for each of the four scenarios using Micro Saint Sharp's Animator3D capability. Some examples are shown in Figure 3. The movement of personnel, equipment, pallets, aircraft, and armor pieces are all shown in a three dimensional environment. As the simulation is running users can move the camera around to obtain different views of the simulation as well as zoom in and out of the scene.

Figure 3 – Animator3D Examples

Step 6: Execute each scenario
The model was constructed so that non-modelers can easily change key parameters before executing the model. The key parameters include: which scenario to execute (A, B, C, or D), the number of vehicles to deploy, timing information for each

major task, the number of pallets to unload from the plane, the number of equipment available, and the number of soldiers available. Once these variables have been edited or verified, the simulation can be executed and results stored.

While the model is executing the user sees a 3D graphical depiction of the model. The movement of personnel, equipment, pallets, aircraft, and armor pieces are all shown in the Micro Saint Sharp Animator3D tool.

Users can also watch Micro Saint Sharp's symbolic animation capability as the model is running. This capability provides an animated view of the network diagram. Users can watch as entities flow through the network or wait in queues before being processed. This type of animation is particularly useful in debugging the model.

Step 7: Analyze results

The last step is to analyze the generated results. The data generated from the model includes: the optimal number of soldiers and equipment required to install the armor, the number of armor panels installed by each soldier, the amount of time required to unload the pallets, the amount of time required to "up-armor" the vehicle, the number of times each task was performed, and the amount of time any task was held up due to resource (human or equipment) constraints.

Using the simulation results, system engineers can make better informed decisions regarding the trade-offs between number of people required, number and type of equipment required, and the time required to armor the vehicles. In addition, they can analyze the effects of work stress on the people. The human performance simulation can also be used to execute various "what-if" scenarios such as:

- "What if there are only 4 soldiers available to armor each vehicle instead of the optimal 6?"
- "What if only one forklift and no cranes were available?"
- "What if it takes a longer amount of time to unload the armor from the plane?"
- or "What if heat stress is applied?"

Step 8: Optimize the Simulation

To determine which combination of options would best meet the objectives of 1) satisfying production rates, and 2) yielding the lowest cost, the cases were first run using the optimization capability included with Micro Saint Sharp.

Optimization deals with finding the best (optimal) solution to problems that in general can be expressed in the form of an objective function (to be optimized) and a set of constraints (which restrict the values of the decision variables).

To find the optimal solution, the following parameters were defined:

- *An objective function* which is an algebraic function consisting of model parameters, either input or output or both, that represents the desirability of that option. The objective functions for this study were 1) the time required to "armor up" the vehicles, and 2) the cost (labor and equipment).

- *A set of parameters that are to be varied* reflecting the solution space to be searched. For this study the parameters to be varied were the number of personnel and the number of material handling equipment.

Once the above items were defined, the process of optimization within Micro Saint Sharp and OptQuest is simply to select the "Begin Optimization" menu item. The optimization technique employs a combination of algorithms that seek to efficiently find the best solution.

The optimization procedure uses the outputs from the simulation model, which evaluates the affect of the inputs that were fed into the model. On the basis of this evaluation, and on the basis of the past evaluations that are integrated and analyzed with the present simulation outputs, the optimization procedure decides upon a new set of input values. The optimization procedure is designed to carry out a special "non-monotonic search," where successively generated inputs produce varying evaluations, not all of them improving, but which over time provide a highly efficient path to the best solutions. The process continues until some termination criterion is satisfied (usually given by a limit expressing the user's preference for the amount of time to be devoted to the search).

As the optimization runs a plot of the input variables and output objective function are graphed and displayed (Figure 4).

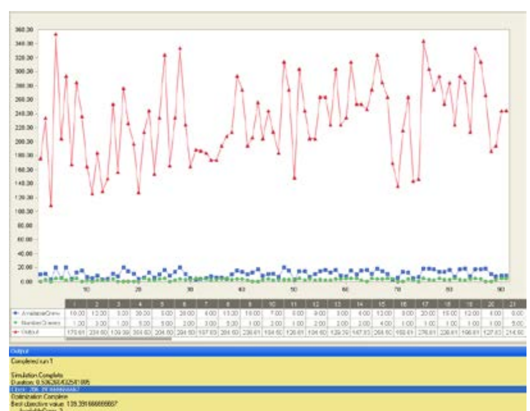

Figure 4 – OptQuest Output

The optimization was run for a scenario that required 5 vehicles to be deployed and assumed a maximum of 50 soldiers available. Results from running the optimization across the 4 scenarios is shown in Table 1.

Scenario	Number of Soldiers	Number of Material

	Required	**Handling Equipment**
A – 1 man lift	17	NA
B – 2 man lift	30	NA
C – 7 large pieces	18	5
D – 1 large piece	15	2

Table 1: Optimization Results

CONCLUSION

One aspect of the FCS effort concentrates on evaluating alternative strategies for placing the armor on the chassis and sizing the armor based on human performance. Simulation is an ideal tool for helping to quantify the benefits (i.e. number of panels, size of panels, labor hrs, and time required) associated with alternative scenarios. During this effort, it was shown that human performance simulation models can be constructed to allow easy input of alternative approaches. A graphical animation of the process was developed to aid in debugging and demonstrating the results. Using simulation, engineers were able to quickly and inexpensively examine multiple different design scenarios while understanding their impact on the human.

ACKNOWLEDGEMENTS

The work referenced in this poster was sponsored by Ms. Samantha Holdener, Mr. Torrey Pike, and Mr. George Thomas from BAE Systems in Santa Clara, CA.

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