COMPUTER MODELING IN FUNCTIONAL ALLOCATION

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ABSTRACT

The complexity of simulation systems has created a challenge for system designers in creating systems that are optimal for both machine and human performance. One of the most useful Human Factors analyses in creating an optimal simulation system is Functional Allocation. While several methodologies exist for Traditional Functional Allocation between humans and computers, many problems exist with current approaches. WARSIM 2000, a computer-based training simulation, has tackled the challenge using computer modeling tools. A new approach, Systematic Functional Allocation, was developed in response to problems identified with Traditional Functional Allocation. This paper outlines Traditional Functional Allocation and its associated problems, provides a general description of Systematic Functional Allocation and describes how the new approach was executed for WARSIM 2000. A sampling of computer models, as well as output reports are provided and discussed. Systematic Functional Allocation has assisted WARSIM Human Factors engineering in making critical design recommendations which have significantly impacted the system design. While this methodology was created specifically for WARSIM, it has potential for use by other simulation systems and domains.

AUTHORS' BIOGRAPHIES

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INTRODUCTION

The demand by the military community for sophisticated simulation systems to address training and readiness needs has increased dramatically. The complexity of these simulation systems has created a challenge for system designers in creating systems that are optimal for both machines and humans. More than ever, these designers are looking to Human Factors engineering (HFE) for guidance. Because technological capabilities have far surpassed the way humans can manually perform certain tasks, simulation training systems are being engineered with increasing automation. HFE must lead the way to narrow the gap between the built-in complexity of automated systems and the capacity of the human to adequately and efficiently respond to that system while completing the tasks required to effectively perform the job. Through various analyses throughout the design cycle, HFE provides sound user-centered design recommendations. One of the most useful analyses in creating an optimal simulation system is Functional Allocation.

Functional Allocation is a method used to decide how system tasks are shared between humans and machines (Hancock & Scallen, 1991). Such decisions are based on the capabilities and limitations of humans and machines in terms of accuracy, speed, reliability, flexibility and cost (Booher, 1990). In addition to capabilities and limitations, other less comparative factors should be considered such as task criticality, user expectations, social norms, and system requirements. The end result of a Functional Allocation analysis is a detailed specification that identifies the degree to which system tasks are to be performed manually by humans or are to be automated by machines.

The use of Functional Allocation analysis has recently contributed to the design of WARSIM 2000. WARSIM 2000 is a computer-based simulation system being developed to support training of U.S. Army commanders and their staffs from battalion through theater level. One key issue being addressed by WARSIM is that of manpower reduction. Existing simulation exercises can be manpower intensive. For example, to facilitate a corps level training exercise, the legacy system, Corps Battle Simulation (CBS), required in excess of 1000 staff members. Performing a functional allocation analysis provided an empirical method for quickly analyzing the most effective way to utilize the capabilities of humans and advancing technologies in system performance. Led by WARSIM HFE, a new approach to Functional Allocation was developed in response to problems identified with Traditional Functional Allocation (TFA). The new approach, Systematic Functional Allocation (SFA), was successfully executed for WARSIM 2000 and provided invaluable information to system designers.

TRADITIONAL FUNCTIONAL ALLOCATION

While Functional Allocation is a long-standing analysis performed by HFE and system engineering, a common method does not exist. Most methods, however, follow the same basic steps as illustrated in Figure 1.

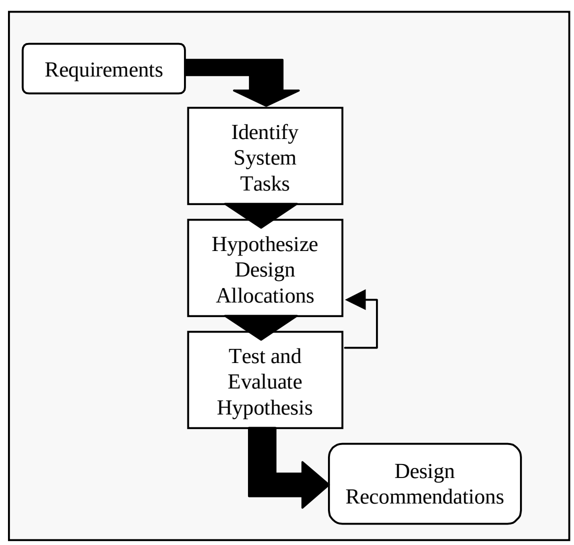

Figure 1. Traditional Functional Allocation

Identify System Tasks

In general, system tasks are identified by a detailed analysis of the system and derived requirements. This typically includes coordination with system designers and the end users. Unfortunately, early in the design cycle, system analysis information is very high level and it is difficult to identify system tasks in any detail. Consequently, this causes HFE to predict what system tasks and subtasks will be performed based solely on information they can gather. This information gathering process can be very time consuming and tedious. After system tasks have been identified, the next step is to hypothesize how either humans, machines, or both will accomplish the tasks.

Hypothesize Design Allocations

There are many guidelines available to HFE regarding which tasks humans and/or machines most effectively perform (Woodson, 1981). The best know is Fitts List (Fitts, 1951) which attempts to qualify tasks where humans surpass machines and vice versa. Using such guidelines, HFE can evaluate system tasks and predict the best combination of automation and manual control. One of the difficulties in hypothesizing how tasks should be allocated is that the capabilities of technology are continually changing. For example, in the past, a task that required inductive reasoning was always allocated to humans. Now, with the advances in artificial intelligence, computers may better perform an inductive reasoning task (Bradshaw, 1997). Consequently, many of the existing guidelines for Functional Allocation are dated and may lead HFE to make less than optimal allocations.

Test and Evaluate Allocations

Once allocations have been proposed, the next step is to test and evaluate. This is the most critical aspect of functional allocation. While most methods adequately evaluate individual allocations, they lack the ability to sufficiently evaluate the allocations as a whole. It is important to determine, prior to making recommendations, whether the performance requirements being imposed on the system users are within their capabilities. When uncertainties are identified, it is necessary to re-evaluate task allocations.

Design Recommendations

At the completion of the analysis, detailed recommendations are provided to system designers. The degree to which these recommendations are incorporated into the design is usually a function of scope of requirements, cost, and time. Additionally, it is essential that the design recommendations be provided early in the design cycle and to be continually monitored for implementation.

COMPUTER MODELING

Functional Allocation provides valuable information to simulation system designers. However, it is clear that traditional methods have encountered many difficulties. One solution identified by WARSIM Human Factors engineers was the use of computer modeling. Modeling lends itself well to helping solve human engineering design problems and is quickly becoming an integral tool for HFE.

The opportunities to use computer modeling in the development of training simulation systems have increased considerably. There are many reasons for this, most having to do with rising development costs, compressed schedule requirements and the need for performance enhancement. Functional Allocation provided yet another opportunity to take advantage of this technology.

In general, modeling allows a logical organization of system concepts, components, and tasks showing their constraints and relationships. Computer models provide the capability to build a hypothetical system, run it and collect quantitative performance data all before a single line of code is written for the real simulation system. Flexibility is a key advantage of using computer modeling for analysis. In a matter of minutes, an entire system can be redesigned and evaluated before expensive design decisions are made. With the visual representation provided by a model, design recommendations can be more clearly communicated and user expectations can be better facilitated. Using results from the simulated models, critical design recommendations can be made with confidence.

Clearly, computer modeling offers many capabilities that are needed in a Functional Allocation analysis. In particular, WARSIM HFE was interested in using modeling to empirically test and evaluate proposed task allocations. SFA was developed to capitalize on the strengths of computer modeling and incorporate strategies to avoid the problems of TFA as described. While developed for WARSIM, SFA is system independent and could prove useful to other simulation systems and domains. A generic description of the method is provided, followed by a detailed description of its use on WARSIM 2000.

SYSTEMATIC FUNCTIONAL ALLOCATION

SFA follows the same basic approach of Traditional Functional Allocation methods, as depicted in Figure 2. However, it differs from traditional methods in that it uses computer modeling, leverages off the legacy system, only examines key system tasks, and is performed by a cross-functional team. The SFA approach can be broken into four technical phases:

1) Front End Analysis,
2) Development of Models
3) Analysis of Models, and
4) Design Recommendations.

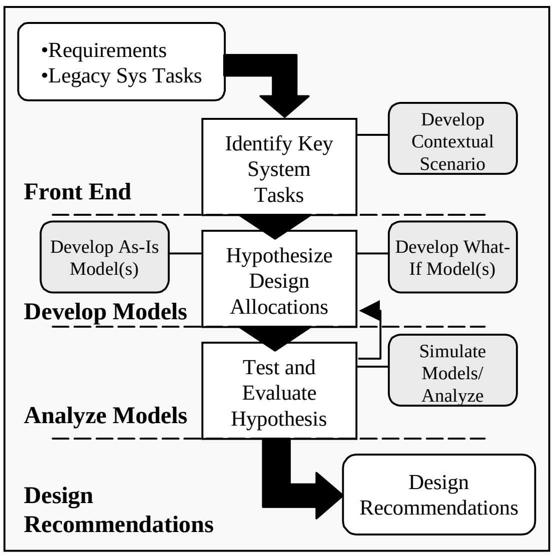

Figure 2. Systematic Functional Allocation

Front End Analysis

Front end analysis is the first phase of a SFA (see Figure 3).

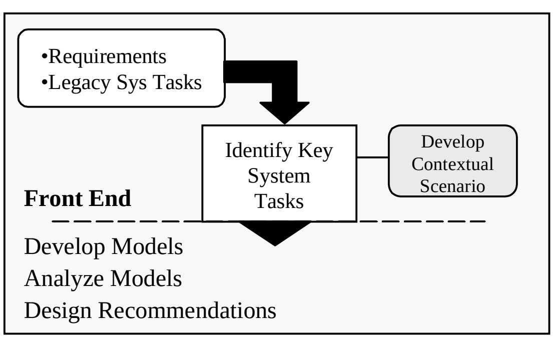

Figure 3. SFA: Front End Analysis

Front end analysis establishes a cross-functional team and provides fundamental information from which computer models will later be developed. The major steps accomplished during front end analysis are:

Formation of a cross-functional team:
A cross-functional team of Human Factors engineers, software engineers, subject matter experts and customer representatives is established. All team members are working toward a common objective and participate in a series of workgroups throughout the analysis. The cross-functional team ensures that there is confidence when design recommendations are made with regard to automation vs. manual control.

Review of system requirements:
The entire analysis takes place within the context of system requirements. It is important to review any existing system documentation. Software engineers contribute significantly to this task.

Analysis of legacy system tasks:
One of the problems found in traditional functional allocation methods is that it can be time-consuming and difficult to identify system tasks early in the design cycle. SFA leverages known information from the legacy system to identify system tasks. This allows for the analysis to be completed quicker and earlier in the design cycle. Documentation review, observation, and interviews are methods for performing the analysis of the legacy system tasks. Subject matter experts play a major role in this task.

Identification of key system tasks:
Rather than analyzing all system tasks, SFA examines key system tasks that are critical to system performance. While an initial set of key tasks is identified during the front end analysis, this set is dynamic in that tasks may be added, deleted or modified. Methods for identifying key tasks include review of system requirements, legacy system analysis, and interviews with subject matter experts and customer representatives.

Development of a contextual scenario:
Finally, a scenario describing a context for which the system will be used is developed. The scenario should be somewhat generic and attempt to reflect a typical use of the system. The scenario later serves as a baseline from which the models are developed.

Develop Computer Models

After completing the front end analysis, the second phase of SFA is development of the computer models (see Figure 4).

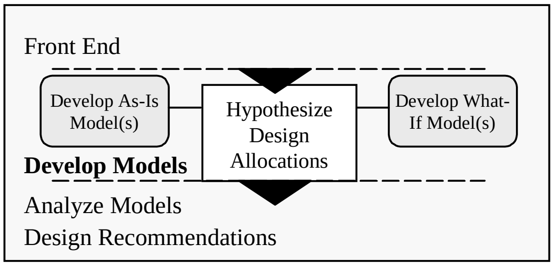

Figure 4. SFA: Develop Computer Models

Utilizing the information gathered and generated in the front end analysis, model development is done in a series of working groups with the cross-functional team. The major steps in developing the models are:

Develop As-Is model:

Using the contextual scenario, an As-Is computer model is developed based on how key tasks were performed using the legacy training simulation. The model should include tasks or actions performed by the training audience, the simulation controllers/analysts, and the simulation software/hardware. For all tasks in the model, time to complete tasks and required personnel are defined. Depending on the complexity of the system, it may be necessary to develop multiple As-Is and subsequently What-If models.

Hypothesize Design Allocations:

After developing the As-Is models, the next step is to hypothesize how the same tasks could optimally be performed by humans and/or machines in the new system. Using the legacy system to identify system tasks provides quick insight into the new system tasks. Evaluation of the system tasks is done in a similar fashion to traditional functional allocation. The requirements to accomplish each task are identified and then compared to the capabilities and limitation of humans and machines. The cross-functional team provides a comprehensive understanding of human/machine capabilities and limitations and continually considers end-user needs. Factors such as accuracy, speed, reliability, flexibility and cost are considered, as well as user expectations and social norms. For each of the identified tasks, an allocation between manual control, automation or a combination of both is proposed. Additionally, any recommendations on how machines could aid humans in performing manual tasks are included. Military-Handbook-46855A recommends that controls and displays, manning, procedures, and dynamic allocation be considered. The proposed allocations, relevant recommendations and any assumptions are then documented.

Develop What-If Models:

When allocations are being proposed, What-If computer models are developed based on how key system tasks could be performed using the new training simulation. Multiple What-If models may be developed so that different allocations can be compared against each other. To ensure comparability between the As-Is and What-If models the same contextual scenario should be used. Additionally, all events/tasks in the As-Is models should be incorporated and/or accounted for in the What-If model.

When hypothesizing allocations, it may be beneficial to create and run "mini What-If models" during working group sessions to quickly answer questions.

Analyze Models

After the computer models are created, the third phase of SFA requires analyzing the computer models (see Figure 5).

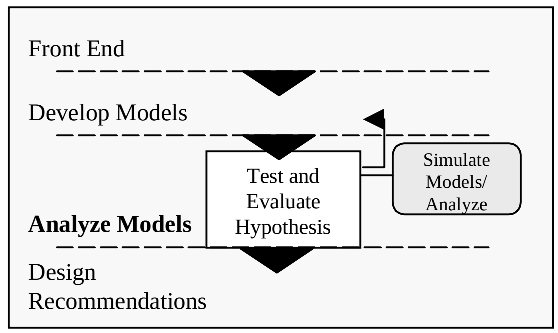

Figure 5. SFA: Analyze Models

Analysis begins by simulating the models and collecting output data. Most computer modeling tools provide data collection and analysis tools, which allow this to be a relatively simple task. Two types of analyses are of interest:

1) Comparison of two or more What-If models, and
2) Comparison of the As-Is model to one or more What-If models.

Two output variables are of particular interest in evaluation of the models:

1) Utilization of humans (e.g. training audience, controllers, analyst), and
2) Total time for the proposed system to complete tasks.

Both measures provide a common quantitative metric that can be used to compare the models. Total time for the proposed system to complete scenario tasks provides insight into the efficiency of the proposed allocations, where utilization of the humans can be correlated to workload.

Also of interest are bottlenecks in system tasks, delays in task execution, task frequency, task duration, and total required manning. If output data is not provided by the modeling analysis tool, most tools have the capability for unique variables to be created. However, there is usually more quantitative output data than required to evaluate the proposed allocations. Through the use of computer modeling, SFA provides a method to empirically test and evaluate proposed allocations very early in the design cycle. This is one of the greatest advantages of SFA over traditional functional allocation methods.

Note: It may be useful to analyze the As-Is model prior to hypothesizing allocations. Analysis of the As-Is model can identify legacy system inefficiencies and manpower intensive tasks, both of which are key areas of concentration for the What-If proposed allocations.

Design Recommendations

Finally, after all analysis is complete, allocation recommendations are documented (see Figure 6)

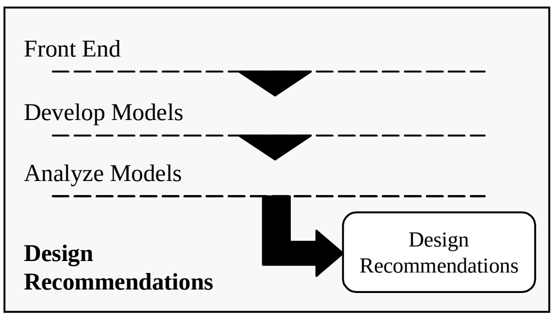

Figure 6: SFA Design Recommendations

Recommended allocations, as well as recommendations for controls and displays, manning, and procedures, are communicated with system designers. Since software engineering was involved in the analyses, the recommendations should already be familiar and accepted by the designers. However, it is important to continually monitor the recommendations throughout the development of the system. As the design evolves, it may be necessary to revisit the analyses if key system tasks change or if any assumptions are found to be incorrect. Also, if any of the proposed recommendations result in a drastic change from the legacy system, it may be necessary to develop a change management plan.

Limitations

Many strengths of SFA have already been discussed, however, like most analyses, SFA also has its limitations. Foremost, the new system being developed must be replacing a legacy system. If a legacy system does not exist or is deemed incomparable, this method should not be utilized.

Secondly, the cross-functional team must make subjective predictions for the future system. The team must predict what the new systems tasks will be and subsequently, predict human and machine capabilities. Consequently, the analysis findings are based on assumptions and educated predictions.

While these limitations are significant, it is important to remember that the goal of any Functional Allocation analysis is to provide design recommendations very early in the system design. Since early in the design very little is know about the actual system, HFE is required to perform predictive analyses. Therefore, as the design evolves it is extremely important that modifications are made to the analysis as needed.

A CASE STUDY: WARSIM

Front End Analysis

A cross-functional team was assembled to perform a functional allocation analysis for WARSIM 2000. Dynamics Research Corporation Human Factors engineers led the effort as part of the Lockheed Martin Information Systems' Integrated Development Team. The team consisted of Human Factors engineers (contractor and government), subject matter experts (both U.S. Army and CBS), user representatives (National Simulation Center), and software engineers. All team members were familiar with the system requirements at a high level, while individual team members were extremely familiar with subsets of requirements that were relevant to their own responsibilities.

The entire team contributed to formulating an approach to the functional allocation analysis. As a result, the Systematic Functional Allocation approach was developed. After formalizing the approach, an in-depth review of existing computer modeling tools was conducted. The requirements for the modeling tools were:

- Minimal training required to get started
- Models created through visual and graphical techniques (No simulation programming)
- Models quickly and easily modified for What-If analysis
- Provide expanded capabilities and flexibility
- Data collection and analysis tool provided
- Models graphically simulated and animated
- Inexpensive

While there are many commercially available computer modeling tools, the one that best met the team's requirements was Process Model®.

Concurrent to the modeling tool review, an analysis of the legacy system, CBS, was conducted. It consisted of reviewing CBS documentation, interviewing ex-CBS controllers and analysts, and observation of CBS training exercises by team engineers.

During the CBS analysis, it was identified that roleplayers and computer operators manually control system tasks from several functional "workcells". A workcell is a group of individuals that perform related simulation tasks to support the training exercise. Narrowing the analysis to a representative sample of functional workcells provided a means to focus on key system tasks. The workcells that were identified by subject matter experts as representative were Scenario Preparation, Maneuver, Aviation, Field Artillery, Combat Support, Division Logistics, Corps Logistics, Corps Armored Cavalry Regiment, and After Action Review. It was hypothesized that the findings from the key workcells could potentially generalize to other workcells not being studied.

A realistic battle scenario, based on a Division Warfighter training exercise, was created by subject matter experts to define the context for the workcell tasks which were to be modeled later. The scenario consisted of five major events: Occupy an Assembly Area, Hasty Attack, Movement to Contact, Hasty Defense, and Counter Attack. Since it was not feasible to analyze all of the selected workcells for each defined major event, a representative sample was selected.

Given the complexity of the analysis, the team decided to break it into smaller studies concentrating on each of the identified workcells. The study conducted for the Maneuver Brigade workcell performing a Movement to Contact event is the focus of this paper.

Develop Models

The As-Is model reflected a typical CBS Maneuver Brigade workcell conducting a Movement to Contact. Movement to Contact was selected as the battle event because it created a high level of activity in the workcell and the simulation. The tasks selected for the As-Is model were representative of those taking place in a typical maneuver workcell, covered the Mission Training Plan tasks and incorporated the simulation activities required to accomplish the warfighting tasks. In the contextual scenario, sixteen workcell staff provided command and control for two battalion task forces. The main events in the model were as follows:

1) Military Decision Making as defined in FM 101-5,
2) Execution of Movement to Contact,

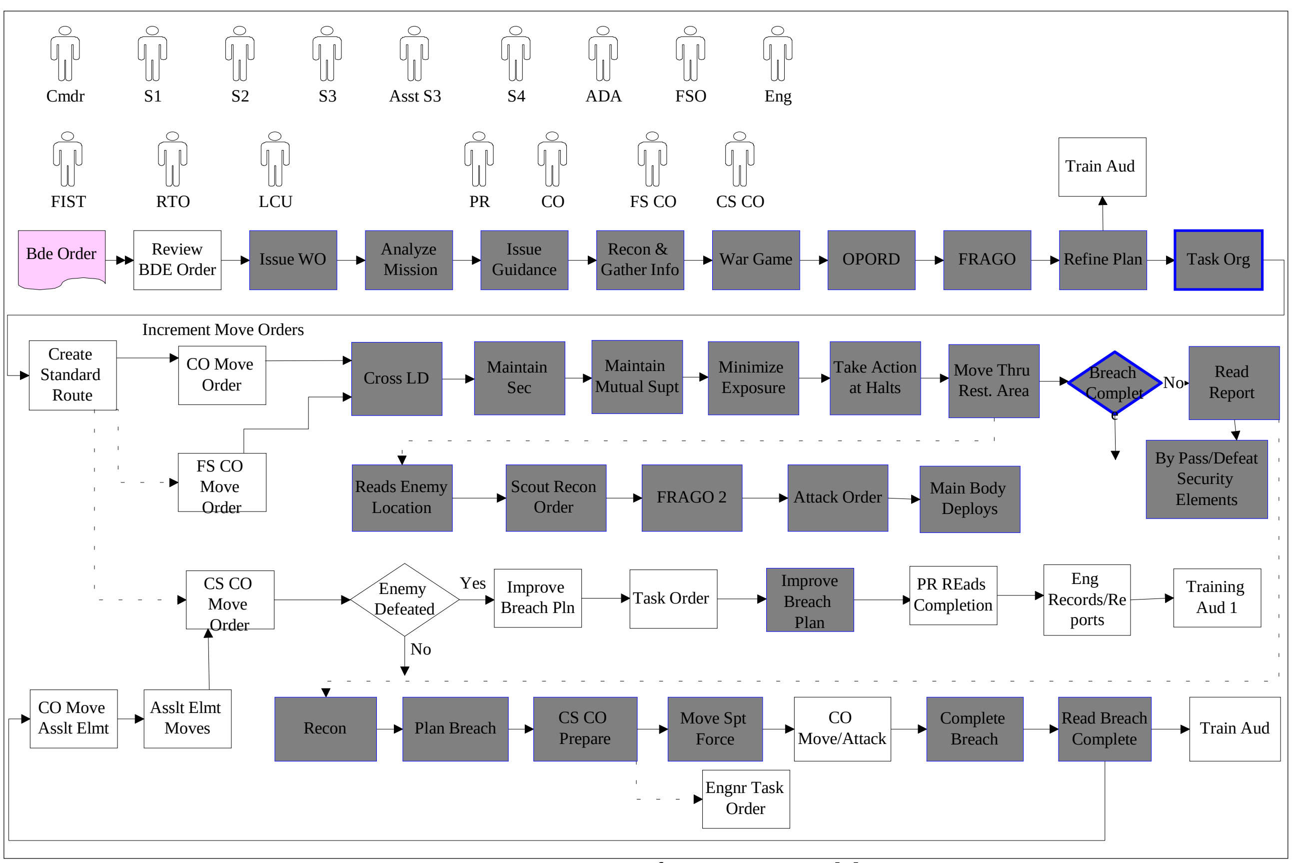

Figure 7. Representation of CBS As-Is Model

3) Actions taken when encountering obstacle,
4) Actions taken when encounter a security element,
5) Reading enemy location, and
6) Deploying the main body.

A representation of the As-Is model is shown in Figure 7.

After completing the CBS As-Is model, the team analyzed the system requirements and hypothesized how the identified system tasks could optimally be performed using WARSIM. To gain a better understanding of possible inefficiencies in CBS, the As-Is model was simulated and the results were analyzed. In general, the results indicated that some human controllers and roleplayers were underutilized and were manually performing repetitive tasks that could easily be automated. When hypothesizing task allocations for WARSIM, the team identified each of the system task requirements, identified problems in how they were performed in CBS and, using the team's collective expertise, brainstormed new solutions. The proposed task allocations for WARSIM were then documented in a What-If design matrix. Also included in the What-If design matrix, were recommendations for controls and displays, manning and procedures.

To ensure comparability of the As-Is and What-If models, the same battle scenario was used for both. The What-If model reflected proposed ways for performing WARSIM tasks in a Maneuver Brigade workcell conducting a Movement to Contact. All the events/tasks in the As-Is model were incorporated into the What-If model. However, many of the events/tasks were accomplished differently in the WARSIM What-If model as compared to the CBS As-Is model in order to maximize the human/machine capabilities. The What-If model was initially developed as the team discussed and hypothesized task allocations. Using a large screen projector, the team was able to use the modeling tool to facilitate many of the discussions. Later, using the What-If design matrix, HFE finalized the model. The initial What-If model had four workcell staff members controlling two battalion task forces (two staff members per battalion task force). Subsequently, after analysis, the workcell staff was increased to six (three staff members per battalion task force). A representation of the initial What-If model is shown in Figure 8.

Analyze Models

The results from the computer modeling indicate that the proposed task allocations between humans and machines will result in a more optimal system. The results indicate that staffing for the Maneuver Brigade workcell can be reduced from sixteen to six (66% savings) without system performance degradation. Modeling data, which shows CBS tasks performed using WARSIM in 48% less manhours, supports these conclusions. Additionally, it is predicted that three workcell staff can control each battalion task force being played in the Maneuver Brigade workcell.

The *Staff Percent Utilization* in the CBS As-Is model is shown in Figure 9. Sixteen workcell staff members were analyzed in the model. As can be seen, their

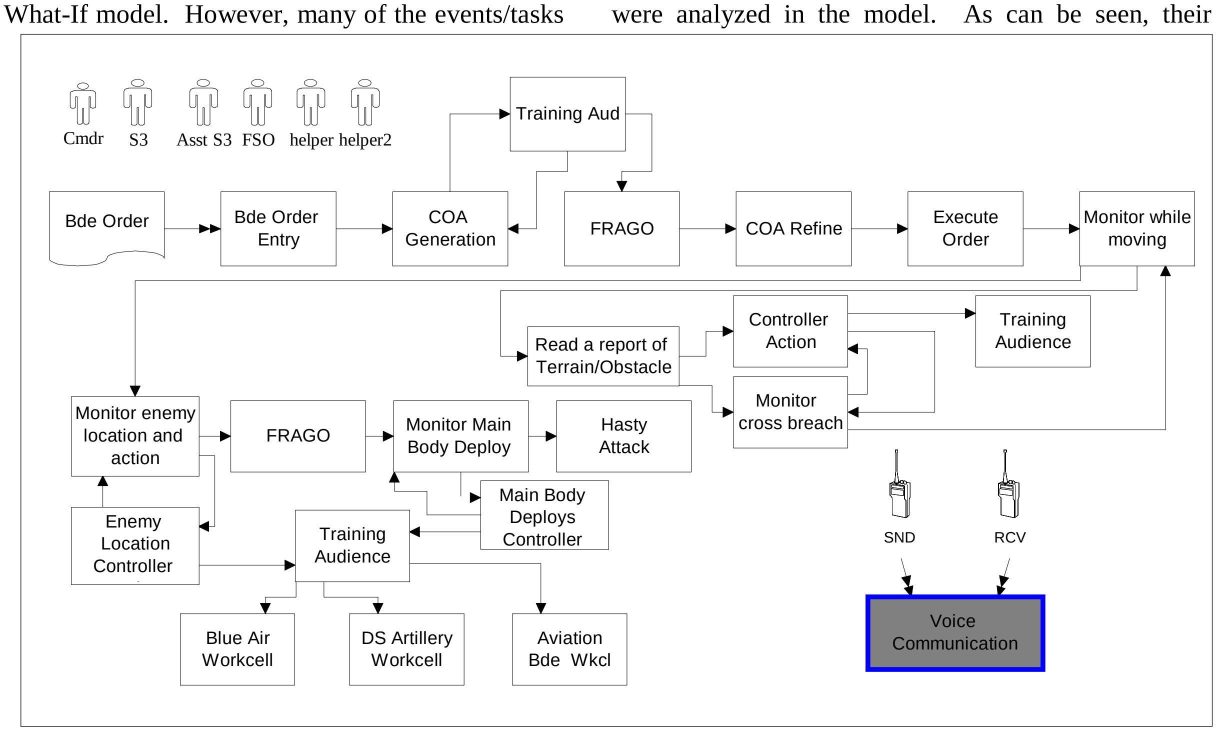

Figure 8. Representation of WARSIM What-If Model

extent of utilization varied considerably. For example, one staff member was busy performing tasks 45% of the time during the simulation while another was performing tasks only 22% of the time.

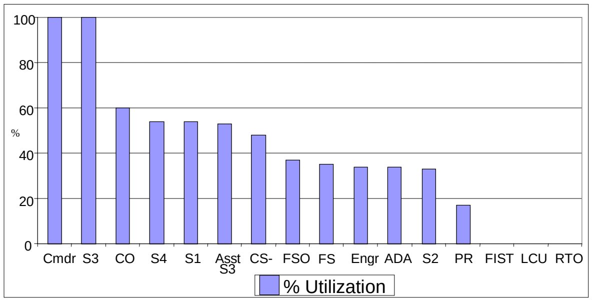

Figure 9. CBS As-Is Staff Utilization

In the What-If model, percent utilization was used to assess whether staff workload was acceptable given the proposed task allocations. Prior to simulating the What-If model, the team defined an acceptable threshold for utilization. The threshold was based on the following:

- Workload as measured by staff utilization should not exceed 95%. At the 95%-100% range, it was expected that there would be a decrement in staff performance and ultimately affects the training effectiveness of the exercise.
- 25% spare staff utilization was required. This reserve would account for workload peaks in the battle scenario.

Given the 95% upper threshold and the 25% spare utilization requirement, acceptable utilization was set at 70% or less as shown in Figure 10. If after running the model, utilization for any workcell staff in the What-If model was greater than 70%, workload would be predicted to be unacceptably high and changes would be required to the What-If model proposed task allocations.

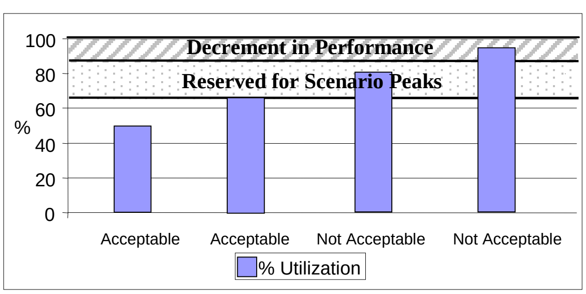

Figure 10. Staff Utilization Threshold

The percent utilization of the staff members in the WARSIM What-If Model is shown in Figure 11. This model had 4 staff members monitoring and controlling two Battalion Task Forces. Workload was deemed unacceptable, greater than 70%, for 3 of the 4 workcell staff.

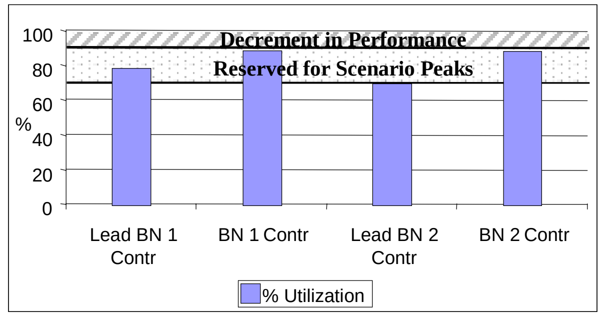

Figure 11. What-If Model Staff Utilization

Since the modeling results indicated that human workload was unacceptable in the What-If model, it was necessary for the team to make modifications. This required that the team revisit how tasks were going to be accomplished in WARSIM, or be allocated between humans and machines. The most simplistic solution was to increase the number of staff members, so that the work could be distributed across more staff members. This was deemed an acceptable solution and a Revised WARSIM What-If model was developed.

The percent utilization of the staff members in the Revised WARSIM What-If Model is shown in Figure 12. This model had 6 staff members monitoring and controlling two Battalion Task Forces. Workload was deemed acceptable, less than 70%, for all staff.

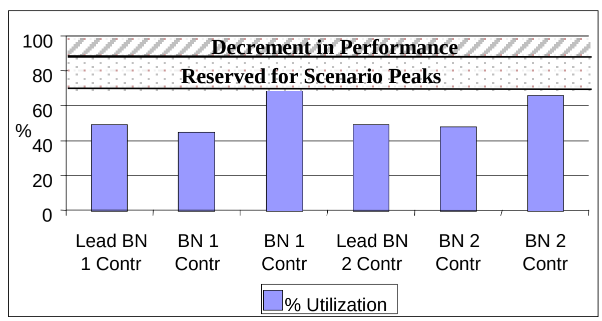

Figure 12. Revised What-If Model Staff Utilization

Also of interest in evaluating the proposed allocations, is the *Time for Task Completion*. This metric provides insight into how efficiently the As-Is and What-If systems perform the tasks required by humans in the scenario. As shown in Figure 13, the CBS As-Is model required 121 manhours to complete all tasks. However, the Revised WARSIM What-If model only required 63 manhours to complete all tasks or 48% savings from the CBS As-Is model.

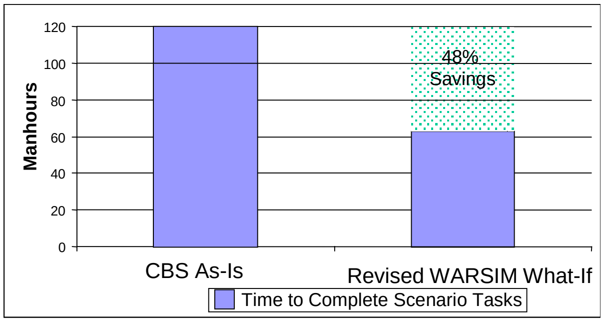

Figure 13. Time for Task Completion by Model

Finally, the last metric of interest is *Required Staff*. As shown in Figure 14, the CBS As-Is model required 16 staff per 12-hour shift to complete all tasks for the control of 2 battalion task forces. The Revised WARSIM What-If model required 6 staff per 12-hour shift to complete all tasks with 3 staff members providing control for each battalion task force. This is 66% savings from the CBS As-Is model. This savings is only possible when the recommended functionality and the suggested staffing are fully incorporated. If any of the design recommendations are not included or are minimally implemented, these predicted savings are no longer valid.

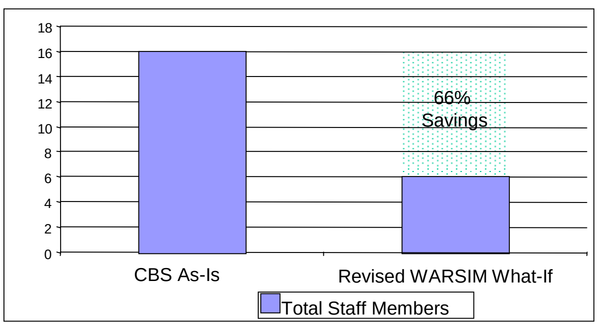

Figure 14. Required Staff by Model

Design Recommendations

After completing the analysis, system design recommendations were documented in an interim report in a manner useful to software engineering. The design recommendations were grouped logically into four categories: Automation, C4I, Human Computer Interface (HCI), and Increased Fidelity. Automation recommendations captured the proposed machine allocations, and C4I, HCI and Increased Fidelity captured proposed machine aids for manual tasks. A description of the type of recommendations included in each category is provided in Table 2.

Type	Description
Automation	Automation will enable complex time consuming manual tasks to be performed by the simulation software. Ideal for automation are tasks that require many staff members or take excessive time for completion (e.g. creating graphic overlays).
C4I	Integration of C4I equipment will provide a direct link for sharing digital information between the training audience and workcell staff. Additionally, it will provide a link between the training audience and the simulation.
HCI	Creation of an improved graphical HCI will provide a quicker and easier interface to the simulation. A graphical HCI will reduce time to input information into simulation (i.e. orders) and retrieve information from the simulation (i.e. unit status).
Increased Fidelity	Providing higher simulation fidelity for a particular function frequently reduces the workload of the workcell staff by: 1) providing more accurate and timely information about units, 2) requiring less translation from the simulation to the training audience and from the training audience to the simulation, and 3) reducing workarounds.

Table 2. Description of Recommendations by Type

Examples of recommendations are provided in Table 3.

Inefficiency In CBS	Recommendation for WARSIM
-Too many manual actions to access information about units under operators control.	**Automation:** Provide capability for workcell staff to access relevant information about units quickly. Techniques include filtering, query or listing. Critical unit information should be automatically displayed to workcell staff, rather than having to request it.
-Analyzing mission and wargaming is time consuming and requires many specialized staff.	**Automation:** Provide capability for simulation to facilitate analyzing the mission and wargaming. Cognitive estimators should provide functions previously performed by the ADA, Engr, S1, S4 and S2 staff.
Workload was not evenly distributed between workcell staff members.	**HCI:** Provide HCI capability to access any unit being played in the workcell from any workstation. This will allow for dynamic task sharing during peak times.
CBS staff members spend unnecessary time recreating the graphic overlays that come from the Training Audience.	**C4I:** Provide the capability for graphic overlays created by the training audience to be shared with the workcell staff using C4I. Overlays should be in a format that is reusable.

Table 3. Example of System Design Recommendations

Discussion

The recommendations provided to system designers have significantly impacted system development. As the system design progresses, some of the recommendations are being implemented completely, some at a modified level and others, have been found to be outside of the requirements. The most valuable aspect of the systematic functional allocation analysis was identifying critical issues very early in design. Some of the identified issues would not have otherwise surfaced until late in the design. The early identification provided significantly more time for evaluation of solutions.

The Maneuver Brigade analysis, reported here, is a piece of an effort still in progress. Along the way, many lessons were learned. These lessons include:

- The graphical animation provided by the computer modeling tool was very powerful. It quickly communicated ideas and facilitated discussions between designers and users. Initially, it helped to gain the support of program management in conducting the analysis.
- It was very difficult to schedule working groups, since it was necessary for a representative from each of the six functions be present. Scheduling became an elusive event because of the dependency on each member. It is recommended that each function have two representatives, to provide backups such that team productivity is not hampered.
- There was significant reuse of ideas and modeling components from one workcell to another. This allowed for better productivity as the effort progressed.
- Because of the magnitude of the effort, the analysis was limited to initially creating one What-If model per As-Is model. As needed, modifications were made to the initial models.
- Key factors examined in the functional allocation analysis were automation of repetitive tasks and processes, consolidation of common tasks performed by many individuals, and elimination of tasks that add little or no value to the end product.

CONCLUSIONS

SFA was developed and is successfully being utilized for WARSIM 2000, optimizing human/machine performance. The resulting design recommendations have assisted system designers in requirements analysis and have impacted the design considerably. Additionally, the analysis findings are supporting further definition of system hardware, manning, and training. While SFA was developed specifically for WARSIM, the method could be generalized and prove useful for other simulation systems and domains. The approach was accepted by the customer and supported by program management. Future efforts using the SFA approach should tailor execution based on the WARSIM lessons learned.

The use of modeling in Functional Allocation significantly improved HFE's ability to quickly perform a Functional Allocation analysis. Unlike TFA methods, the visualization, simulation and output data provided concrete information from which HFE could make human performance recommendations. As technology continues to advance, HFE will be forever challenged with ensuring systems are optimally meeting human performance requirements. This means designing more complex systems that are as easy or easier to use than predecessor systems. As demonstrated by SFA, HFE should be creative in their analytic approaches and take advantage of available technologies to support their efforts.

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