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Advanced Improved Performance Research Integration Tool (IMPRINT) Vetronics Technology Test Bed Model Development

Diane K. Mitchell

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Human Research & Engineering Directorate

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14. ABSTRACT

A researcher at the U.S. Army Research Laboratory built advanced Improved Performance Research Integration Tool (IMPRINT) models of the U.S. Army Tank-Automotive and Armaments Command (TACOM) Vetronics Technologies Test Bed (VTT) soldier-machine interface (SMI) simulator. These models allow the TACOM system designers and contractors to determine a number of soldier-related issues without modifying the VTT SMI itself. Specifically, TACOM system designers and contractors can use these advanced IMPRINT models to determine which crew members should do which functions and tasks, as well as where automation would benefit the crew members, and optimum placement of controls and displays.

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1. Background

System designers at the U.S. Army Tank-Automotive and Armaments Command (TACOM) have developed a crew integration and automation test bed (CAT) advanced technology demonstrator (ATD). TACOM system designers use the CAT ATD to demonstrate the crew interfaces, automation, and integration technologies required to operate and support future combat vehicles. One of the goals of the CAT ATD program is to use advanced technologies such as speech recognition, three-dimensional (3-D) audio, indirect vision, etc., to decrease crew workload and allow the crew more time to perform their mission.

The CAT ATD consists of two identical advanced technology crew stations, along with a safety driver crew station, integrated into a modified Bradley fighting vehicle chassis. Two crew stations are included in the CAT ATD because the CAT ATD program assumes that the future combat vehicle will be a two-person crew. The two identical crew stations are called the Vetronics Technologies Test Bed (VTT) station soldier-machine interface (SMI) simulator.

TACOM system designers can use the VTT SMI to determine if crew members can drive while they are also performing other mission-related tasks, such as engaging targets, scanning for targets, and command and control. Researchers can also use the VTT to evaluate different configurations and types of displays and controls. For example, they might compare the performance of a crew member who is sending command and control (C2) messages by pushing buttons on a flat panel display to the performance of that same crew member who is using verbal commands to send C2 messages. To make these comparisons, the equipment in the VTT would have to be reconfigured. Furthermore, to ensure that the results of their comparisons are valid, the system designers would have to test a large number of crew members operating the VTT SMI. However, reconfiguring the VTT SMI equipment and obtaining an adequate number of crew members to test would be expensive. Therefore, TACOM system designers asked U.S. Army Research Laboratory (ARL) researchers to build human performance models to represent the performance of the crew members operating the VTT SMI.

TACOM provided the ARL human performance models to General Dynamics Land Systems (GDLS) engineers, who are the contractors responsible for the next phase of the CAT ATD. GDLS engineers can modify these models or build their own similar models to represent several different configurations of equipment and function allocations. Multiple runs of the ARL models should be useful in predicting the optimum configuration of VTT SMI equipment and function allocation between crew members. The GDLS engineers would then use the optimum configuration of equipment and allocation of functions predicted by the models to evaluate crew member performance of mission functions in the VTT. This evaluation process allows the contractor to evaluate more configurations of equipment in less time with fewer crew members and is therefore more effective and less expensive for TACOM.

2. Model Development

2.1 VTT SMI Description

The VTT consists of two crew stations. Each crew station contains the same equipment: a seat, a yoke, two pedals, keyboard, and six computer displays. The crew station layout is shown in Figure 1. The crew station operator functions as a commander and driver or gunner and driver. If both crew stations are operating, one crew member is the gunner, the other crew member is the commander, and either crew member could be the driver. In addition, the crew members swap the driving tasks if necessary.

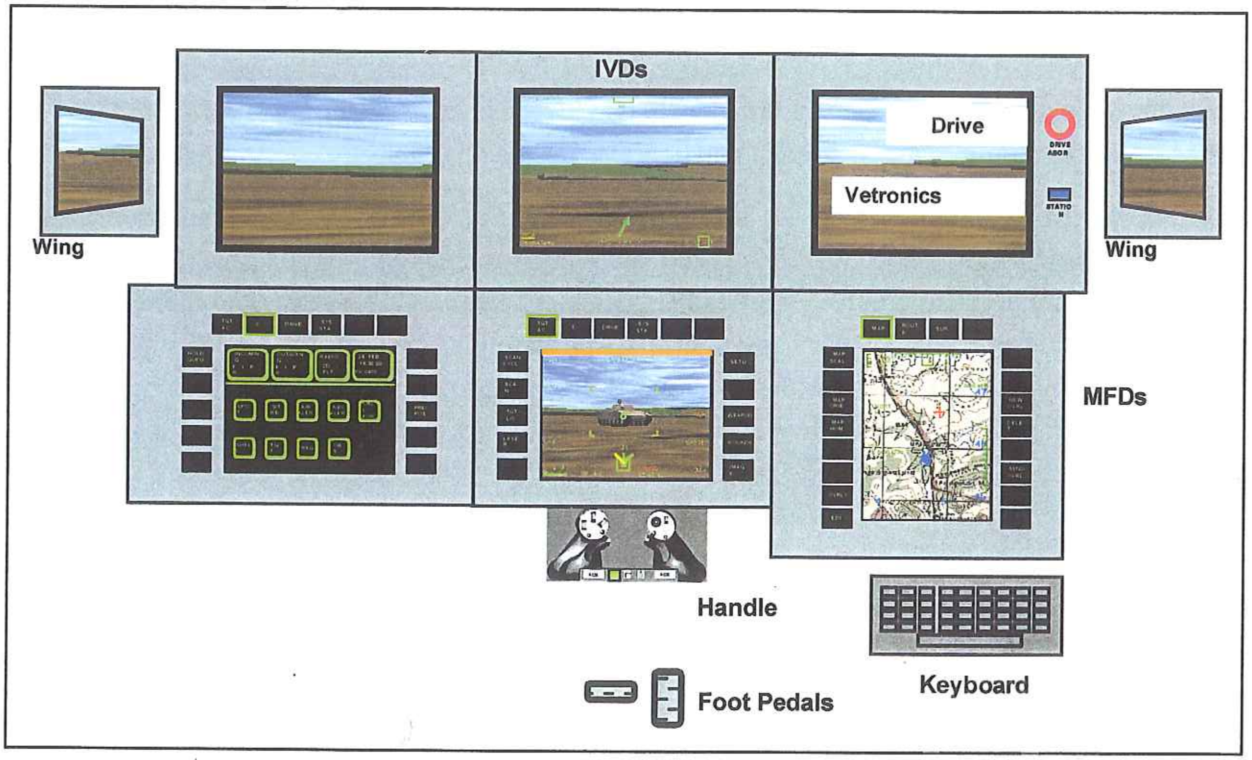

Figure 1. Vetronics technology test bed station SMI.

A crew member simulates driving the VTT using an indirect driving system. This indirect driving system allows the crew member driving in the VTT to see outside the vehicle through the use of video imagery. This video imagery is displayed for the crew member on three of the six computer displays that are situated horizontally in each crew station. The remaining three displays in the crew station are multi-functional displays. These displays are arranged horizontally and situated just below the indirect vision displays. The crew member selects any one of these multi-functional displays to show the instrument panel needed for simulated driving of the vehicle. Each crew station is also equipped with a pedal and yoke to simulate steering, accelerating, and decelerating of the vehicle.

In addition to a simulated driving capability, the VTT is equipped with a simulated target acquisition capability that allows the operator to search, detect, recognize, identify, "lock on," and track computer-generated targets. If two crew members are operating in the VTT, the target acquisition system permits each crew member to search independently for the targets. To show the target acquisition information, the crew member chooses any one of the three multi-functional displays.

In addition to simulated driving and target acquisition systems, the VTT is equipped with a C2 system, situational awareness capability, and auditory alerts. The C2 system permits digital and voice (intercom and radio) message communications. The situational awareness data are battlefield data that are displayed on a two-dimensional (2-D) color map or with a 3-D battlefield visualization capability. The C2 and battlefield visualization information can be displayed on any one of three multi-functional displays. The auditory alerts are warnings, cautions, and alert messages to the crew members when conditions warrant, i.e., a digital message is sent or acknowledged. The crew member is equipped with a headset intercom system that allows him or her to hear the auditory warnings. This intercom system also permits him or her to talk to the other crew member and send radio messages.

TACOM system designers use the capabilities of the VTT simulator to evaluate the crew interfaces, automation, and integration required to operate and support future combat vehicles. As part of the evaluation, TACOM system designers developed two combat scenarios for the simulator: scenario 1, a tank mission, and scenario 2, a scout mission. These scenarios present crew members in the simulator with a flow of tactical events that require them to perform the functions and tasks they would perform in combat during a tank or scout mission. As the crew members perform these tasks, the TACOM system designers observe them and identify potential human factors problems with the controls, displays, and allocation of tasks between crew members (Smart, Rapkoch II, Dahill, Fritz, and Williams, 1997).

One critical human factors area evaluated by the TACOM system designers is mental workload. The system designers want the mental workload to be evenly distributed and manageable as the crew members perform their tasks. To help them predict the mental workload of the crew members as they perform their tasks, ARL researchers have built task-network models of the VTT simulator. To build these networks, they used a human performance-modeling tool called IMPRINT.

2.2 IMPRINT Description

IMPRINT is a PC-based, human performance-modeling tool. System designers or analysts use IMPRINT to estimate the likely performance of a new military system by building models of each operational or maintenance mission that the system will be required to accomplish

(MicroAnalysis and Design, 1998). Because one of the critical components of operator and system performance is operator workload, IMPRINT has two options for generating workload profiles: visual, auditory, cognitive, and psychomotor workload option (VACP) and an advanced workload option. ARL researchers used the advanced workload option for the VTT modeling project. The underlying structure for the advanced workload option, as well as IMPRINT itself, is task network modeling and discrete event simulation.

Task network models are computer-based simulation models that the system designer can use to predict task times, task accuracy, and mental workload. The model consists of the tasks needed to accomplish a particular job or mission, the operator who performs each task, the amount of time it takes each task to execute, probability of success and the sequence by which the tasks are performed.

To build a task network model, the system designer begins with a mission or job that an operator(s) will be performing. Next, the system designer reduces the mission to the specific tasks and subtasks that the operator(s) need to accomplish to perform the mission. He or she then enters the sequence by which the operator(s) perform the tasks. This process is relatively easy for the designer to perform and can be done early in the design process. It has the added benefit of forcing the designer to think in great detail about all of the proposed system. In addition to the tasks to be performed and their sequence, the system designer building a task network model must also estimate the time required for the operator to complete each task. These task times are then entered into the computer model and used to calculate overall system performance time. If the task network model is a deterministic model with non-parallel tasks, then the times entered for each task will sum to the estimated mission time. With a stochastic task network model, however, the times for each task can be drawn from a distribution of times. The resulting system performance times for the stochastic model are an average of the randomly selected times. Because human behavior varies, the stochastic task network model is a more realistic representation of system operators than the deterministic model. Therefore, the IMPRINT software is based on a stochastic rather than deterministic task network modeling technique.

In addition to being a stochastic task network modeling tool, IMPRINT uses discrete event simulation to model human performance. Discrete simulation and continuous simulation are two broad classes of simulation models. The type of simulation an analyst uses depends upon the types of problems to be solved. "For example, a model of traffic flow on a freeway would be discrete if the characteristics of and movement of individual cars are important. Alternatively, if the cars can be treated 'in the aggregate,' the flow of traffic can be described by differential equations in a continuous model" (Law and Kelton, 1991). Because the system designer is interested in the operator's tasks individually, not as an aggregate, discrete simulation was selected as the basis for IMPRINT. More specifically, IMPRINT is based on a discrete *event* simulation. A discrete *event* simulation is appropriate when the elements of the process modeled have a distinct beginning and ending as do all the missions and tasks modeled with IMPRINT.

The specific task network tool and discrete event simulation model used in the IMPRINT software is the commercially available Micro Saint.

Micro Saint is a task network simulation language developed by MicroAnalysis and Design (MA&D) for the U.S. Army Materiel Research and Materiel Command. Micro Saint makes it simple for system designers to build task network models by providing a graphical user interface (GUI) and flow chart approach to modeling. Using Micro Saint, the system designer builds a graphical representation of the task network that is also a graphical representation of the job or mission that the system operator will be performing. Figure 2 depicts an example of a graphical representation of a task network.

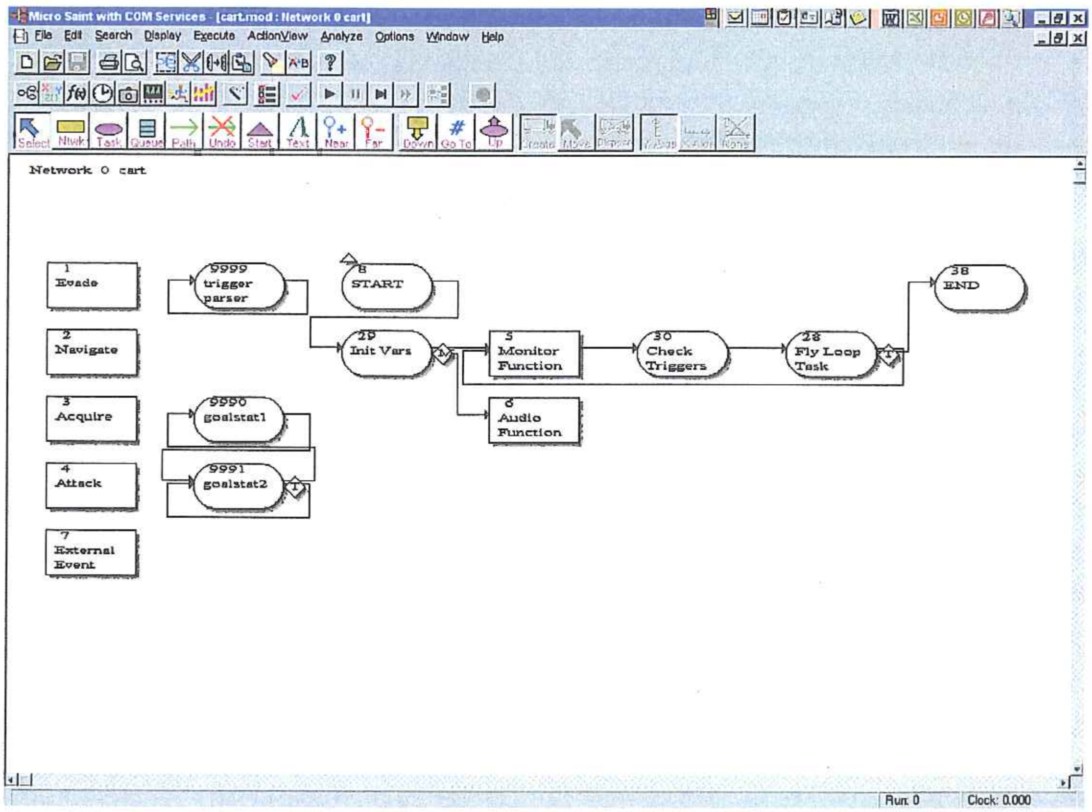

Figure 2. An example of a task network.

As Figure 2 depicts, the system designer uses rounded rectangles to represent modeled tasks and arrows to connect the tasks to represent the order of task execution within the mission. Once the designer has completed the task network, the Micro Saint software links the tasks, task times, and individual performance together in the model and simulates the system operator performing a mission. The system designer uses a modified version of the Micro Saint GUI to model the operator's tasks with IMPRINT. In addition to modeling the tasks and task times, however, the system designer can also use IMPRINT to model operator mental workload with either of its two options, VACP or advanced workload analysis. The advanced workload analysis was selected for this project because the workload estimate generated from this option allows the analyst to consider what particular equipment the operator is using to do his or her tasks.

2.3 Advanced Workload Analysis

The relationship between workload and performance is complex. It is not simply that as workload increases, performance decreases. Instead, the relationship between workload and performance is traditionally described as an inverted "U" relationship because decrements in performance may occur if workload is either too low or too high. Furthermore, there can be a disassociation between workload and performance at certain levels. This means that as workload increases, the operator's performance may not decrease because the operator has a strategy for handling task demands to compensate for the increased workload. Hart (1989) proposed that operator workload strategies play an important role "in determining the relationship between objective task demands, experienced workload, and system performance (p.4)." The advanced workload analysis feature of IMPRINT allows the system designer to incorporate operator workload management strategies into the workload model.

To obtain a workload estimate using the advanced workload analysis option, the system designer first selects a job or mission that the operator(s) of the proposed system will perform. Next, the system designer segregates the selected mission into the tasks the operator(s) will be performing in order to accomplish this mission. The task sequence and the operator(s) who will perform these tasks are then identified. Next, the advanced workload analysis option links workload to the specific equipment used by the operator. This option links workload and equipment because it contains an embedded workload calculation algorithm. This algorithm, which is depicted in Figure 3, is based on a variation of the W/INDEX model (North and Riley, 1989). It calculates workload based on the resources being used by the operator and incorporates the fact that multiple tasks are being performed simultaneously. In addition, the algorithm relates the resources used to crew station displays and control surfaces (Little et al., 1993). Because the advanced workload analysis option contains this algorithm, the system designers must specify the equipment interfaces (e.g., keyboard, helmet-mounted display) that operators will be using to accomplish each of their assigned tasks. Furthermore, the designer must also specify the mental resources that a crew member uses with each equipment interface as he or she performs each task.

With the advanced workload, method, the mental resources are a set of five channels: visual, auditory, cognitive, psychomotor, and speech. In addition, the system designers can create their own resources. For example, the system designers' research may indicate that the tactile resource is important for their design. They can then add this to the resource list in the advanced workload analysis option. However, no default scales are available to help the designers estimate workload for this resource. They must substantiate values for this resource, based on current research. If the system designers choose to use the default resources, they can rate the amount of each of these resources required to do a task with 7-point rating scales. These scales are modified versions of scales developed by McCracken and Aldrich (1984). The McCracken and Aldrich scales have been revised in the advanced workload analysis option because the original scales were developed for estimating workload for the Army's light helicopter. Based on subject matter experts' (SMEs') recommendations, some of the scale values were revised to represent workload for Army tanks. In addition, the psychomotor resource was divided into two separate resources: motor and speech. The revised scales are provided in Table 1. The system designers use these scales to estimate the resources required for each task an operator performs. After the system designer has entered the workload values, the workload algorithm embedded in IMPRINT calculates the mental workload. The calculation method in this algorithm is based on multiple resource theory (MRT).

$$W_T = \left[\sum_{i=1}^{l}\sum_{t=1}^{m} a_{t,i}\right] + \left[\sum_{i=1}^{l} c_{i,i}\sum_{t=1}^{m} a_{t,i} + \sum_{i=1}^{l-1}\sum_{j=i+1}^{l} c_{i,j}\sum_{t=1}^{m-1}\sum_{s=t+1}^{m}\left(\left(a_{t,i}+a_{s,j}\right)+\left(a_{t,j}+a_{s,i}\right)\right)\right]$$

W_T = instantaneous workload at time T

i, j = 1…l are the interface channels

t = 1…m are the operator's tasks or activities

$a_{s,i}$ = attention to channel i required to perform simultaneous task s

$a_{t,i}$ = attention to channel i required to perform task t

$c_{i,j}$ = conflict between channels i and j

$c_{i,i}$= conflict within channel I

and

1. if $a_{t,i}$ or $a_{s,j} = 0$, then $(a_{t,i} + a_{s,j} = 0)$;

2. if $a_{t,j}$ or $a_{s,i} = 0$, then $(a_{t,j} + a_{s,i} = 0)$.

Figure 3. Workload algorithm.

According to MRT, when an individual performs a task, he or she requires different mental operations and to some extent, each operation uses the mental processing resources necessary to accomplish the task. These mental resources are limited and a supply-and-demand problem occurs when the individual performs two or more tasks that require a single resource. As a result of time sharing of resources, some task performance times may increase, probability of successfully completing a task may change, or performance times may decrease (Little et al., 1993). These MRT concepts are the underlying assumptions for the advanced workload option in IMPRINT. MRT theory, however, also explains how two tasks can conflict with each other.

According to the multiple resource model, two concurrent tasks will suffer greater interference to the extent that the component tasks are more difficult (demand more resources) and that the components compete for overlapping resources. Furthermore, the effects of difficulty and resource overlap interact. The greater the degree of resource overlap, the more pronounced will be the effect of the level of difficulty of one task on the level of performance of another task (Little et al., p 9). The workload algorithm in the advanced workload analysis option incorporates the MRT findings. It sums the resource demands and also includes penalties for situations when two tasks require the same resources and for situations when the use of different resources causes interference. The workload algorithm itself is presented in Figure 3.

Table 1. Revised UH-60 helicopter workload component scales

Scale Value	Descriptors	New Values
	Visually unaided (naked eye)	
1.0	Visually register/detect (detect occurrence of image)	3.0
3.7	Visually discriminate (detect visual differences)	5.0
4.0	Visually inspect/check (discrete inspection/static condition)	3.0
5.0	Visually locate/align (selective orientation)	4.0
5.4	Visually track/follow (maintain orientation)	4.4
5.9	Visually read (symbol)	5.0
7.0	Visually scan/search monitor (continuous/serial inspection, multiple conditions)	6.0
5.0	Visually aided (night vision goggles [NVG])	
4.0	Visually register/detect (detect occurrence of image) with NVG	5.0
4.8	Visually inspect/check (discrete inspection/static condition (with NVG)	5.0
5.0	Visually discriminate (detect visual differences) with NVG	7.0
5.6	Visually locate/align (selective orientation) with NVG	5.0
6.4	Visually track/follow (maintain orientation) with NVG	5.4
7.0	Visually scan/search/monitor (continuous/serial multiple conditions) with NVG	7.0
	Auditory	
1.0	Detect/register sound (detect occurrence of sound)	1.0
2.0	Orient to sound (general orientation/attention)	2.0
4.2	Orient to sound (selective orientation/attention)	4.2
4.3	Verify auditory feedback (detect occurrence of anticipated sound)	4.3
4.9	Interpret semantic content (speech) simple (1 to 2 words) complex sentences	3.0 6.0
6.6	Discriminate sound characteristics (detect auditory difference)	6.6
7.0	Interpret sound patterns (pulse rates, etc.)	7.0
	Cognitive	
1.0	Automatic (simple association)	1.2
1.2	Alternative selection	1.2
3.7	Sign/Signal recognition	3.7
4.6	Evaluation/judgment (consider single aspect)	4.6
5.3	Encoding/decoding, recall	5.3
6.8	Evaluation/judgment	6.8
7.0	Estimation, calculation, conversion Rehearsal	6.8 5.0
	Psychomotor (this scale was divided into speech and motor in revised scale	
1.0	Speech Speech simple (1 to 2 words) complex (sentence)	 2.0 4.0
	Motor	
2.2	Discrete actuation (button, toggle, trigger)	2.2
2.6	Continuous adjustive (flight control, sensor control)	2.6
4.6	Manipulative	4.6
5.8	Discrete adjustment (rotary, vertical thumbwheel, lever position)	5.5
6.5	Symbolic production (writing)	6.5
7.0	Serial discrete manipulation (keyboard entries)	7.0

The first part of the workload algorithm computes the resource demands for all active tasks. Therefore, each time a new task is started, the algorithm adds the workload ratings for each resource for the new task and all other tasks being performed at that time. The next two terms within the second bracket of the equation compute the penalties for two tasks using the same resource at the same time and two tasks requiring different resources at the same time. For example, if one task requires a system operator to look at a computer screen on the right side, while a second task occurring simultaneously requires the operator to look at a computer screen on the left side, then the equation assigns a penalty to the task. In this case, the penalty would be that one task could not be performed. In other cases, the penalty might be that a task's time is increased. The penalty is assigned because the two tasks are using the same resource at the same time. The system designer determines the amount of interference between resources being used by concurrent tasks by entering values into a conflict matrix provided in the software. The conflict matrix displays each resource paired with the equipment interface that uses the resource. For each resource and interface pair, the designers enter conflict values based on guidance from their own research, or the software can provide default values based on the MRT literature. The conflict values can range from 0 (represents no conflict) to 1.0 (represents total conflict). The conflict values will be unique to each system design because the values are linked to both equipment interfaces and resources. Each design will have a different set of equipment interfaces that use specific resources and therefore its own set of conflict values.

After the system designers have provided conflict values and workload ratings for each operator for each task, the algorithm calculates the workload for each operator before the start of a new task, at the start of a new task, and finally when a task is completed. In addition to calculating this overall workload, the advanced workload analysis option allows system designers to specify how the system operator will manage the workload. They do this with the workload management strategies. These strategies, however, were not used in the VTT modeling effort.

The advanced workload analysis reports include a mission summary, critical path report, workload graphs, and reports describing the operator activity, overload, and channel conflicts. From these reports, system designers can view the total workload value over time for each operator of the system. Because this value is on an ordinal scale, it allows the system designer to make only relative comparisons of workload at different times during the mission. This means that the system designer should not compare specific overall workload numbers. Instead, the designer examines the workload graphs and determines where the workload peaks are and which tasks were operating at that time and contributed to the peaks. The designer can then select these tasks as candidates for redesign, automation, or reallocation to another crew member (Archer, 1998). Furthermore, the process of building and entering data into the models helps the system designers to think about those interfaces and tasks that are contributing factors to workload and performance.

2.4 VTT IMPRINT models

The task network models ARL built were built in advanced workload IMPRINT. They represented two crew members performing the functions and tasks of two scenarios provided by TACOM. Scenario 1 was a tank mission and Scenario 2 was a scout mission. For each scenario, two models were built at different levels of task detail. Specifically, one model included tasks for each operator button push. The tasks in the other model were broader tasks. An example of a task in the first model might be "push C2 button." The task in the second model might be "send C2 message." Examples of the task networks for each model are provided in Figures 8 and 9.

ARL researchers decided that the button-push models were necessary because it was anticipated that the nature of some tasks might change in future versions of the VTT. Specifically, some of the command and control tasks that are currently performed by a user touching a flat panel display might be converted to voice-activated commands. Comparing the mental workload of these two sets of interfaces, touch versus voice, would necessitate a model built to the button-push task level. Therefore, ARL researchers modified the initial tank and scout models to more detail that simulated operations as simplistic as a keystroke.

The initial models and the button-push models developed by ARL consisted of two sets of VTT models: two tank models and two scout models (see Table 2). The VTT tank models are called VTT tank and VTT tank Alexandria. The VTT tank Alexandria model is detailed to the button-push level. In both models, ARL built an advanced IMPRINT task network of a tank commander and a gunner performing the functions and tasks of TACOM scenario 1 in the VTT SMI. In the preliminary simulation runs, the tank commander performs the functions of driving, monitoring communications from higher headquarters, scanning for targets, communicating with the gunner. Additionally, the commander performs all command tasks associated with the tank mission, e.g., developing the fire plan, planning routes, etc. The gunner performs the functions of scanning for targets, communicating with the commander, engaging targets, and destroying targets.

In subsequent runs, the driving function is reallocated to the gunner. In these runs, the gunner drives and performs the functions of scanning for targets, communicating with the commander, engaging targets, and destroying targets (see Table 3).

The VTT scout models are similar to the tank models. The models are called VTT Scout and VTT Scout Alexandria. The VTT Scout Alexandria models tasks to the button-push level. In both models, ARL built an advanced IMPRINT task network of a platoon leader and a sergeant performing the functions and tasks of TACOM scenario 2 in the VTT SMI. In the preliminary simulation runs, the platoon leader performs the functions of driving, monitoring communications from higher headquarters, scanning for targets, communicating with the sergeant. Additionally, the platoon leader performs all reconnaissance tasks associated with the scout mission. The sergeant performs the functions of scanning for targets, communicating with the commander, engaging targets, and destroying targets.

Table 2. Advanced IMPRINT models of the VTT

IMPRINT Model	Level of Task Detail
VTT Tank	no button- push tasks
VTT Tank Alexandria	button-push tasks included
VTT Scout	no button-push tasks
VTT Scout Alexandria	button-push tasks included

In subsequent runs, the driving function is reallocated to the sergeant. In these runs, the sergeant drives and performs the functions of scanning for targets, communicating with the commander, engaging targets, and destroying targets (see Table 3).

Table 3. Analysis conditions

Analysis Condition	Model Name	VTT Scenario	Crew Members	Primary Responsibility	
				Driving	Scanning
1	Scout Alexandria	2(scout)	Platoon Leader	x	x
			Sergeant		x
2	Scout Alexandria	2(scout)	Platoon Leader		x
			Sergeant	x	x
3	Tank Alexandria	1(tank)	Tank Commander	x	x
			Gunner		x
4	Tank Alexandria	1(tank)	Tank Commander		x
			Gunner	x	x

In addition to building the task networks for the scout and tank models, the ARL researchers had to incorporate workload data into the models. The IMPRINT workload equation is presented in Figure 3. To satisfy the requirements of this IMPRINT workload equation, the ARL researchers entered into the IMPRINT model the following information: interface used by the crew member to perform the tasks, the mental resources required to perform the task, the amount of the resource required, based on the 7-point scales presented in Table 2, and conflict values for the multiple tasks occurring simultaneously. Based on these values, the IMPRINT software calculated workload predictions for the operators as they perform the tasks associated with each function in each mission. The researchers then examined these workload predictions to see if they exceeded acceptable workload levels.

3. Analysis and Discussion

After the ARL researchers completed the simulation runs for the scout and tank models, they analyzed the workload data. The data were analyzed for the button-push-level models only. The button-push-level models were VTT Scout Alexandria and VTT Tank Alexandria. The no-button-push models, VTT Tank and VTT Scout, contain similar tasks as the button-push models, VTT Tank Alexandria and VTT Scout Alexandria. The tasks were decomposed into greater detail in the button-push models. Because the difference in models was simply attributable to level of detail, the analysis results for the no-button-push VTT Tank model and the button-push VTT Tank Alexandria would be the same. However, in the VTT Tank Alexandria, the analysis would tell exactly what button pushes contributed to the workload. This is also true for the VTT Scout and VTT Scout Alexandria models. Therefore, the button-push VTT Tank Alexandria and VTT Scout Alexandria were the models runs analyzed.

The first step in analyzing the workload data is to determine a workload threshold for the data. The workload threshold is the point where high workload is expected to create a decrement in performance. Initially, ARL researchers selected a workload threshold of 40 ±10 as a basis from which an evaluation of workload overload would be performed. They selected this value because previous research (Reid and Colle 1988) had determined 40 ±10 to be the critical workload values for predicting operator overload in an air crew study. However, the tasks in the Reid and Colle study were flying tasks, and the tasks in the VTT are ground vehicle tasks. In addition, the Reid and Colle workload ratings were obtained from a subjective workload scale rather than the McCracken and Aldrich scales used in IMPRINT.

Considering these differences, when ARL and MA&D SMEs reviewed the workload peaks from the model runs, they determined that this was too low a threshold for the VTT tasks. The tasks performed by the subjects when the workload was in the 30 to 50 range could most likely be performed simultaneously without performance decrement. However, a review of the tasks occurring when the workload was 60 or above indicated that performance decrements might occur in this range. Therefore, the researchers selected 60 as workload threshold for this study. The following sections detail each model simulation run and the tasks that the operators were performing when they experienced a state of overload.

3.1 Condition 1. Scout Alexandria – Platoon Leader (PL) Driving and Scanning for Targets

This model scenario was designed to emulate a scout mission being conducted in the VTT simulator and allows assignment of operator tasks performed versus automated tasks. The two crew members performing the scout mission were a platoon leader and a sergeant. In this instance, the platoon leader was assigned the driving and scanning for target tasks with no automation aids for the tasks. The model represented the tasks necessary to accomplish the scenario objectives of route reconnaissance, tactical planning, moving to and occupying objective position. These scenario objective functions are supplemented by the operator functionality necessary to successfully accomplish these objectives. Tasks included among the operator functionality built into the model account for operator actions such as monitoring command and control (C2), platoon leader scanning for targets, platoon leader driving, sergeant and platoon leader communicating, and a variety of other functions. For the purposes of the first scout Alexandria condition, the sergeant was eliminated from the driving tasks because the platoon leader was the driver. However, the sergeant did scan for targets and communicate with the platoon leader via a headset.

The model runs showed that the platoon leader experienced 109 instances of overload over the course of a 3-hour mission scenario while performing scanning and driving tasks. The tasks that occurred most frequently during the instances of overload were the following:

PL glances at indirect vision display

PL scans for targets with thumb on control

PL adjusts steering using handle

PL press accelerator

PL talks via headset.

The highest instance of operator overloading had a total workload score of 199.16. The tasks that were performed at this time were

PL presses accelerator

PL scans for targets thumb on control

PL adjusts steering using handle

PL glances at indirect vision display

PL listens via headset

Together, it would seem that these tasks should not be overly taxing on the operator, with a single task demand score of 40.9, but the inter-channel conflict score was a 152.18, resulting in the extreme total workload score. There are also inter-channel demands caused by the number of simultaneous tasks scheduled. This means that each task being performed here instigated much conflict between the resources required to perform the task. Clearly, the score occurred as a result of conflict between visual resources and motor resources, noting that the overloaded tasks stated before indicate a great deal of demand placed on these resources. There were multiple visual demands for scanning and monitoring situational awareness via the indirect vision display pushing the inter-task demand value beyond limits.

3.2 Condition 2. Scout Alexandria – Sergeant Driving and Scanning for Targets

This scenario was run during the exact same conditions as condition 1, with the exception that the sergeant replaced the platoon leader in all driving and scanning for target tasks. In this scenario, the sergeant experienced 41 instances of overloading. The sergeant's instances of overload were fewer than those experienced by the platoon leader in condition 1. The reason for this discrepancy is that the platoon leader was required to perform a greater number of other tasks outside the scope of driving and scanning for targets (e.g., monitoring C2 communications and overriding the sergeant's weapon control). The sergeant was required to perform far fewer of these peripheral tasks than the platoon leader, thus the fewer instances of overloading.

The following five tasks occurred most frequently in this condition:

Sergeant scans for targets, thumb on control

Sergeant presses accelerator

Sergeant listens via headset

Sergeant glances at indirect vision display

Sergeant adjusts steering using handle

It is interesting to note that these are the same five tasks that had the greatest frequency of occurrence in condition 1. The highest instance of operator overloading had a total workload value of 177.02. The tasks being performed during this time were

Sergeant listens via headset

Sergeant scans for targets, thumb on control

Sergeant presses accelerator

Sergeant glances at indirect vision display

Sergeant checks instruments on drive display

Sergeant adjusts steering using handle

Similar to condition 1, these tasks combined for an extremely high inter-channel conflict value of 134.24. Also, these are nearly the same tasks involved in the highest instance of operator workload in condition 1 with the exception of the sergeant checking instruments on drive display task.

3.3 Condition 3. Tank Alexandria – Tank Commander (TC) Driving and Scanning for Targets

This model scenario was designed to emulate a two-person crew operating a tank in the VTT simulator and allows various configurations of operator task assignments and task automation to be exercised. The two crew members performing this tank mission were a tank commander and a gunner. In this condition, the tank commander was assigned to perform driving tasks as well as scan for target tasks with no automation aid available. The objective functions represented by this model range from conduction of a tactical road march, performing a support by fire, hasty occupation of a battle position and platoon consolidation. Further, the model accounts for operator functional tasks such as tank commander monitoring C2, communication with the gunner, and tank commander override gunner weapon control. In this condition, the gunner was eliminated from all driving and scan for target tasks. The model produced the following results:

The tank commander experienced 164 instances of overloading in this condition over the course of a 3-hour scenario. The tasks that occurred most frequently during this time were

TC adjusts steering using handle

TC glances at indirect vision display

TC presses accelerator

TC scans for targets, thumb on control

The highest instance of operator overloading had a total workload value of 193.87. The tasks that were occurring during this instance were

TC develops plan using map multifunction display

TC scans for targets thumb on control

TC monitors main menu for incoming message

TC listens via headset

TC glances at indirect vision display

A high inter-channel conflict score provided the extreme workload in this case once again with the inter-channel conflict value at 151.77.

3.4 Condition 4. Tank Alexandria – Gunner Driving and Scanning for Targets

This condition was run during the exact same conditions as condition 3 with the exception that the gunner performed the driving tasks instead of the tank commander. In this condition, the gunner experienced 32 instances of overloading. Again, the discrepancy between the amount of overloading experienced by the gunner versus the tank commander is attributable to the number of extra peripheral tasks that the tank commander was required to perform. Some of these peripheral tasks include TC monitoring C2 as well as TC overriding gunner weapon control. The tasks that occurred most frequently during this time were the following:

Gunner adjusts steering using handle

Gunner presses accelerator

Gunner glances at indirect vision display

Gunner scans for targets, thumb on control

Gunner talks via headset

The highest instance of operator overloading occurred at time 10042.83 with a total workload value of 120.96. The following tasks were occurring simultaneously during this instance of overload:

Gunner talks via headset

Gunner adjusts steering using handle

Gunner checks instruments on drive display

Gunner presses accelerator

Gunner glances at indirect vision display

Gunner scans for targets, thumb on control

Inter-channel conflict provided the extremely high workload in this instance, with a value of 72.66. Also, these tasks are nearly the same as the tasks that caused extreme overloading in condition 3, with the exception of these tasks:

TC develops plan using map multifunction display

TC monitors main menu for incoming message

This would seem to indicate that "communicating via headset, glancing at indirect vision display, and scanning for targets, thumb on control" require resources that interfere greatly with other resources the operator requires to accomplish a task. Notably, these are similar tasks that are occurring during the extreme instances of workload from conditions 1 and 2.

4. Conclusions and Recommendations

Based on the IMPRINT analysis results, the crew member who is acting as the commander of the tank or scout vehicle will experience high workload when he or she is expected to use the sight to scan for targets while he or she is also driving and performing tasks associated with commanding the vehicle. Therefore, the commander's workload could be alleviated if some of the driving or scanning tasks were automated. The current version of the VTT will include an autonomous mobility capability and automated target scanning which should alleviate the commander's workload by eliminating the need to scan for targets. However, the commander will need to be able to determine if a target detected by the automated system is friend or foe. Therefore, future modeling efforts should look at the commander's ability to effectively perform the identification task while he or she is performing other tasks.

The high workload peaks experienced by the commander during driving and scanning also occurred because he or she was required to look at two different screens or use two different sets of controls at the same time. Some of these events that occur in the model may not occur in the real world. The discrepancy between the real world and the model occurs because IMPRINT does *not* attempt to reschedule tasks when conflicts occur. It is a task-loading model, not an operator-loading model. If the operator is scheduled to perform four simultaneous visual tasks, IMPRINT will allow all four tasks to occur with a *very* high workload value. Two things can mitigate the predictions made by this form of modeling. The first is that the actual human will prioritize which tasks he or she attends to and will serialize his or her operation as time allows. The second is that the scheduling of these events is based on a Monte Carlo engine. The Monte Carlo engine actually determines what tasks will be performed in what order. This randomness of scheduling represents the attention demands placed on the operator, regardless whether the operator can actually attend to the demand. Therefore, TACOM SMEs should review the workload analysis and identify the points where the tasks would be occurring simultaneously and the commander could not perform an alternate strategy. These points should then be analyzed to determine if the tasks could be (1) redesigned to reduce workload, (2) automated to reduce operator workload, or (3) situated differently between the system operators to reduce workload.

In addition, researchers could try changing the modality required for tasks during those points when workload is very high. For example, for those points where the commanders are required to perform simultaneous visual tasks, presenting some of the visual information in a different mode might reduce their workload by reducing conflict within the visual channel. For example, the C2 messages might be voice activated rather than visual button pushes. This change is a proposed modification of the VTT.

Furthermore, the workload associated with driving tasks for both the commander and the gunner might be reduced if they share driving. The VTT does have the capability for the driving to switch back and forth between crew members. Future models or testing should look at the effects on workload, situational awareness, and performance for the crew members when the switching occurs.

The ARL researchers were asked to build the simulator model using the scenario that TACOM researchers used in their Grayling test. This TACOM scenario is very scripted. Therefore, the tasks in the model are very serial and are executed in a known sequence with little or no variation from the expected course of execution. Unforeseen events and variable states of the world (e.g., voice communications from headquarters, unexpected threats) are not accounted for; thus, workload would remain consistent across multiple runs of the model. A more dynamic series in the model and in the Grayling scenarios would provide a more realistic measure of operator workload. In addition, this dynamic scenario would allow the model tasks and workload values to be validated. Workload values, task times, and task accuracies could be collected from two crew members as they perform the concurrent tasks in the dynamic scenario. These data would then be added to the models, and further analyses could be conducted with the validated models.

5. References

Archer, S. *Improved Performance Research Integration Tool (IMPRINT) Analysis Guide 4.0*; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1998.

Hart, S.G. *Crew Workload Management Strategies: A Critical Factor in System Performance.* Paper presented at the Fifth International Symposium on Aviation Psychology, Columbus, OH, April 1989.

Law, A.M.; Kelton, W.D. *Simulation Modeling & Analysis*; 2nd ed.; McGraw-Hill Book Co: New York, 1991.

Little, R.; Dahl, S.; Plott, B.; Wickens, C.; Powers, J.; Tillman, B.; Davilla, D.; Hutchins, C. *Crew Reduction in Armored Vehicles Ergonomic Study (CRAVES)*; ARL-CR-80; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1993.

McCracken, J.H.; Aldrich, T.B. *Analyses of Selected LHX Mission Functions: Implications for Operator Workload and System Automation Goals*; Technical Note ASI479-024-84; U.S. Army Research Institute Aviation Research and Development Activity: Fort Rucker, AL, 1984.

Micro Analysis & Design. *Improved Performance Research Integration Tool (IMPRINT) Analysis Guide Version 4.0*; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 1998.

North, R.A.; Riley, V.A. W/INDEX: A Predictive Model of Operator Workload. In *Applications of Human Performance Models to System Design*; McMillan, G.R., Ed.; Plenum Press: New York, 1989.

Reid, G.B.; Colle, H.A. Critical SWAT Values for Predicting Operator Overload. *Proceedings of the Human Factors Society* 32nd Annual Meeting, Santa Monica, CA, 1988.

Smart, D.L.; Rapkoch II, J.M.; Dahill, J.B.; Fritz, B.H.; Williams, G.S. Advanced Technology Combat Vehicle (ATCV) Crew Station Evaluation Report; U.S. Army Tank-Automotive and Armaments Command: Warren, MI, 1997.

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