Harnessing the Power of Multiple Tools to Predict and Mitigate Mental Overload

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Abstract. Predicting the effect of system design decisions on operator performance is challenging, particularly when a system is in the early stages of development. Tools such as the Improved Performance Research Integration Tool (IMPRINT) have been used successfully to predict operator performance by identifying task/design combinations leading to potential mental overload. Another human performance modeling tool, the Multimodal Interface Design Support (MIDS) tool, allows system designers to input their system specifications into the tool to identify points of mental overload and provide multi-modal design guidelines that could help mitigate the overload identified. The complementary nature of the two tools was recognized by Army Research Laboratory (ARL) analysts. The ability of IMPRINT to stochastically identify task combinations leading to overload combined with the power of MIDS to address overload conditions with workload mitigation strategies led to ARL sponsorship of a proof of concept integration between the two tools. This paper aims to demonstrate the utility of performing low-cost prototyping to combine associated technologies to amplify the utility of both systems. The added capabilities of the integrated IMPRINT/MIDS system are presented with future development plans for the system.

Keywords: mental workload, overload, IMPRINT, MIDS, command and control, multimodal, integrated toolset.

1 Introduction

Throughout the system development process, it is important to consider the effect of system design decisions on operator performance. However, predicting this effect is challenging, particularly when a system is in the early stages of development. Tools such as the Improved Performance Research Integration Tool (IMPRINT) and the Multimodal Interface Design Support (MIDS) tool individually provide analysts with

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great capability to examine the mental workload of system operators but with some limitations. By merging their individual power, the combination could create a powerful capability to predict and mitigate mental overload. Combining the strengths of sophisticated modeling tools such as IMPRINT and MIDS can provide a great advantage to analysts needing to conduct complex system analyses. In this paper, we describe the process and benefits of performing low-cost prototyping to combine associated technologies using the IMPRINT and MIDS integration as a case study. The paper concludes by presenting the added capability of the integrated prototype system and planned extensions of the technology.

1.1 Improved Performance Research Integration Tool (IMPRINT)

IMPRINT, developed by the U.S. Army Research Laboratory (ARL), has been used successfully to predict system performance of conceptual systems as a function of operator performance by predicting the mental workload of the operators and identifying task/design combinations that lead to mental overload [6]. It is a dynamic, stochastic, discrete event simulation tool that enables analysts to represent all of the functions and tasks required to complete a particular mission. When building the model, the analyst must parameterize each task with data, such as time the task will take to be performed and how much mental demand the task will place on the operator. All of the functions and tasks are coded to determine the order in which they will be performed to simulate the execution of the mission by the operators. During the model execution, IMPRINT calculates the mental workload associated with all of the combinations of tasks that occur during the mission and provides various reports for the analyst to review. With this data, the analyst can examine the mental workload profile of each operator over the whole mission to identify workload peaks and which tasks the operator is performing during those peaks. Due to its stochastic nature, IMPRINT is an excellent tool for identifying those potential workload peaks thereby predicting mental overload; however, once overload is detected, it does not provide guidance on how to change the system design in order to mitigate the mental overload. It is currently up to the analyst to draw upon their knowledge of human performance research to determine what should be done to mitigate the identified peaks.

1.2 Multimodal Interface Design Support (MIDS) Tool

Another human performance modeling tool, developed by Design Interactive, Inc., is the Multimodal Interface Design Support (MIDS) tool. It also calculates mental workload based on a modified version of the Workload Index (W/INDEX) equation [5], but for a slightly different purpose. The MIDS tool allows system designers to input the specifications of task and user interface (in the form of task type, display type and mental workload demand) to calculate overall estimated workload and identify points of mental overload. During these overload peaks, MIDS relates tasks ongoing during those instances with specific multimodal design guidelines and heuristics that could be implemented into the system design to mitigate the overload. While the capability of MIDS to connect mental overload to potential mitigation strategies is powerful, it is focused on a generalized set of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) tasks, and does not include stochastic task execution.

1.3 The Idea

ARL analysts recognized that the respective strengths of MIDS and IMPRINT could be used to compensate for the constraints of each tool. For the past decade, ARL analysts have used IMPRINT to predict when human operators are likely to experience high workload [1-3]. At the completion of these projects, however, program managers (PMs) requested recommended design modifications that would mitigate the high workload predicted by IMPRINT. Since IMPRINT did not provide this type of guidance, the analysts followed their own techniques for developing design recommendations, which are inherently limited by the experience and knowledge of the analyst. This created an inconsistent process and could lead to contradictory recommendations being provided from various IMPRINT analysts. In attempting to address this problem, the ARL analysts identified the MIDS tool as a potential solution. Because the MIDS tool contains consistent guidelines on how to mitigate mental overload, the analysts could use it to develop mitigation strategies for the PMs.

Although the analysts could use the MIDS tool to develop mitigation strategies, it was not the complete solution. While the MIDS tool capability to predict workload is very similar to IMPRINT, MIDS is not a stochastic modeling tool and is also focused on C4ISR tasks, which meant that analysts would still need to use IMPRINT to better predict mental overload and then use MIDS to obtain the guidelines. Ultimately, this two-stage process requires the entire modeling process to be performed twice and provides an opportunity for discrepancies to occur between the two models, making it difficult to match up states of overload detected in IMPRINT with design guidance provided in MIDS. Therefore, the ARL analysts suggested incorporating the guideline consistency of MIDS with the stochastic capability of IMPRINT to allow analyst a streamlined capability to predict and mitigate mental overload in their system analyses. The next section describes the development of an integration approach and the challenges encountered during the effort.

2 Proof of Concept Integration

After exploring multiple methods to integrate IMPRINT and the MIDS tool, a proof of concept MIDS plug-in was developed which allowed IMPRINT to seamlessly pass information to the MIDS plug-in which would present appropriate design guidelines to analysts.

2.1 Selection of an Integration Approach

Prior to developing a link between IMPRINT and MIDS, multiple approaches were evaluated to determine the optimal method to input the task model information into MIDS to drive guideline presentation. Because the goal of this initial integration was a proof of concept system, the evaluation of these approaches was based on: 1) the capability to provide all of the necessary information for MIDS to properly trigger guidelines associated with times of predicted overload; and 2) the modifications required to IMPRINT and level of effort associated to integrate each approach. Specifically, the selection criteria targeted an integration approach that highlighted benefits of integrating MIDS into IMPRINT without significant modifications to IMPRINT. The selected integration method resulted in developing a MIDS plug-in that will accept a single exported IMPRINT operator workload spreadsheet as input.

As seen in Figure 1, the process of developing the required worksheet within IMPRINT is performed as a three step process of entering mission data, running the simulation, and requesting the report based on the simulation run. If the MIDS plug-in is installed, the system detects this and allows the IMPRINT analyst to request the associated guidelines. The workload resources that were added to the IMPRINT model must then be associated with the standard human information processing resources available within MIDS. Once these steps are completed, MIDS accepts the operator workload spreadsheet that is developed by IMPRINT as the workload input to drive the extraction of relevant MIDS design guidelines at each point of overload.

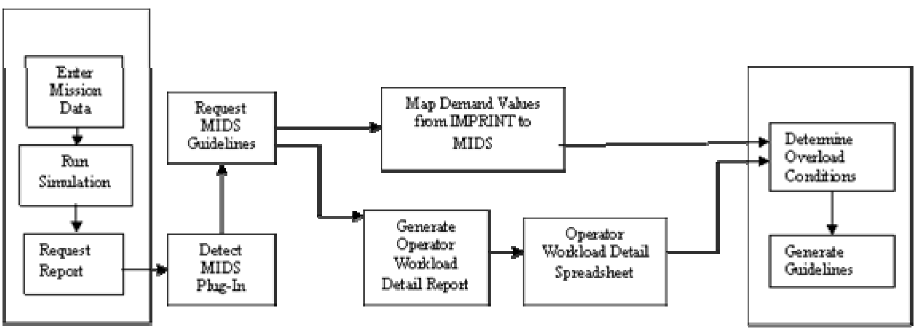

Fig. 1. Integrated MIDS/IMPRINT System- Plug-in Approach

This method provided the MIDS plug-in with all the information that was needed to trigger guidelines and also did not require major changes to IMPRINT.

2.2 Addressing Integration Challenges

Although IMPRINT and MIDS are similar in many ways, variations within the tools provided challenges to their integration.

Timing of Workload Evaluation. Since both tools look at mental workload relating to shifting concurrent tasks over time, the identification of mental overload is dependent upon when mental workload is calculated during the model run. The MIDS tool calculates workload on a second by second basis by adding all of the tasks that occur at that given second regardless of whether or not the tasks have changed (i.e. a new task has begun or a previous task has ended). However, IMPRINT calculates workload whenever a contributing task starts or stops; not at regular intervals. This allows the analyst to identify mental overload that occurs at any time in the model unlike the second interval dependency of the MIDS tool approach. The IMPRINT approach also avoids reporting mental workload for tasks that have not changed. With this in mind, the MIDS plug-in was modified to follow the IMPRINT approach.

Discrepancies in Workload Calculations. Although both tools' workload calculations are based on W/INDEX, MIDS utilizes a modified version of the index to account for separate verbal and spatial cognitive resources which allows for more directed design guidance. To ensure that the most appropriate calculation was utilized in the integrated tool, a comparative analysis was performed.

To evaluate the difference between workload levels calculated between the two systems, an identical test scenario was created within IMPRINT and MIDS. The workload levels calculated by each system were compared to: 1) determine if the average workload levels varied across systems; and 2) identify any discrepancies between when mental overload would be detected by each tool. The results of this comparison show that there were only negligible average differences between the total and individual resource average workload scores across the two systems (Table 1). There were no occasions where mental overload was detected differently between the two systems due to the workload calculations used. Although there were eight additional cases of overload detected using the MIDS calculation, this was due to task time rounding done in the MIDS tool. In the MIDS tool, task times less than 1 second are rounded up to seconds while IMPRINT calculates on a millisecond level. This caused an extended task to occur concurrently with another task, leading to an erroneous overload condition. This revelation further supported the need to adopt IMPRINT's approach of calculating workload when tasks begin and end instead of at 1-second intervals. The overall results of the comparison suggest that the workload values calculated by IMPRINT could be used to drive the selection of MIDS guidelines.

Matching Mental Resources. Another challenge involved the naming of mental resources within each tool. IMPRINT allows analysts to re-name or create mental resources, while MIDS uses a specific set of mental resources. Since the design guidelines are tied directly to the mental resources, it would be difficult to match up any mental resources that were different than those used in MIDS. To overcome this challenge, it was determined that analysts would need to map their IMPRINT mental resources to those used within the MIDS plug-in. As shown in Figure 2, once the MIDS plug-in is launched, a "Resource Mapping Request" interface appears that requires users to match each resource in IMPRINT with the resources available within MIDS.

Table 1. MIDS/IMPRINT Comparative Workload Results

Workload Resource	Average Difference	Overload Mismatches
Visual	0.01	0
Auditory	0.01	0
Motor	-0.01	0
Speech	0.00	0
Cognitive	-0.40	8*
Total	-0.38	0

*Due to differences in timescales used

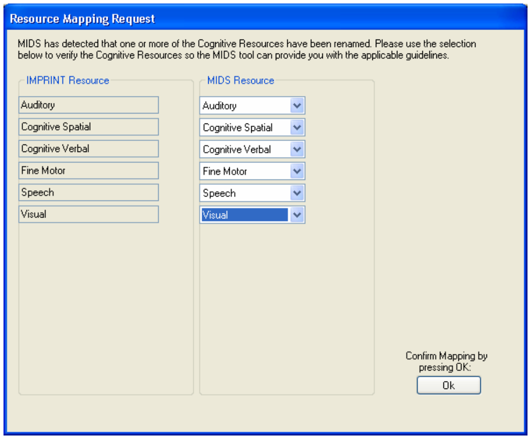

Fig. 2. Resource Mapping Request Window

2.3 The MIDS Plug-in

Because MIDS is designed as a plug-in, IMPRINT must determine whether or not the plug-in is installed on the system. If so, when an IMPRINT analyst completes the model execution and opens reports, the reports window provides an option to launch the MIDS Plug-in (labeled "MIDS guidelines") as depicted in Figure 3.

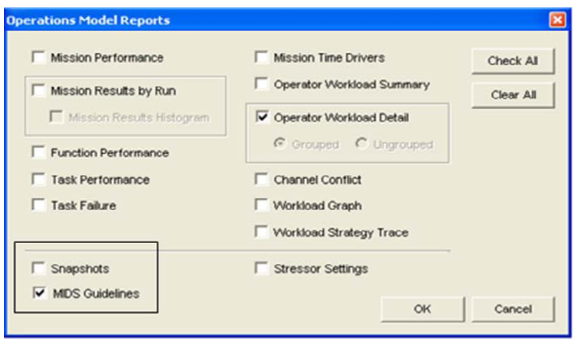

Fig. 3. Modified Report Request Interface

Once the "MIDS Guidelines" box is checked, the analyst selects "OK" and completes the Resource Mapping discussed earlier, the MIDS plug-in reads the corresponding IMPRINT report and opens the MIDS interface.

MIDS Plug-in Interface. The MIDS plug-in interface (Figure 4) was designed to ensure that analysts can easily gather design requirements and associate them with points of predicted mental overload.

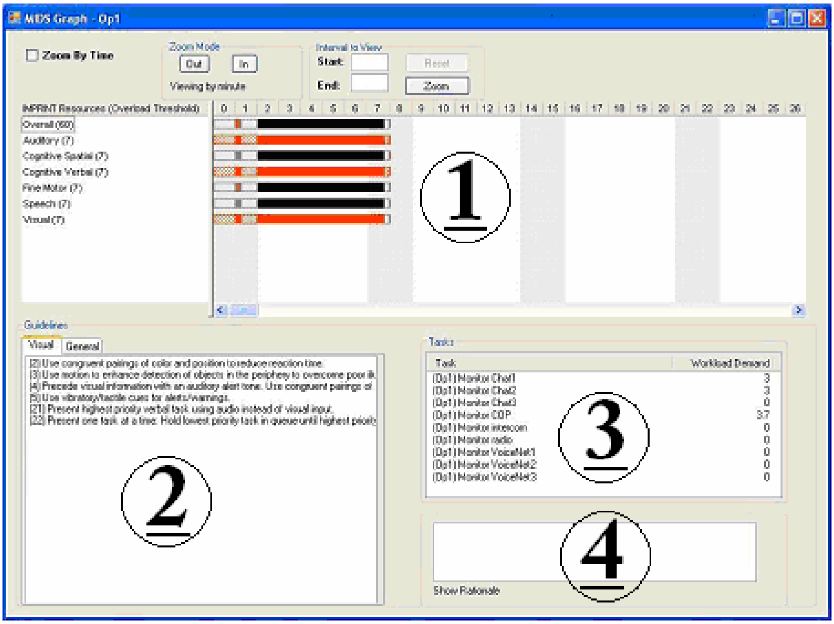

Fig. 4. MIDS Interface

The MIDS Timeline pane (Figure 4, Pane 1) provides a visual summary of predicted mental overload for each mental resource within the IMPRINT model run. The default setting of the MIDS plug-in show a timeline of the scenario where red cross-hatch bars represent conditions of overload and white bars depict conditions where workload is below threshold. Red bars can be selected by a left-click of the mouse which then highlights the section of the timeline associated with the selected overload. When a section of the scenario is highlighted, the MIDS Plug-in will display a list of tasks performed at that time and guidelines targeted at reducing the overloaded resources in the lower portion of the interface labeled “Guidelines.” The interface allows the user to change or manipulate the timeline presented in the graph and access guidelines related to specific instances of overload.

The Guidelines pane displays the multimodal guidelines applicable during the user-selected instance of overload in the MIDS Timeline (Figure 4, Panes 2-4). An analyst is able to view guidelines specific to a selected overloaded resource or general design guidelines not specifically triggered by overload and the specific tasks to which the guideline(s) apply. The Guideline pane has three subcomponents:

- Guideline Selection Pane (Pane 2) - This pane lists all the multimodal design guidelines applicable to the instance of overload selected in the MIDS timeline. Within this display, one tab is presented for each overloaded resource during the selected time instance. For example, if a period of time is selected where there is only Visual overload present, then that tab becomes active along with a “General” tab, which is used to present broader level guidelines for the tasks that are ongoing at that time. Guidelines listed in any tab may be selected to obtain further detail regarding the information provided. When selected, a separate window is created that identifies which of the active tasks (see Task Presentation Pane section) the guideline is applicable to. In addition, detailed guidance is also displayed in the Guideline Presentation Pane.

- Task Presentation Pane (Pane 3) - When a user selects a time instance from the MIDS timeline, the Task Presentation Pane is populated with the tasks that are active during that period of the analyzed mission along with the resource-specific workload demand associated with each.
- Guideline Presentation Pane (Pane 4) - When a guideline is selected in the guideline selection pane, the complete presentation (full text version) of the guideline is presented here. Whenever a guideline is selected and presented in this portion of the display, the "Show Rationale" option is also active, providing a link to a brief explanation of the guideline and its source.

3 Validation

To validate the utility and applicability of the MIDS plug-in and the guidelines it is intended to provide, a future command and control (C2) concept IMPRINT model was

Table 2. Example of guidelines triggered at a given instance during the validation scenario

Clock	Task	Overload	Guidelines Triggered
1:05:14	Monitor COP		
	Monitor Chat	Visual	2 Use congruent pairings of color and position to reduce reaction time.
		Visual	3 Use motion to enhance detection of objects in the periphery to overcome poor illumination.
		Visual	4 Precede visual information with an auditory alert tone. Use congruent pairings of pitch and position to reduce reaction time.
		Visual	5 Use vibratory/tactile cues for alerts/warnings
		Cognitive Verbal	21 Present highest priority verbal task using audio instead of visual input.
		Cognitive Verbal	22 Present one task at a time: Hold lowest priority task in queue until highest priority task is complete.
	Monitor VoiceNet/radio/intercom	Auditory	42 Present one auditory task at a time: Hold lowest priority verbal task in queue until highestpriority task is complete.
	Obtain and Process voice info	Auditory	30 Keep auditory warning messages simple and short.
		Auditory	42 Present one auditory task at a time: Hold lowest priority verbal task in queue until highest priority task is complete.
		Cognitive Verbal	44 Use written text for conveying detailed, long information.
		Cognitive Verbal	45 Add spatialized audio to aid identification of auditory verbal messages in noisy environments.
	Communicates via typing	Cognitive Verbal	21 Present highest priority verbal task using audio instead of visual input.
		Cognitive Verbal	22 Present one task at a time: Hold lowest priority task in queue until highest priority task is complete.

modified to create a 30-minute scenario. The original model was built in IMPRINT to identify potential mental overload issues within a futuristic C2 battalion [4].

The modified model was executed in IMPRINT and the results were read by the MIDS plug-in to extract all guidelines triggered by the scenario. For this model 25 unique guidelines were presented that could be used to aid system designers in the redesign process. Table 2 provides an example of guidelines triggered at one instance during the C2 scenario. When guidelines are triggered, the type of overload and the task to which the triggered guideline should be applied are also displayed. Each of the guidelines triggered was reviewed by the MIDS integrators (Time and resources did not allow for an independent validation) to ensure they were applicable for the condition of overload for which they were designed to mitigate. Specifically, the team went through the process of theoretically applying the guideline to the interfaces that were actively in use within the concept IMPRINT model, rating each into the categories of “applicable” or “not applicable.” The results of this analysis showed that 100% of the triggered guidelines were applicable at the time that they were triggered, demonstrating the validity of integrated guidelines.

4 Conclusion

The proof of concept integration of IMPRINT and MIDS showed the benefit of bringing together the strengths of both tools to address complex issues associated with system design. It also demonstrated a low cost approach to developing a proof-of-concept integrated toolset that can be used to integrate other tools with complementing capabilities into IMPRINT. This prototype will be the basis of future efforts to enhance IMPRINT to provide analysts with the ability to not only predict and identify areas of mental overload, but to also recommend validated multimodal design changes to minimize overload and enhance system performance. In the future, the goal is to integrate the MIDS plug-in into IMPRINT more seamlessly and provide detailed reports on identified guidelines related to the associated mental overload. Another planned enhancement is the capability to prioritize all of the identified guidelines and incorporate them back into the IMPRINT model to demonstrate the potential impact those guidelines have on mental workload if adopted by the system designer. These enhancements will ease the burden on system analysts when providing clear, substantiated design recommendations to enhance system design to their customers. By harnessing the power of these tools, system analysts will have a powerful modeling tool that predicts mental overload and provides tailored human performance research guidance to mitigate overload thereby helping them develop more successful systems.

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