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Development of a User-Defined Stressor in the Improved Performance Research Integration Tool (IMPRINT) for Conducting Tasks in a Moving Vehicle

by Josephine Q. Wojciechowski

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14. ABSTRACT

Human performance modeling tools are used to predict the effect of human performance on the system. The U.S. Army Research Laboratory developed a human performance modeling tool, the Improved Performance Research Integration Tool (IMPRINT), which allows an analyst to investigate the effect of subjecting operators to environmental stressors on mission performance. The latest version of IMPRINT has the capability to create user-defined stressors to study the effect of stressors on human performance and therefore system performance. This study used data that predict the effect on task time and performance based on task characteristics when Soldiers are riding in a moving vehicle to create a user-defined stressor in IMPRINT. A case study was completed on a simple model of command and control tasks. The user-defined stressor was applied to show the effect of completing these tasks on task time and accuracy after participants were in a moving vehicle for 0, 1, 2, 3, 4, and 5 hours. The data from the study indicate that tasks are affected differently, but most data show an increase in time to complete and a decrease in the accuracy of the operator. This study shows the effect of operating in a moving vehicle. These data are useful not only to system design but also to the development of tactics and procedures.

15. SUBJECT TERMS
human performance modeling; IMPRINT; "on the move"; stressors

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1. Introduction

Designing a new system for combat use is a complex process rife with decisions in which total system performance must be traded against other variables such as cost. One of the most variable yet significant contributors to total system performance is Soldier performance. Understanding how the Soldier works with the system is a critical step in this process.

Determining human performance through empirical study is often difficult because of costs, safety, and practicality. For that reason, predictive human performance modeling is a method that complements empirical data collection and is appropriate for use early in system design during concept evaluation. A human performance modeling tool that has been developed at and applied by the U.S. Army Research Laboratory (ARL) is the Improved Performance Research Integration Tool (IMPRINT). IMPRINT allows the analyst to answer many different questions about the impact of Soldier performance on total system performance (ARL, 2005). IMPRINT has been used to answer questions about the mental workload required to perform individual tasks, the likely time and accuracy of a sequence of tasks, the manpower required to attain acceptable system availability, and the most effective allocation of functions between Soldiers and automation. One question of current interest is how performance is affected when the operator is in a moving vehicle.

IMPRINT includes performance moderators that allow the analyst to investigate the changes in mission performance when time and accuracy are affected by stressors such as wind and cold, heat and humidity, fatigue, noise, and chemical protective gear (Micro Analysis & Design [MA&D], 2005). The effect of stressors on time and accuracy is applied to tasks based on the nature of the task, which is described when it is assigned to taxonomic categories or taxons. Each task may be described by as many as three taxons[1]. Nine possible taxons are available: perceptual (visual recognition and discrimination), cognitive (numerical analysis or information processing and problem solving), motor (fine motor – discrete, fine motor – continuous, gross motor – light, or gross motor – heavy), and communication (oral or reading and writing). Analysts match taxons to the task and enter the percentage that each taxon contributes to the task. This is the basis for the stressor's effect on time and accuracy.

In 2003, IMPRINT was revised so that analysts could develop their own user-defined stressors (MA&D, 2005). This allows analysts to use data about time and accuracy effects from an environmental factor and apply them to the tasks performed by the operator in that environment to determine the impact on the mission to be completed. This new IMPRINT feature was used to predict the changes in performance when Soldiers are operating in a moving vehicle. This report describes how the "on-the-move" stressor was developed from data in literature.

[1]Taxons are categories that characterize a task, based on the skills required to perform the task.

2. Background Data

In 1998, researchers at ARL completed an investigation into the effect on cognitive processes attributable to endurance, vibration and noise while in a moving vehicle (Schipani, Bruno, Lattin, King, & Patton, 1998). The study used cognitive measures to assess performance while Soldiers were in a military ground vehicle in an off-road environment. Subjects were presented with a battery of cognitive tests and measurements were taken at different speeds and times as long as 8 hours. The data from this study were used to develop performance degradation data for three cognitive skill categories (i.e., conceptual, speed loaded, and reasoning) associated with a taxonomy developed by Fleishman and Quaintance (1984). The complete Fleishman's taxonomy includes a set of 50 skills and abilities by which each task can be described. The eight categories formed by grouping the skills are shown in figure 1.

A literature review then revealed data about performance degradation for the other five categories in this taxonomy: communication, vision, audition, psychomotor, and gross motor. This review led to development of tables of degradation for each of the major categories (Schipani, 1998). Percent degradation of accuracy and time from that review are shown in tables 1 through 8.

Cognitive Skill and Experience Clusters

Communication	Conceptual	Reasoning	Speed-loaded
1. Oral Comprehension	5. Memorization	13. Inductive Reasoning	19. Time Sharing
2. Written Comprehension	6. Problem Sensitivity	14. Category Flexibility	20. Speed of Closure
3. Oral Expression	7. Originality	15. Deductive Reasoning	21. Perceptual Speed and Accuracy
4. Written Expression	8. Fluency of Ideas	16. Information Ordering	22. Reaction Time
	9. Flexibility of Closure	17. Mathematical Reasoning	23. Choice Reaction Time
	10. Selective Attention	18. Number Facility	
	11. Spatial Orientation		
	12. Visualization		

Perceptual-Motor Ability Clusters

Vision	Audition	Psychomotor	Gross Motor
24. Near Vision	31. General Hearing	34. Control Precision	41. Extent Flexibility
25. Far Vision	32. Auditory Attention	35. Rate Control	42. Dynamic Flexibility
26. Night Vision	33. Sound Localization	36. Wrist-Finger Speed	43. Speed of Limb Movement
27. Visual Color Discrimination		37. Finger Dexterity	44. Gross Body Equilibrium
28. Peripheral Vision		38. Manual Dexterity	45. Gross Body Coordination
29. Depth Perception		39. Arm-hand Steadiness	46. Static Strength
30. Glare Sensitivity		40. Multi-Limb Coordination	47. Explosive Strength
			48. Dynamic Strength
			49. Trunk Strength
			50. Stamina

Fleishman, E. A. and Quaintance, M. K. (1984) Taxonomies of Human Performance: The Description of Human Tasks., Orlando: Academic Press.

Figure 1. Skills and abilities.

Table 1. Performance degradation for conceptual tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	4	1
2-3	7	4
3-4	8	6
4-5	10	11
5-6	15	14
6-7	23	16
7-8	32	17

Table 2. Performance degradation for speed-loaded tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	8	8
2-3	12	9
3-4	15	11
4-5	18	12
5-6	22	17
6-7	25	23
7-8	39	32

Table 3. Performance degradation for reasoning tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	8	12
2-3	12	14
3-4	17	16
4-5	20	18
5-6	24	20
6-7	30	22
7-8	37	25

Table 4. Performance degradation for vision tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	4	9
2-3	7	14
3-4	9	16
4-5	11	18
5-6	15	21
6-7	23	22
7-8	33	25

Table 5. Performance degradation for audition tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	2	1
2-3	5	3
3-4	7	5
4-5	9	10
5-6	14	12
6-7	18	16
7-8	22	19

Table 6. Performance degradation for communication tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	2	1
2-3	5	3
3-4	7	5
4-5	9	10
5-6	14	12
6-7	18	16
7-8	22	19

Table 7. Performance degradation for psychomotor tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	0	0
1-2	3	1
2-3	6	3
3-4	7	5
4-5	9	10
5-6	14	12
6-7	18	14
7-8	23	16

Table 8. Performance degradation for gross motor tasks (Schipani, 1998).

Time (hours)	Degrade performance by percent	Increase task completion time by percent
0-1	1	1
1-2	8	8
2-3	12	10
3-4	15	11
4-5	18	12
5-6	22	18
6-7	26	25
7-8	37	33

In 1999, a human performance model of a battalion command and control vehicle was built at ARL and executed over a 24-hour scenario (Wojciechowski, Plott, & Kilduff, 2005). The model consisted of a complex network of tasks, and each task was described by the skills and abilities needed to perform that task according to the Fleishman taxonomy. Since command and control (C2) is a highly cognitive process, it was necessary to provide a means within the model to assess the effect of vehicle motion on the performance of cognitive processes. The data in tables 1 through 8 were originally developed to determine the effect on the performance time in the tasks in this model (Wojciechowski et al., 2005). With the development of a user-defined stressor capability in IMPRINT, these data can be used to develop a stressor for IMPRINT models, which determines not only the impact on time but also the degradation of performance attributable to operation in a moving vehicle.

The taxons in IMPRINT are used to characterize the tasks. These taxons were developed in order to allow the user to determine how the stressor will affect the tasks. With the Berliner, Angell, and Shearer (1964) task taxonomy as a starting place and incorporating key features of Wicken's (1984) structure for processing resources, the taxons in IMPRINT were developed to meet two objectives: to provide a minimum number to guide the development of the IMPRINT performance shaping functions and the stressor degradation algorithms and to classify tasks but not task elements. The result was the nine taxons previously described (O'Brien, Simon, & Swaminathan, 1992). Developing a user-defined stressor requires the use of the taxons in IMPRINT.

3. Development of an IMPRINT Stressor

The first step in developing the IMPRINT "on-the-move" stressor was to relate the eight major categories of Fleishman's taxonomy to the taxons in IMPRINT. Tasks have to be described by the taxons in order to apply the stressor in the model run. Table 9 shows how the two taxonomies relate. The data from tables 1 through 8 can then be used to develop the user-defined stressors and to apply them to the correct tasks.

Table 9. Relationship between Fleishman's skill categories and IMPRINT taxons.

Fleishman's Skill Category	Taxon Category	IMPRINT Taxons
Audition		
Communication	Communication	Oral, Written
Vision	Perceptual	Visual Recognition/Discrimination
Speed Loaded		
Conceptual	Cognitive	Numerical Analysis
Psychomotor	Motor	Fine Motor Discrete, Fine Motor Continuous
Gross Motor	Motor	Gross Motor Light, Gross Motor Heavy
Reasoning	Cognitive	Information Processing/Problem Solving

When using a stressor in IMPRINT, an analyst typically runs the model without the stressor applied to understand baseline performance. Then the stressor is applied and the model execution runs are repeated to measure the relative impact of operating under that environmental stressor. Within the user-defined stressor capability, stressor effects are pre-processed before model execution and IMPRINT does not normally have the ability to change the level of the stressor during the course of the model run. (The reader should note, however, that IMPRINT's external model call capability does support dynamically adjusted stressor levels.) Therefore, when developing an on-the-move stressor, an analyst would look at the effect on performance of a person being in a moving vehicle for a specific time. In other words, the analyst would run the baseline or no degradation condition. Then, the analyst would apply the stressor for the time of interest (e.g., 3 hours) and run the model again. The analyst can use the two sets of data to compare the operator's performance while the operator is doing the same set of tasks for the two separate conditions (baseline and after moving for 3 hours). If the analyst were also interested in another time (e.g., 8 hours), the stressor would be applied and the model run a third time. This would give three sets of data. The first would be a baseline (i.e., performance while not moving). The second set would be operator performance of the same set of tasks after simulation of the operator riding in a moving vehicle for 3 hours. The third set would be performance of the same set of tasks after simulation of the operator riding in a moving vehicle for 8 hours. Therefore, the input required for development of this stressor is the impact on time and accuracy for specific time periods such as found in Schipani (1998).

These data could be used directly for specific hours of degradation. Additionally, a regression equation was developed in Excel[2] for each of the data sets shown in tables 1 through 8 to select any specific times between 0 and 8 hours. In these equations, x represents time in a moving vehicle and y represents the change in task time or accuracy. The equations are listed below for each of the Fleishman categories except for audition and speed loaded because they do not match with any IMPRINT taxons. We developed table 10 from these equations by inserting the hour of movement and calculating the change in time or accuracy. The data from this table were then entered directly into IMPRINT to build the stressor.

The process of entering the data into IMPRINT, version 7, is fairly simple and requires that the information be entered on two separate user interfaces. The first interface requires the analyst to give the stressor a name (see figure 2). Then the analyst must define the stressor. This causes the stressor level screen to appear (see figure 3). IMPRINT allows five levels to be assigned for each stressor (i.e., 1, 2, 3, 4, and 5 hours). There are five possible entries for each level: the name of that level, the equation for accuracy changes, whether the accuracy change is a decrease or increase, the equation for the time changes, and whether the time change is a decrease or increase. The analyst adds each level and then defines the accuracy and time degradation as shown for 2 hours in figures 4 and 5, respectively. The accuracy and time degradation screens allow the analyst to calculate how task performance is altered for each task type (i.e., taxon) because of this stressor condition.

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[2]Excel is registered trademark of Microsoft.

Communication

Equation for time $y=0.02857x - 0.04607$
Equation for accuracy $y=0.03131x - 0.04464$

Vision

Equation for time $y=0.03131x + 0.01536$
Equation for accuracy $y=0.04190x - 0.06107$

Conceptual

Equation for time $y=0.02726x - 0.03643$
Equation for accuracy $y=0.04107x - 0.06107$

Psychomotor

Equation for time $y=0.02488x - 0.03571$
Equation for accuracy $y=0.03119x - 0.04036$

Gross Motor

Equation for time $y=0.03976x - 0.03143$
Equation for accuracy $y=0.04464x - 0.02714$

Reasoning

Equation for time $y=0.02917x + 0.0275$
Equation for accuracy $y=0.04857x - 0.03357$

Table 10. Time and accuracy degradation for IMPRINT stressor equations.

	Hour of Movement	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Time Increase	Oral or Written	0.0	0.011	0.040	0.068	0.097	0.125	0.154	0.182
	Visual Recognition/ Discrimination	0.0	0.078	0.109	0.141	0.172	0.203	0.235	0.266
	Numerical Analysis	0.0	0.018	0.045	0.073	0.100	0.127	0.154	0.182
	Fine Motor Discrete or Continuous	0.0	0.014	0.039	0.064	0.089	0.114	0.138	0.163
	Gross Motor Light or Heavy	0.0	0.048	0.088	0.128	0.167	0.207	0.247	0.287
	Information Processing	0.0	0.086	0.115	0.144	0.173	0.203	0.232	0.261
Accuracy Degradation	Oral or Written	0.0	0.018	0.049	0.081	0.112	0.143	0.175	0.206
	Visual Recognition/ Discrimination	0.0	0.023	0.065	0.107	0.148	0.190	0.232	0.274
	Numerical Analysis	0.0	0.021	0.062	0.103	0.144	0.185	0.226	0.267
	Fine Motor Discrete or Continuous	0.0	0.022	0.053	0.084	0.116	0.147	0.178	0.209
	Gross Motor Light or Heavy	0.0	0.062	0.107	0.151	0.196	0.241	0.285	0.330
	Information Processing	0.0	0.064	0.112	0.161	0.209	0.258	0.306	0.355

Examples of the accuracy and time equations are shown in the following equations for 2 hours of moving operations.

Decrease for accuracy = (V * 0.06463) + (N * 0.06214) + (I * 0.11214) + (D * 0.05321) + (C * 0.05321) + (L * 0.10678) + (H * 0.10678) + (O * 0.04929) + (W * 0.04929)

Increase for time = (V * 0.10929) + (N * 0.04535) + (I * 0.11501) + (D * 0.03893) + (C * 0.3893) + (L * 0.08785) + (H * 0.08785) + (O * 0.03964) + (W * 0.03964)

The following is an example of the calculation for the change:

Assume that the task is “Determine if in travel lane”. This task can be characterized by two taxons, visual recognition and information processing. If we assume that they are weighted as visual recognition, 0.37 and information processing, 0.63, putting these two values in the accuracy equation will yield a 9.5% decrease in accuracy.

$$\Delta_{accuracy} = (0.37 * 0.06463) + (0.63 * 0.11214) = 0.0946$$

Putting the taxon weights in the time equations yields an 11.3% increase in time.

$$\Delta_{time} = (0.37 * 0.10929) + (0.63 * 0.11501) = 0.1129$$

The baseline mean accuracy for this task was 88.0% and the mean time was 1.83 seconds. If the “on-the-move” stressor were applied, the mean accuracy would be 79.7% and the mean time would now be 2.03 seconds. The model could then be run to determine the effect of a Soldier being in a moving vehicle on the overall mission, given the change in task time and accuracy.

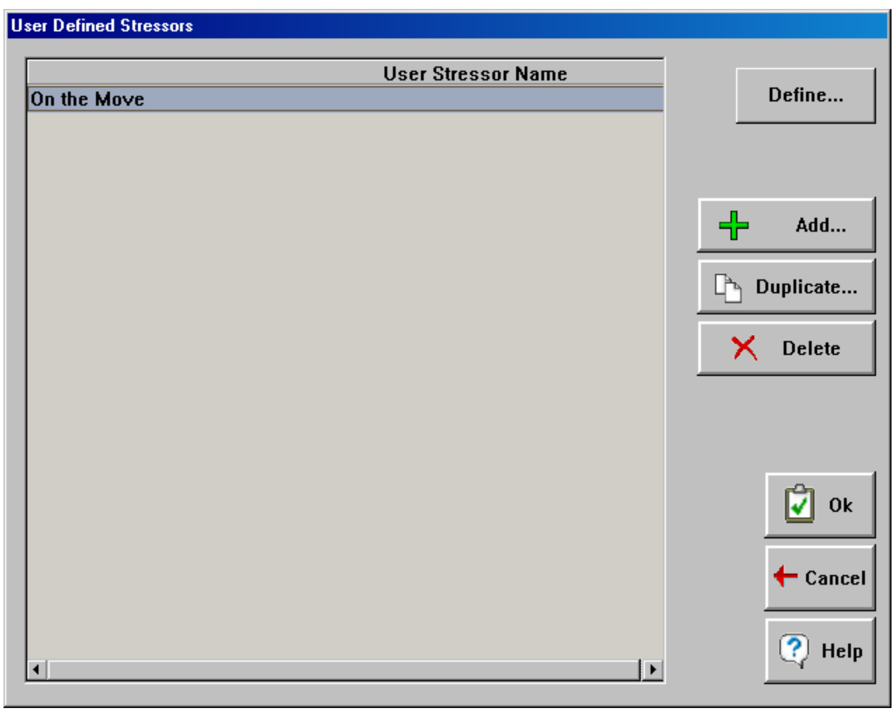

Figure 2. User-defined stressor interface.

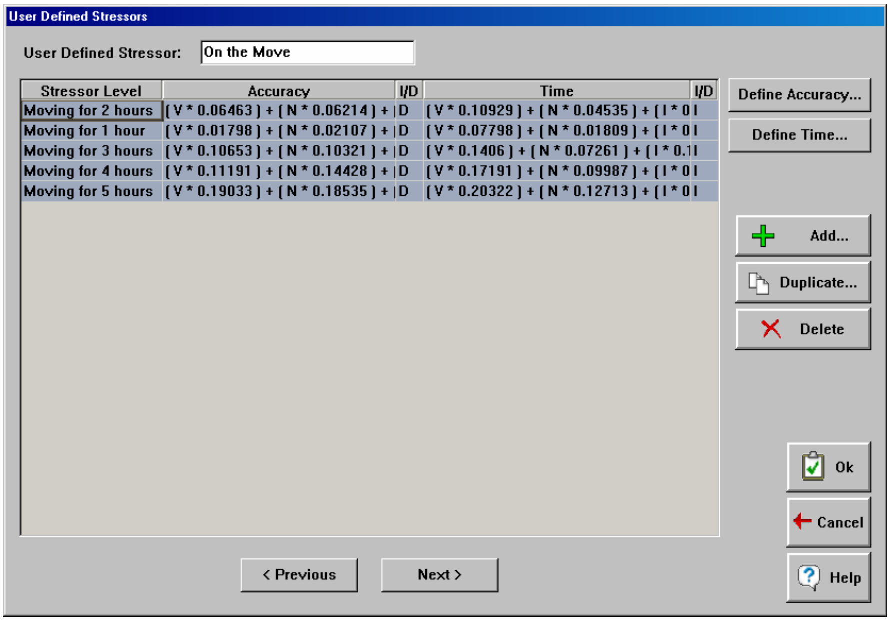

Figure 3. Stressor levels in IMPRINT.

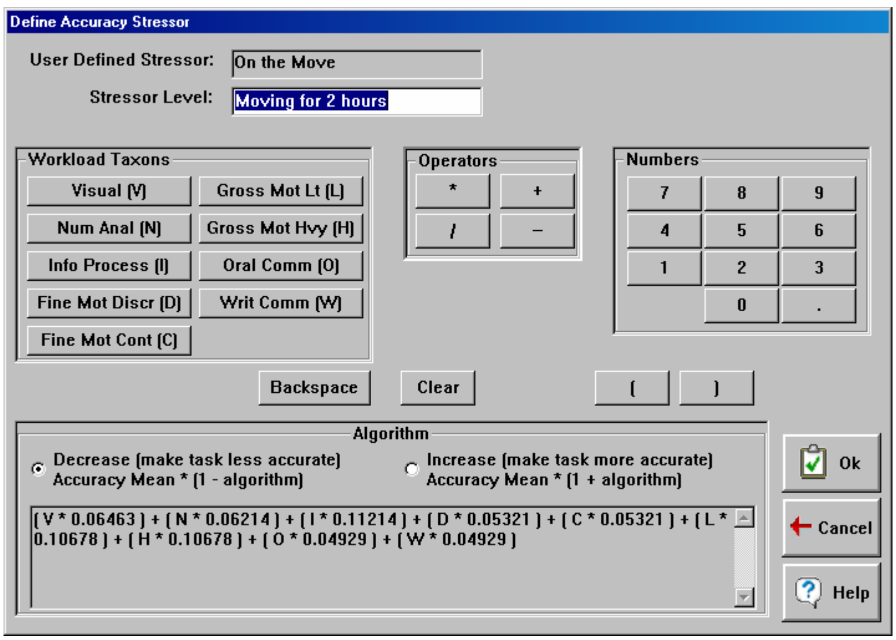

Figure 4. Accuracy stressor definition screen.

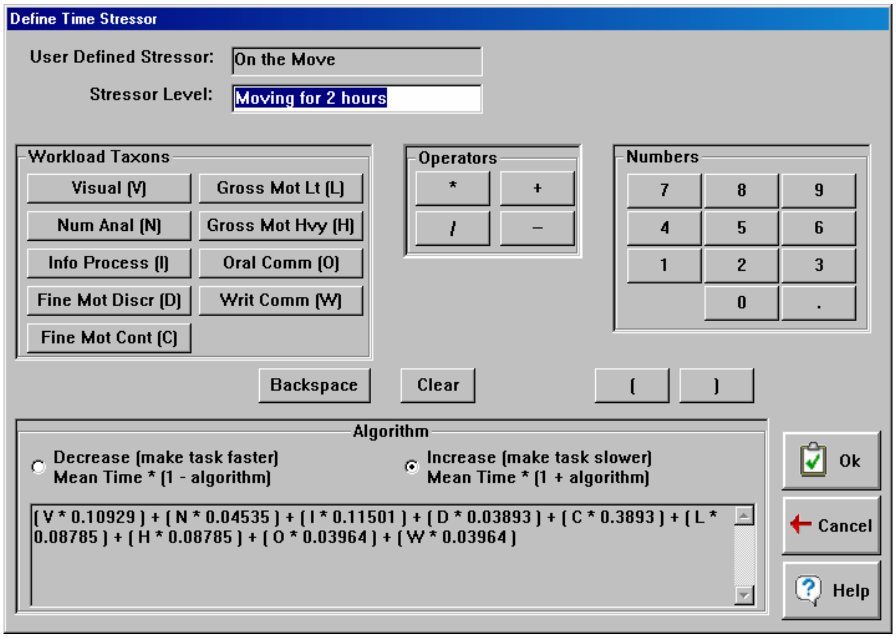

Figure 5. Time stressor definition screen.

4. Case Study

In order to show the impact that an "on-the-move" stressor would have on a mission, a sample model was built. The model is a very simplistic representation of C2. It consists of five functions: receive radio message, receive e-mail message, scan and decide, send radio message, and send e-mail message. It was built in IMPRINT version 7 with the use of the Goal Orientation module. This module is one of three techniques for building operator performance models in IMPRINT. Goal Orientation allows the analyst to represent mission functions as separate goals. Each function consists of a nearly serial set of tasks. The functions are represented as goals and the scenario that drives the sequencing of the functions is controlled in the primary network. Diagrams of the functions are provided in appendix A.

In the Goal Orientation module of IMPRINT, goals are prioritized and a matrix is developed to determine how the functions interact (ARL, 2005). The "goal action" matrix for this case study is show in figure 6. As a goal is triggered, IMPRINT looks at the matrix to determine if any higher priority goals that have been triggered to start would have suspended this goal. If not, the goal is initiated. Otherwise, the goal waits to begin until the higher priority goal(s) have ended. Then, IMPRINT stops any lower priority goals that the matrix indicates should be interrupted or aborted (ARL, 2005).

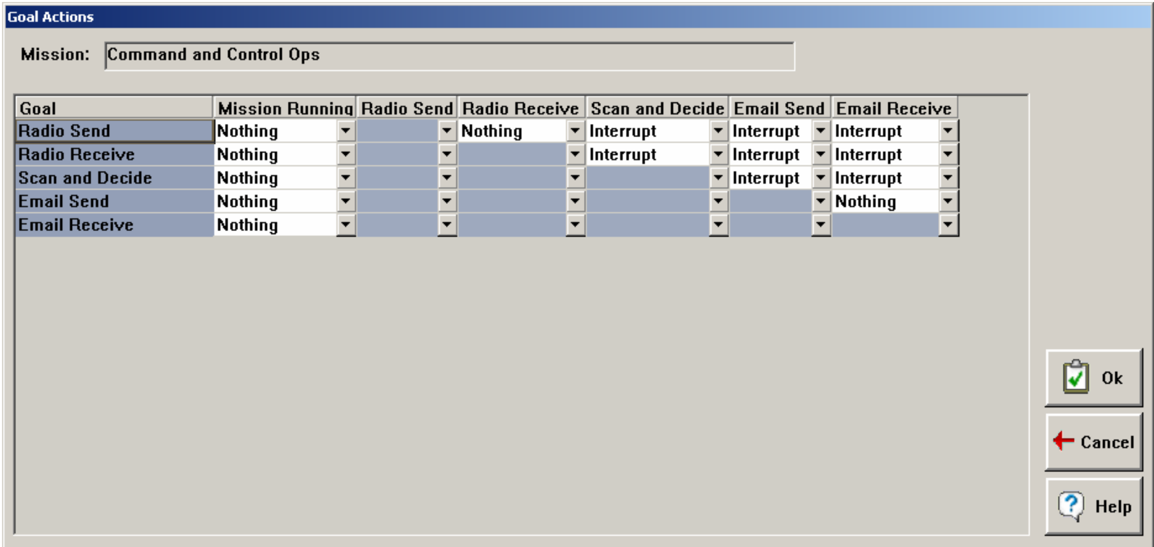

Figure 6. Goal action matrix from IMPRINT.

The next step was to enter data about time and accuracy for the tasks. Task data for this study are given in appendix B. Each task was assigned an estimated mean time and standard deviation. Additionally, a mean accuracy and standard deviation were assigned. Tasks can also be given time and accuracy standards. Standards indicate the acceptable time and error rate for the task. The accuracy standard, mean, and standard deviation are used to calculate a probability of success for the task. This probability is used to determine if the task fails. Failure consequences are then assigned to determine if the task failure has no effect on the mission, the mission fails as a result of the task failure, the impact on the other tasks as a result of this task failing, or some combination of these options (ARL, 2005). The mean times for these tasks were estimated with the IMPRINT micromodels. Time standards were estimated based on the mean times and standard deviations.

This sample model was then run 20 times with these time and accuracy data as a baseline condition. The on-the-move stressor was then applied to represent the same tasks after a Soldier was in a moving vehicle for 1, 2, 3, 4, and 5 hours each. The differences in the task time and accuracy from condition to condition depend on the taxon(s) that describe the task and the weighting of the taxon. The differences are shown in table 10. The effect of the stressor can be shown in several different performance measures.

Figure 7 shows the effect of riding in a moving vehicle on task time for these tasks. This table lists the mean time for each task over 20 runs. As expected, the table shows that many tasks took longer after a Soldier was in a moving vehicle. The longer the time moving, the longer the task took. Also included in this figure are the time standards for the tasks. The graphs show that most of the tasks increased in task time as time in the moving vehicle increased. Table 11 shows the percentage of time that each task does not meet the time standard for that task. Only a few tasks do not meet the time standard. This is because the standards were set fairly high. Time standards for each task are shown in figure 7.

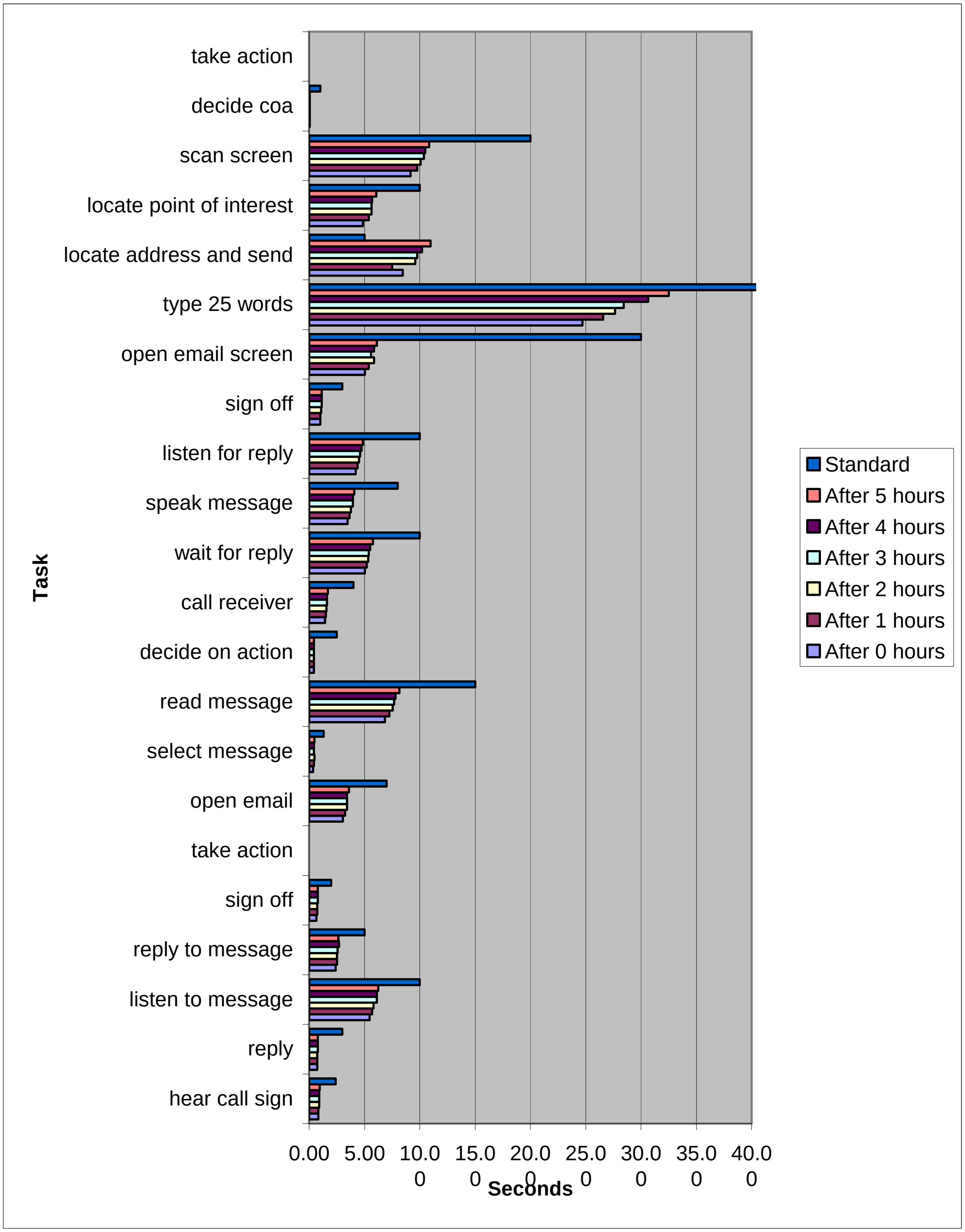

Figure 7. Mean time for each task under the conditions tested.

Table 11. Percent of time that the task met the time standard set for that task under conditions tested.

Task	After 0 hours	After 1 hour	After 2 hours	After 3 hours	After 4 hours	After 5 hours
take action	100.00	100.00	100.00	100.00	100.00	100.00
decide coa	100.00	100.00	100.00	100.00	100.00	100.00
scan screen	100.00	100.00	100.00	100.00	100.00	100.00
locate point of interest	99.50	99.09	98.88	98.80	99.09	98.27
locate address and send	56.89	60.81	55.24	59.17	54.55	56.99
type 25 words	100.00	100.00	100.00	99.62	99.14	98.54
open email screen	100.00	100.00	100.00	100.00	99.69	99.80
sign off	100.00	100.00	100.00	100.00	100.00	100.00
listen for reply	100.00	100.00	100.00	100.00	100.00	100.00
speak message	100.00	100.00	100.00	100.00	100.00	100.00
wait for reply	100.00	100.00	100.00	100.00	100.00	100.00
call receiver	100.00	100.00	100.00	100.00	100.00	100.00
decide on action	100.00	100.00	100.00	100.00	100.00	100.00
read message	100.00	100.00	100.00	100.00	100.00	100.00
select message	100.00	100.00	100.00	100.00	100.00	100.00
open email	100.00	100.00	100.00	100.00	100.00	100.00
take action	100.00	100.00	100.00	100.00	100.00	100.00
sign off	100.00	100.00	100.00	100.00	100.00	100.00
reply to message	99.52	99.53	99.32	99.54	99.39	98.64
listen to message	98.81	99.06	97.73	97.72	97.35	95.23
reply	100.00	100.00	100.00	100.00	100.00	100.00
hear call sign	100.00	100.00	100.00	100.00	100.00	100.00

Figure 8 depicts the percentage of time that each task met the accuracy standard. Movement of the vehicle affects the accuracy of the tasks. As each task executes, the model checks to see if the accuracy meets the standard that was set for that task. As seen in figure 8, the accuracy of many of the tasks is reduced to a point below the standard set for that task. When this happens, the consequences of failure determine the effect of task failure. A common consequence of failure is that the task must be re-done. Therefore, the number of times that a particular task executes can be an indication of the impact of someone being in a moving vehicle. Figure 9 displays the number of times each task was executed in 20 runs under each condition.

The purpose of this case study was not to examine C2 but to show how a user-defined stressor can impact the model output. This simplistic description of C2 gives us a clear picture of how the stressor effect depends on the type of tasks being executed (taxons assigned) and the complex nature of the task network. The power of user-defined stressors lies in the ability to show how an environmental stressor will affect the system without our having to recode IMPRINT. This impact is nonlinear and depends on the task composition and task network. It provides a better estimation than our simply assuming that being in a moving vehicle will impact time and accuracy by set percentages for all tasks, regardless of task type.

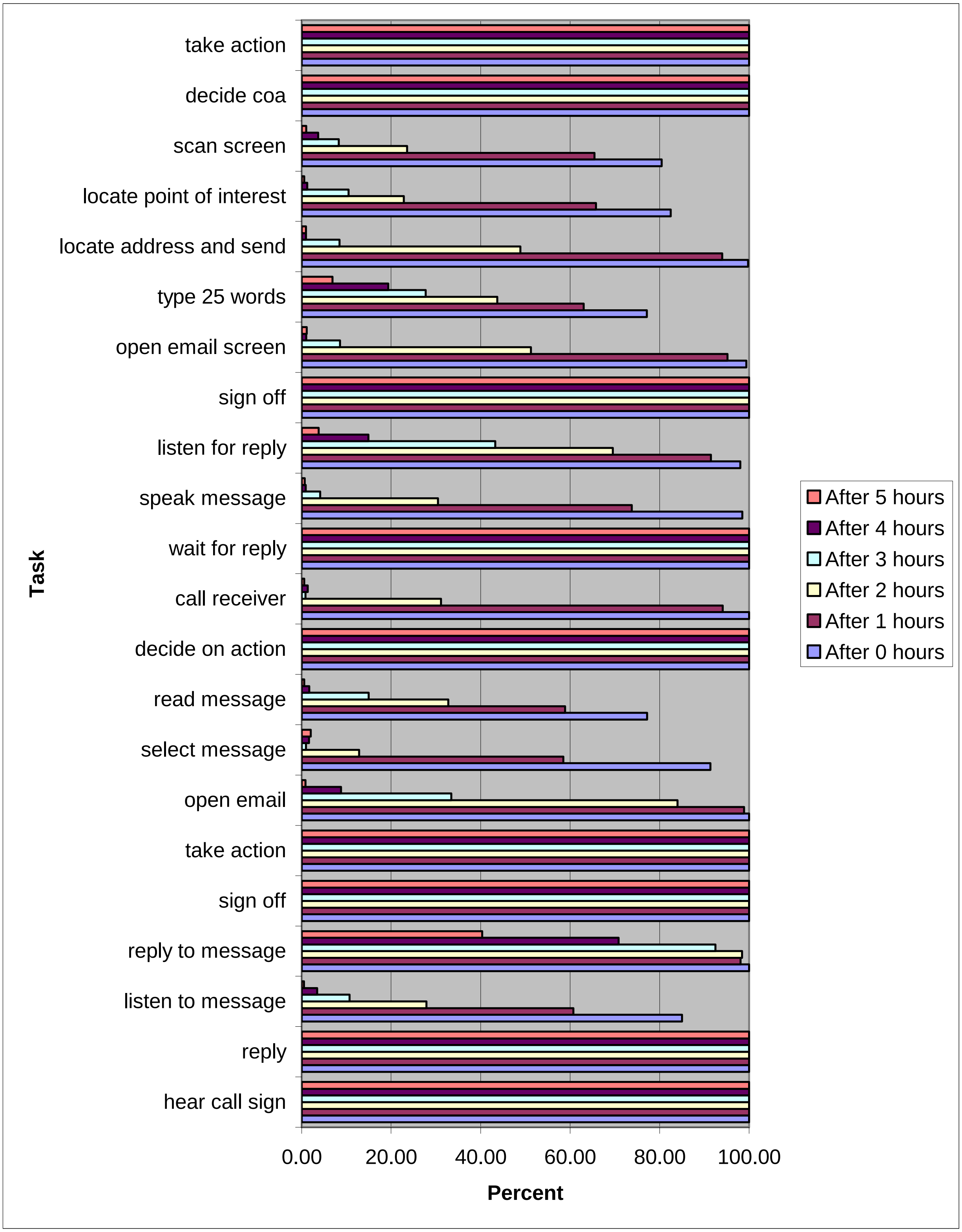

Figure 8. Percent of time that the task met the accuracy set for that task under the conditions tested.

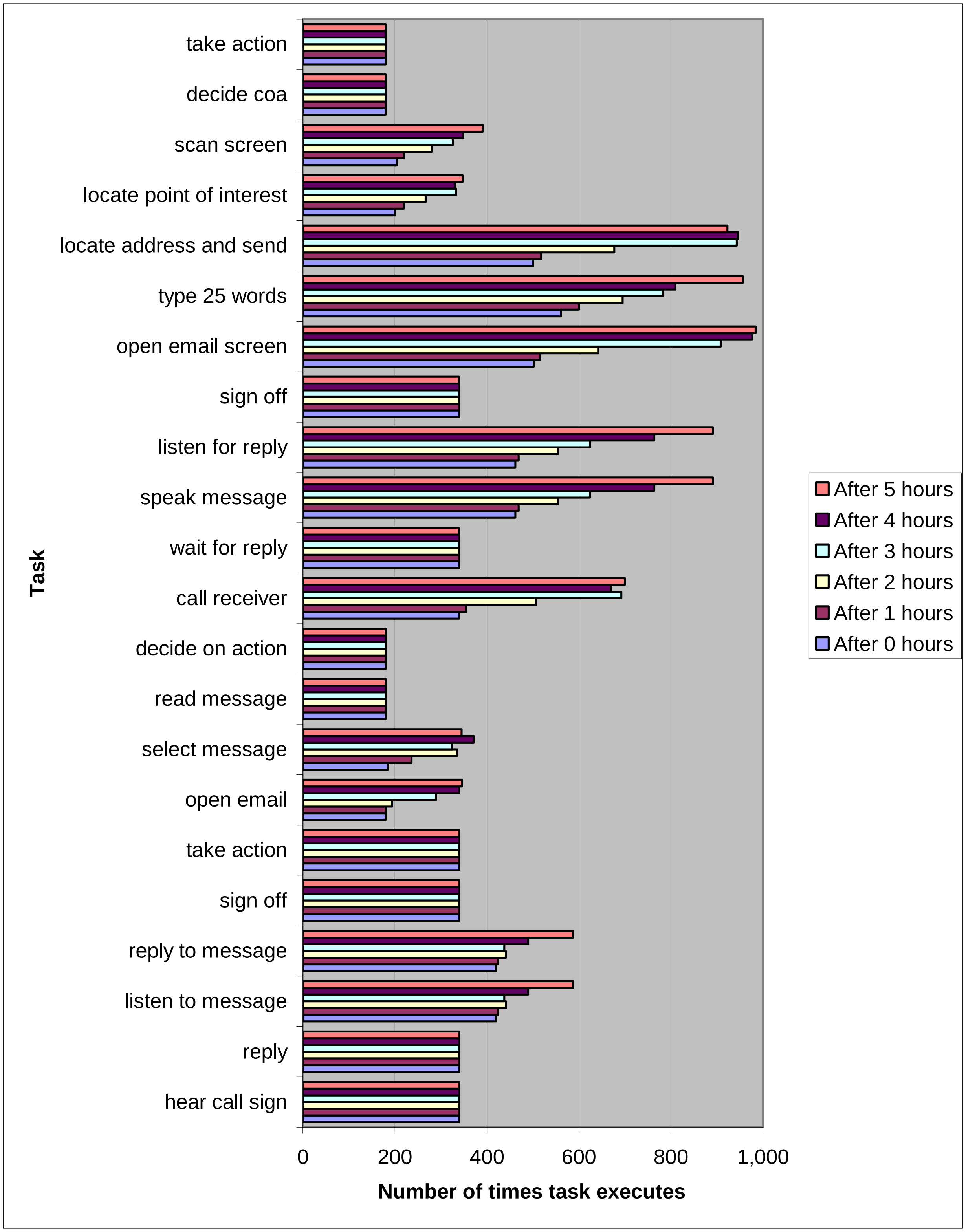

Figure 9. Number of times tasks executed in 20 model runs under the conditions tested.

5. Conclusions

IMPRINT is a useful tool for understanding the importance of human performance on system performance. Although many factors will influence human performance, it is not always obvious how environmental factors will change that performance and affect a particular mission. If data are available, the user-defined stressor option in IMPRINT enables analysts to consider changes in a mission when environmental factors are changed.

The on-the-move stressor described in this report allows analysts to quantify the effect of performing tasks in a moving vehicle after a specific amount of time. This capability is critical to design requirements for future combat vehicles. Survivability and mobility advances have led to designs that often require crew members to operate in vehicles that are moving. This stressor can help determine which tasks are most affected and which tasks are least affected. With this in mind, improved decisions can be made about vehicle design and about tactics and procedures. For example, tasks that are most affected could be scheduled, if possible, during times when vehicle is not or has not been moving.

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Appendix A. Network Diagrams

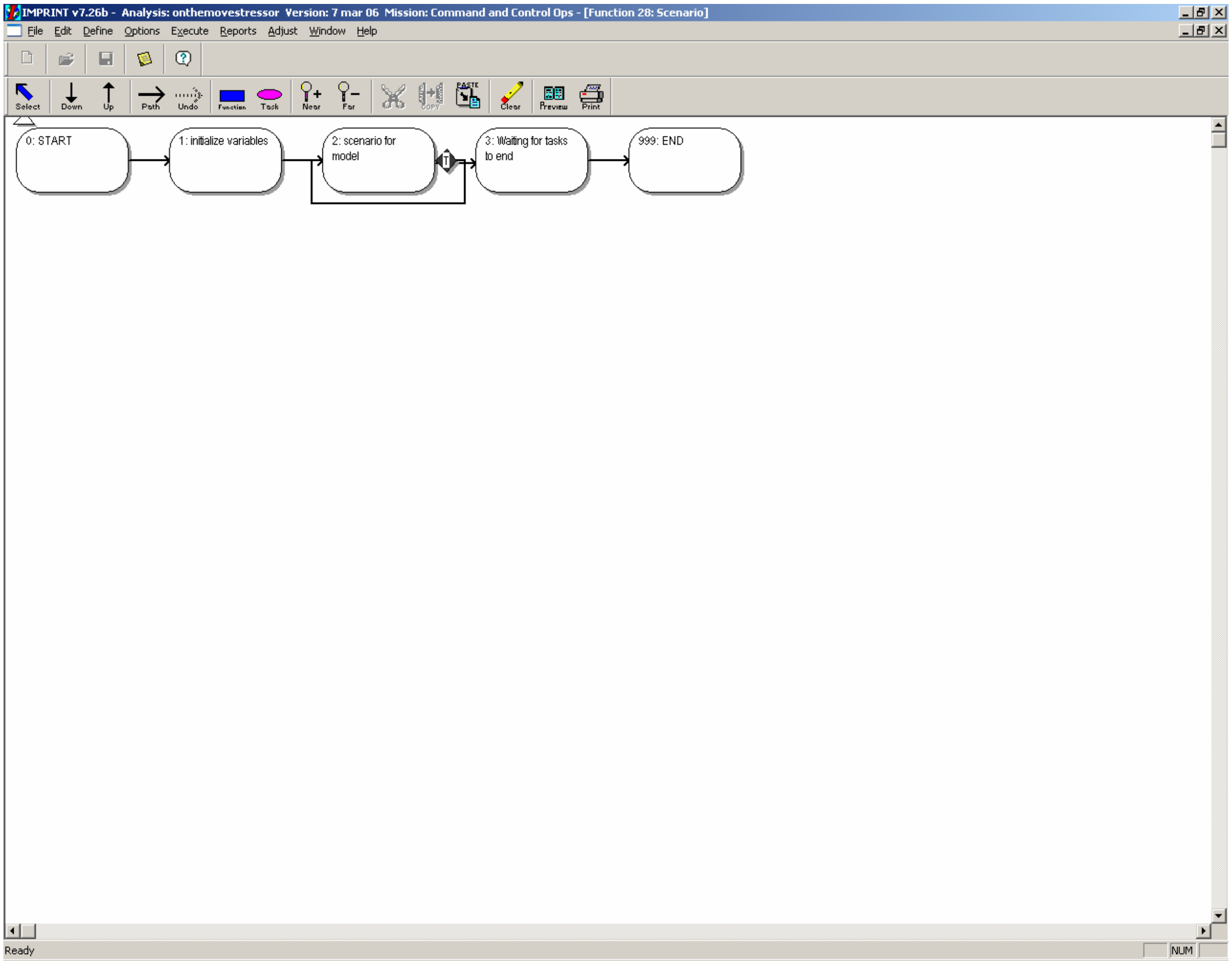

Figure A-1. Main network (controls the scenario).

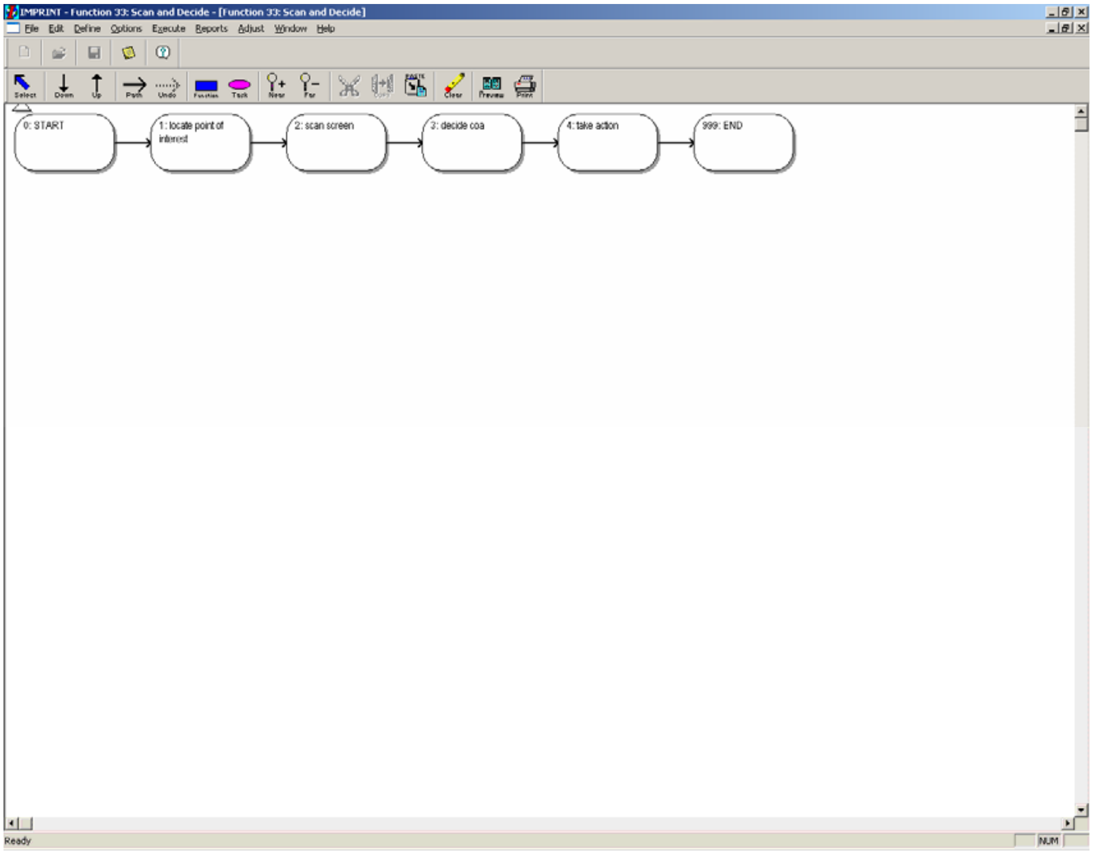

Figure A-2. Scan-and-decide network.

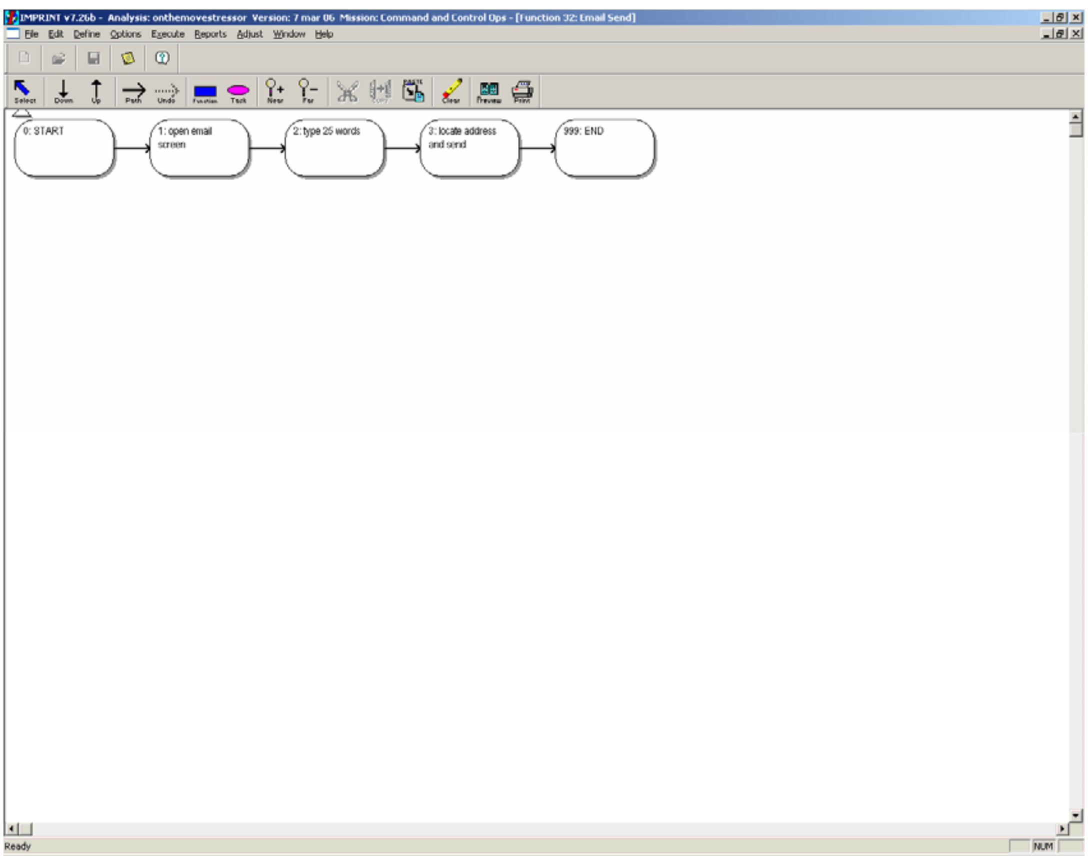

Figure A-3. E-mail send network.

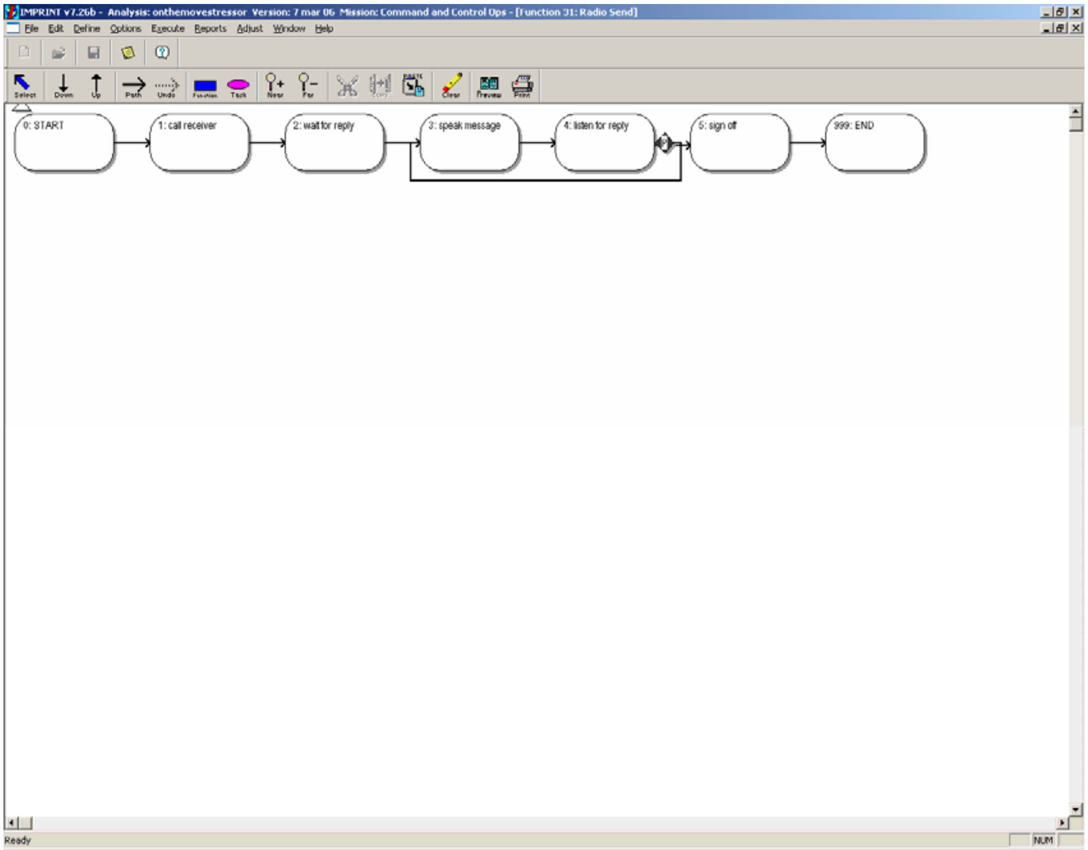

Figure A-4. Radio send network.

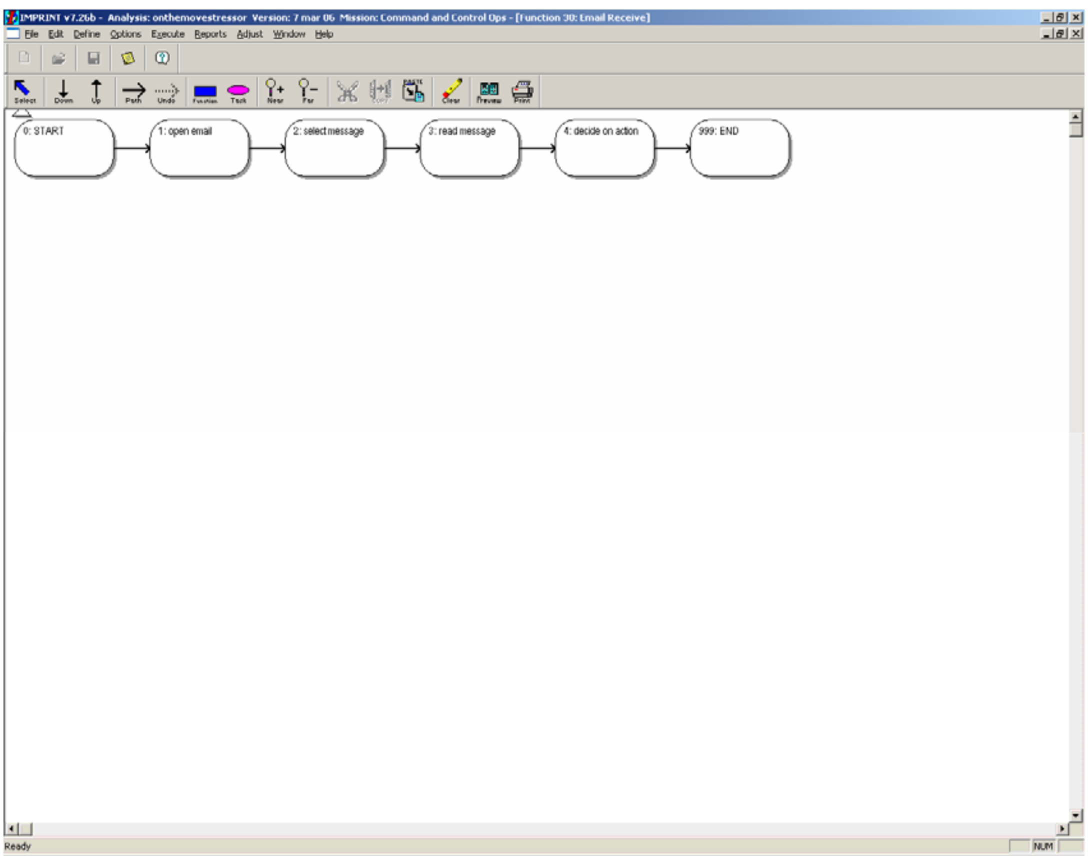

Figure A-5. E-mail receive network.

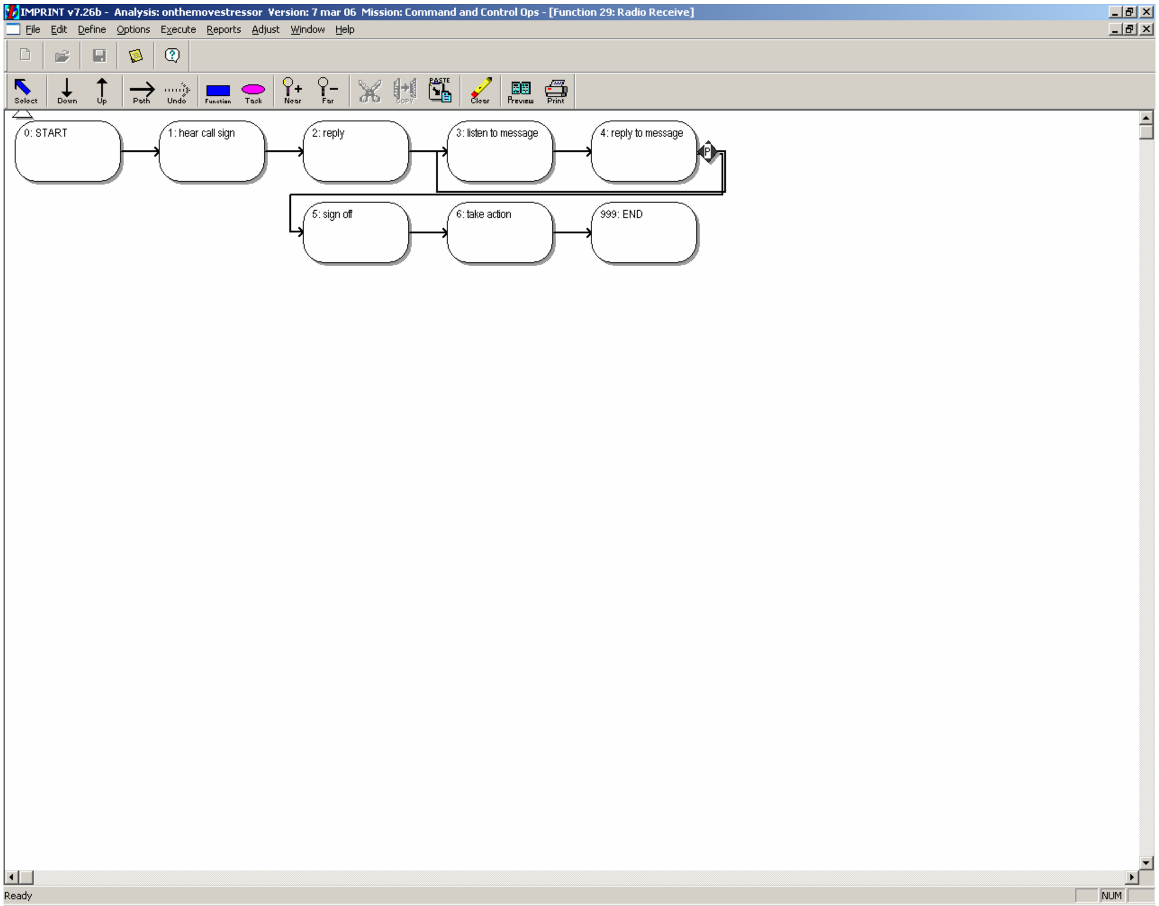

Figure A-6. Radio receive network.

Appendix B. Case Study Task Data

Table B-1. Case study task time data.

Task ID	Task Name	Function Name	Time Mean	Time StdDev	Distrib Type	Time Std
1	hear call sign	Radio Receive	00:01.0	00:00.1	Normal	00:02.4
2	reply	Radio Receive	00:01.0	00:00.1	Normal	00:03.0
3	listen to message	Radio Receive	00:05.4	00:02.0	Normal	00:10.0
4	reply to message	Radio Receive	00:02.4	00:01.0	Normal	00:05.0
5	sign off	Radio Receive	00:00.7	00:00.1	Normal	00:02.0
6	take action	Radio Receive	00:00.0	00:00.0	Normal	00:00.0
1	open email	Email Receive	00:03.0	00:01.0	Normal	00:07.0
2	select message	Email Receive	00:00.4	00:00.1	Normal	00:01.3
3	read message	Email Receive	00:06.9	00:01.0	Normal	00:15.0
4	decide on action	Email Receive	00:00.4	00:00.1	Normal	00:02.5
1	call receiver	Radio Send	00:01.4	00:00.2	Normal	00:04.0
2	wait for reply	Radio Send	00:05.0	00:01.0	Normal	00:10.0
3	speak message	Radio Send	00:03.5	00:01.0	Normal	00:08.0
4	listen for reply	Radio Send	00:04.2	00:00.0	Normal	00:10.0
5	sign off	Radio Send	00:01.0	00:00.3	Normal	00:03.0
1	open email screen	Email Send	00:05.0	00:02.0	Normal	00:30.0
2	type 25 words	Email Send	00:25.1	00:09.0	Normal	01:30.0
3	locate address and send	Email Send	00:01.2	00:20.0	Normal	00:05.0
1	locate point of interest	Scan and Decide	00:05.0	00:02.0	Normal	00:10.0
2	scan screen	Scan and Decide	00:09.0	00:02.0	Normal	00:20.0
3	decide coa	Scan and Decide	00:00.1	00:00.0	Normal	00:01.0
4	take action	Scan and Decide	00:00.0	00:00.0	Normal	00:00.0

Table B-2. Case study task accuracy data.

Task ID	Task Name	Function Name	Acc Std	Prob Success	Acc Mean	Acc StdDev	Accuracy Measure
1	hear call sign	Radio Receive	0	100	100	0	Percent Steps Correct
2	reply	Radio Receive	0	100	100	0	Percent Steps Correct
3	listen to message	Radio Receive	80	84.12	85	5	Percent Steps Correct
4	reply to message	Radio Receive	80	99.93	96	5	Percent Steps Correct
5	sign off	Radio Receive	0	100	100	0	Percent Steps Correct
6	take action	Radio Receive	0	100	100	0	Percent Steps Correct
1	open email	Email Receive	85	99.94	95	3	Percent Steps Correct
2	select message	Email Receive	88	90.87	92	3	Percent Steps Correct
3	read message	Email Receive	85	84.12	90	5	Percent Steps Correct
4	decide on action	Email Receive	0	100	100	0	Percent Steps Correct
1	call receiver	Radio Send	90	99.98	99	2.5	Percent Steps Correct
2	wait for reply	Radio Send	0	100	100	0	Percent Steps Correct
3	speak message	Radio Send	90	97.73	98	4	Percent Steps Correct
4	listen for reply	Radio Send	85	98.61	96	5	Percent Steps Correct
5	sign off	Radio Send	0	100	100	0	Percent Steps Correct
1	open email screen	Email Send	90	99.62	98	3	Percent Steps Correct
2	type 25 words	Email Send	75	76.25	80	7	Percent Steps Correct
3	locate address and send	Email Send	90	99.62	98	3	Percent Steps Correct
1	locate point of interest	Scan and Decide	90	84.12	95	5	Percent Steps Correct
2	scan screen	Scan and Decide	85	84.12	90	5	Percent Steps Correct
3	decide coa	Scan and Decide	0	100	100	0	Percent Steps Correct
4	take action	Scan and Decide	0	100	100	0	Percent Steps Correct

Table B-3. Case study consequence of failure data.

Task ID	Task Name	Function Name	Degrade Prob	Change Prob	Fail Prob	No Effect Prob	Degrade Task	Degrade Time	Degrade Acc	Change Task	Criterion
1	hear call sign	Radio Receive	0	0	0	100	START	0	0	START	100
2	reply	Radio Receive	0	0	0	100	START	0	0	START	100
3	listen to message	Radio Receive	100	0	0	0	reply to message	10	10	START	100
4	reply to message	Radio Receive	0	50	0	50	START	0	0	listen to message	100
5	sign off	Radio Receive	0	0	0	100	START	0	0	START	100
6	take action	Radio Receive	0	0	0	100	START	0	0	START	100
1	open email	Email Receive	0	50	0	50	START	0	0	open email	100
2	select message	Email Receive	0	50	0	50	START	0	0	select message	100
3	read message	Email Receive	0	0	0	100	START	0	0	START	100
4	decide on action	Email Receive	0	0	0	100	START	0	0	START	100
1	call receiver	Radio Send	0	50	0	50	START	0	0	call receiver	100
2	wait for reply	Radio Send	0	0	0	100	START	0	0	START	100
3	speak message	Radio Send	0	0	0	100	START	0	0	START	100
4	listen for reply	Radio Send	0	50	0	50	START	0	0	speak message	100
5	sign off	Radio Send	0	0	0	100	START	0	0	START	100
1	open email screen	Email Send	0	50	0	50	START	0	0	open email screen	100
2	type 25 words	Email Send	0	50	0	50	START	0	0	type 25 words	100
3	locate address and send	Email Send	0	50	0	50	START	0	0	locate address and send	100
1	locate point of interest	Scan and Decide	0	50	0	50	START	0	0	locate point of interest	100
2	scan screen	Scan and Decide	0	50	0	50	START	0	0	scan screen	100
3	decide coa	Scan and Decide	0	0	0	100	START	0	0	START	100
4	take action	Scan and Decide	0	0	0	100	START	0	0	START	100

Table B-4. Case study task workload data.

Task ID	Task Name	Function Name	Visual Workload	Auditory Workload	Cognitive Workload	Psychomotor Workload
1	hear call sign	Radio Receive	0.00 No Visual Activity	4.90 Interpret Semantic Content (speech)	3.70 Sign/Signal Recognition	0.00 No Psychomotor Activity
2	reply	Radio Receive	0.00 No Visual Activity	4.30 Verify Auditory Feedback	3.70 Sign/Signal Recognition	1.00 Speech
3	listen to message	Radio Receive	0.00 No Visual Activity	4.90 Interpret Semantic Content (speech)	6.80 Evaluation/Judg-ment (consider several aspects)	0.00 No Psychomotor Activity
4	reply to message	Radio Receive	0.00 No Visual Activity	4.30 Verify Auditory Feedback	7.00 Estimation, Calcu-lation, Conversion	1.00 Speech
5	sign off	Radio Receive	0.00 No Visual Activity	4.30 Verify Auditory Feedback	1.20 Alternative Selection	1.00 Speech
6	take action	Radio Receive	0.00 No Visual Activity	0.00 No Auditory Activity	0.00 No Cognitive Activity	0.00 No Psychomotor Activity
1	open email	Email Receive	5.00 Visually Locate/Align (selective orientation)	1.00 Detect/Register Sound	3.70 Sign/Signal Recognition	2.60 Continuous Adjustive (flight or sensor control)
2	select message	Email Receive	5.00 Visually Locate/Align (selective orientation)	1.00 Detect/Register Sound	4.60 Evaluation/Judg-ment (consider single aspect)	2.60 Continuous Adjustive (flight or sensor control)
3	read message	Email Receive	5.90 Visually Read (symbol)	0.00 No Auditory Activity	6.80 Evaluation/Judg-ment (consider several aspects)	0.00 No Psychomotor Activity
4	decide on action	Email Receive	0.00 No Visual Activity	0.00 No Auditory Activity	7.00 Estimation, Calculation, Conversion	0.00 No Psychomotor Activity
1	call receiver	Radio Send	0.00 No Visual Activity	1.00 Detect/Register Sound	4.60 Evaluation/Judg-ment (consider single aspect)	1.00 Speech
2	wait for reply	Radio Send	0.00 No Visual Activity	4.90 Interpret Semantic Content (speech)	3.70 Sign/Signal Recognition	2.20 Discrete Actuation (button, toggle, trigger)
3	speak message	Radio Send	0.00 No Visual Activity	4.30 Verify Auditory Feedback	6.80 Evaluation/ Judgment (consider several aspects)	1.00 Speech
4	listen for reply	Radio Send	0.00 No Visual Activity	4.90 Interpret Semantic Content (speech)	6.80 Evaluation/Judg-ment (consider several aspects)	0.00 No Psychomotor Activity
5	sign off	Radio Send	0.00 No Visual Activity	4.30 Verify Auditory Feedback	1.00 Automatic (simple association)	1.00 Speech
1	open email screen	Email Send	5.00 Visually Locate/ Align (selective orientation)	1.00 Detect/Register Sound	5.30 Encoding/Decoding, Recall	2.60 Continuous Adjustive (flight or sensor control)
2	type 25 words	Email Send	5.00 Visually Locate/Align (selective orientation)	1.00 Detect/Register Sound	5.30 Encoding/Decoding, Recall	7.00 Serial Discrete Manipulation (keyboard entries)
3	find address and send	Email Send	5.00 Visually Locate/Align (selective orientation)	1.00 Detect/Register Sound	5.30 Encoding/Decoding, Recall	2.60 Continuous Adjustive (flight or sensor control)
1	locate point of interest	Scan and Decide	5.00 Visually Locate/Align (selective orientation)	0.00 No Auditory Activity	5.30 Encoding/Decoding, Recall	2.60 Continuous Adjustive (flight or sensor control)
2	scan screen	Scan and Decide	7.00 Visually Scan/Search/ Monitor (continuous)	1.00 Detect/Register Sound	6.80 Evaluation/Judg-ment (consider several aspects)	0.00 No Psychomotor Activity
3	decide coa	Scan and Decide	1.00 Visually Register/ Detect (detect image)	0.00 No Auditory Activity	7.00 Estimation,Calcula-tion, Conversion	0.00 No Psychomotor Activity
4	take action	Scan and Decide	0.00 No Visual Activity	0.00 No Auditory Activity	6.80 Evaluation/Judg-ment (consider several aspects)	0.00 No Psychomotor Activity

Table B-5. Case study task taxon data.

Task ID	Task Name	Function Name	TaxonID1	Wt 1	TaxonID2	Wt 2	TaxonID3	Wt 3
1	hear call sign	Radio Receive	Information Processing/ Problem Solving	0.43	Oral	0.57	none	0
2	reply	Radio Receive	Information Processing/ Problem Solving	0.79	Oral	0.21	none	0
3	listen to message	Radio Receive	Information Processing/ Problem Solving	0.58	Oral	0.42	none	0
4	reply to message	Radio Receive	Numerical Analysis	0.87	Oral	0.13	none	0
5	sign off	Radio Receive	Information Processing/ Problem Solving	0.55	Oral	0.45	none	0
6	take action	Radio Receive	none	0	none	0	none	0
1	open email	Email Receive	Visual Recognition/ Discrimination	0.44	Information Processing/ Problem Solving	0.33	Continuous Fine Motor	0.23
2	select message	Email Receive	Visual Recognition/ Discrimination	0.41	Information Processing/ Problem Solving	0.38	Continuous Fine Motor	0.21
3	read message	Email Receive	Information Processing/ Problem Solving	0.54	Reading and Writing	0.46	none	0
4	decide on action	Email Receive	Numerical Analysis	1	none	0	none	0
1	call receiver	Radio Send	Information Processing/ Problem Solving	0.82	Oral	0.18	none	0
2	wait for reply	Radio Send	Information Processing/ Problem Solving	0.34	Discrete Fine Motor	0.2	Oral	0.46
3	speak message	Radio Send	Information Processing/ Problem Solving	0.87	Oral	0.13	none	0
4	listen for reply	Radio Send	Information Processing/ Problem Solving	0.58	Oral	0.42	none	0
5	sign off	Radio Send	Information Processing/ Problem Solving	0.5	Oral	0.5	none	0
1	open email screen	Email Send	Visual Recognition/ Discrimination	0.39	Information Processing/ Problem Solving	0.41	Continuous Fine Motor	0.2
2	type 25 words	Email Send	Visual Recognition/ Discrimination	0.29	Information Processing/ Problem Solving	0.31	Discrete Fine Motor	0.4
3	locate address and send	Email Send	Visual Recognition/ Discrimination	0.39	Information Processing/ Problem Solving	0.41	Continuous Fine Motor	0.2
1	locate point of interest	Scan and Decide	Visual Recognition/ Discrimination	0.39	Information Processing/ Problem Solving	0.41	Continuous Fine Motor	0.2
2	scan screen	Scan and Decide	Visual Recognition/ Discrimination	0.51	Information Processing/ Problem Solving	0.49	none	0
3	decide coa	Scan and Decide	Visual Recognition/ Discrimination	0.13	Numerical Analysis	0.87	none	0
4	take action	Scan and Decide	Information Processing/ Problem Solving	1	none	0	none	0

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