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A Shadow Unmanned Aerial Vehicle (UAV) Improved Performance Research Integration Tool (IMPRINT) Model Supporting Future Combat Systems

by Bruce P. Hunn and Otto H. Heuckeroth

ARL-TR-3731 **February 2006**

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14. ABSTRACT
This study describes the creation of an IMPRINT (Improved Performance Research Integration Tool) model to describe crew workload levels in the Shadow unmanned aerial vehicle (UAV). Field data were collected for tasks performed by Shadow UAV crews. This model was developed to support the Army's Future Combat System, human robotics interaction Army Technology Objective. The design and operation of this model are discussed, along with several workload conclusions based on the model's operation. Workload for individual crew members and as a crew entity is discussed.

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1. Introduction

1.1 Background

The continuing need for information about future systems is addressed in several Army Technology Objective (ATO) efforts, notably under the Future Combat Systems (FCS) initiative. Implementation of this initiative is augmented by a system of systems approach encompassing several ATO efforts. Each of these efforts requires creation of models that can be integrated into the FCS initial stages of development. This integration is comprised of a sequential building process that can provide understanding of what the Army of the future might resemble. Automation and robotics are keystones of this developing effort. This report details a modeling effort conducted under support by the Human Robotic Interaction ATO, specifically for one of the Army's fielded unmanned aerial vehicles (UAVs) known as the Shadow 200 System.

Modeling and simulation are highly valuable tools that contribute to the understanding of systems that are proposed, in development, or have been fielded. Low cost, high flexibility, and perfect safety can be accomplished with the use of a simulation rather than by the creation of physical models, actual testing, or through the collection of operational data. In this regard, modeling can provide answers to questions that testing may not even be able to duplicate operationally, or modeling can be used to answer questions that would entail undue cost or risk for those personnel who might have to accomplish missions using a particular system.

This report details the specific efforts to create a model that may be used to address the needs of future Army systems development. The modeling system used in this effort is the Improved Performance Research Integration Tool (IMPRINT). IMPRINT has been used for numerous Department of Defense situations in which a discrete event, stochastic model is required (U.S. Army Research Laboratory, 2003b). IMPRINT manages a considerable number of data sets and manipulates those sets so that various system outcomes can be explored as discrete events. It employs a Monte Carlo simulation routine, in a Micro Saint[1] software structure to use system characteristics and their interrelationships to predict system responses in accordance with variation in the dimensions of those systems' characteristics.

1.2 IMPRINT Modeling of the Shadow UAV

Automation has been one of the major areas of technological development that has enabled the exploration of ways and means to produce desired resources and to lead to recommendations for optimal use. One of the complex arenas that automation has facilitated is in the area of robotics. As the sophistication of robotic capabilities has increased, changes in the conditions under which

[1]Micro Saint is a trademark of Micro Analysis & Design, Inc.

the military is being forced to operate are recognized, and questions have been raised about whether these new demands can be met by this specific technological improvement. Among the most highly motivating factors that are driving the military to explore the utility of this emerging technology is how best to counter nonconventional and terrorist type military tactics being used in the near term. Fighting against such tactics with conventional warfare techniques could be expected to lead to heightened casualties, and the use of automated systems may preclude some of those casualties.

The area of semi-automated systems being addressed in this report concerns UAVs. The specific UAV being addressed is the Shadow 200. In earlier work with this UAV, a modeling technique was developed by Micro Analysis & Design, Inc., for the U.S. Army Research Laboratory (ARL) (Barnes & Matz, 1998; Barnes, Knapp, Tillman, Walters, & Velicki, 2000). This modeling involved software coding in Micro Saint software. Subsequent studies with Micro Saint also examined the effects of crew size and crew fatigue on performance in the Shadow UAV system (Walters, Huber, French, & Barnes, 2002). Latter efforts used IMPRINT in addition to Micro Saint. Both sets of software can be characterized as using task network modeling procedures and a discrete event stochastic process.

1.3 The Purpose of This Model's Creation

A key feature of network types of modeling techniques is that they allow the user the opportunity to select from a large array of independent and dependent variables and then obtain some initial estimate of how successful a mission would be completed during a specific set of conditions. Since the number of potentially feasible conditions and measures is large, conducting conventional research with live Soldiers (humans in the loop) would be costly and resource intensive. With the large set of independent and dependent factors that must be considered in the system development process, this modeling technique helps to cost effectively

- Set realistic system requirements,
- Identify future manpower and personnel constraints,
- Evaluate operator and crew workload,
- Test alternate systems crew function allocations,
- Assess performance during extreme conditions, and
- Examine performance as a function of personnel characteristics' training frequency and timeliness.

When the original modeling effort (Walters et al., 2002) for the Shadow 200 was performed with Micro Saint software, the Shadow 200 was undergoing test and development in preparation for its initial operational test and evaluation (IOT&E), which was subsequently completed in May 2002. At that time, training functions, sub-functions, and tasks for operation of the Shadow 200

were emerging. The goal of earlier modeling for the Shadow 200 was to obtain initial estimates of optimal conditions in which operations should be conducted and to make preliminary staffing recommendations.

In modeling conducted during system development, the user community often has limited understanding of the operational characteristics of a system and how the system will be used. This dilemma is often a result of various contractors executing their interpretation of that system's design to specifications, as well as the impact of system design changes made during that process. In this regard, modeling can serve as a potential solution to that dilemma, and in a quantitative way, explain how the system operates to a diverse community. That explanation should result in a common understanding not as easily achieved without the use of such a model.

The earlier Shadow models were developed in order to address the impact of crew size and task allocation, specifically, the effects of varying shift length, rotation schedule, scenario type, and task allocation on system performance time and workload. At the time of those initial Shadow modeling efforts, Micro Saint allowed analysts to also investigate the effects on performance of variables such as fatigue and circadian conditions.

With the emerging Army FCS initiative and an operationally suitable and effective UAV emerging from a successful IOT&E, it was considered conceptually desirable (and feasible) to shift more of the modeling effort from the expert analyst to the user level. The development of IMPRINT software with built-in capabilities for procedures that required specific programming in Micro Saint contributed to this feasibility. The emerging FCS initiative also motivated more comprehensive mission modeling involving models for multiple UAVs and other ground robotic systems. As such, a modeler would be responsible for combining models to evaluate the effects of simulated missions. Since the combining of models for alternate systems is a thrust of the FCS initiative, it would simplify the modeling process if individual models were programmed in a common programming language. This has been the primary motivating factor for the re-programming of the Shadow 200 model in IMPRINT. In addition, this modeling effort was developed to be generic in nature and not rely on a specific mission type in order to be able to fit into the overall FCS modeling effort (this issue is covered in the Objectives section).

Within the context of the FCS initiative, the macro-modeling effort that is planned for the emerging FCS will involve four echelon-based classes of UAVs:

- Class 1 supports platoon echelon, e.g., Raven, micro air vehicle (AV), and small UAV;
- Class 2 supports company echelon, e.g., Interim Class 1 and 2 UAV;
- Class 3 supports battalion echelon, e.g., Shadow 200 Tactical UAV;
- Class 4 supports unit of action (brigade), e.g., Hunter, Extended Range/Multipurpose (ER/MP) UAV.

Macro modeling for the FCS will include many component systems; the Shadow UAV is one of the core systems that will be represented in that model. By the derivation of a model that can replicate the characteristics of the Shadow UAV, this model can stand alone and be used to provide operational expectancies from use of the Shadow 200 during a wide array of mission-related conditions; thus, this model can serve as a keystone in the larger FCS modeling effort.

1.4 Operational Questions to be Examined by this Model

This model contains a significant amount of information about Shadow UAV task performance, based on its operator's manual and information gleaned from operators who have war-time operational Shadow UAV experience. As such, this model should have high face validity as well as content validity in predicting future UAV operations for similar UAV types. This model can also be used to generate discrete event outcomes for any type of operational tasking that follows the operator's manual procedures (which should include all operational tasking).

Specific hypotheses that can be tested at this time, from this model, include answering questions such as

- What is the level of crew workload associated with selected segments of any particular mission?
- What is the level of individual crew workload associated with any particular mission?
- What is the baseline level of workload for the crew overall as well as any individual member of the crew during a mission?
- How many personnel does it take to complete any particular tasking and how long will that tasking take?

These hypothetical questions and more should be answered by this model. Additional tests of hypotheses may be included with a more advanced version of this model which could contain fatigue functions, the use of chemical-biological equipment or variations in operator manning, work techniques, circadian rhythm, or work tasking levels. The preceding efforts would require an advanced IMPRINT model that could be based on this model's format and the data included in this model.

2. Method

This report concerns a model of the Shadow UAV created by the population of an IMPRINT model with data collected from field-experienced Shadow UAV personnel who had just returned from a combat deployment. The structure chosen for the model was based on the UAV's

dash-10 (operator's manual) and contained all the normal operating procedures to accomplish any type of mission.

The specific type of IMPRINT analysis modeled for this report is called a visual, auditory, cognitive, and psychomotor (VACP) workload model. This VACP analysis identifies tasks for any defined mission or procedure using a taxonomy derived from a multiple resource theory basis. Multiple resource theory posits that various brain resources are used to address different elements of task performance.

This VACP approach is based on a four-independent-channel theory articulated by McCracken and Aldrich (discussed in the IMPRINT operator's and analysis manuals) (U.S. Army Research Laboratory, 2003a; 2003b) and is largely qualitative in method (Allender, 2000; McCracken & Aldrich, 1984). It is primarily useful early in the development process where controls and interfaces are not yet defined (such as in FCS). In the model, time standards and criteria can be used for mission level, as well as functional level input. Also, branching logic can be used in four forms: serial, multiple, repeating, and probabilistic. At the task level, the following input can be used: time standards, accuracy standards, performance criteria, time estimates, accuracy estimates, consequences of failure, workload, taxons, and crew assignments.

The primary hypothesis for this model was to examine the levels of workload associated with Shadow UAV operations. The model in this study was based on a representative user sample; however, formal verification, validation, and accreditation were not performed. All workload values are predefined in the model and each contained eight levels with discrete numeric values as derived by McCracken and Aldrich (1984). Verbal descriptors associated with the workload values represent a continuum from low to high and are specific to each type of channel in the VCAP model. This model did not include failure consequences to the mission, but many of those could be inferred from the system being modeled; for example, a fire on the UAV would invariably result in a mission cancellation, as would an engine failure or other catastrophic incident.

High workload was defined as any channel at a level 7.0 (the highest rating of any workload channel) or an aggregate of all channels exceeding a level 7.

An example of the four-workload channel (VACP) approach follows, and it shows the details of how any task or procedure could be broken down into eight levels within each overall category (visual, auditory, cognitive, or psychomotor). The VACP scale is not unidimensional even within a primary category, and the numeric values derived for each area were established by a paired comparison rating method; thus, they are not whole numbers (e.g., for the Visual scale, the numeric values are 0.00, 1.00, 3.70, 4.00, 5.00, 5.40, 5.90, and 7.00; see table 1).

9Table 1. IMPRINT, VACP workload numeric scale values.

Value	VISUAL SCALE
0.00	No Visual Activity
1.00	Visually Register/Detect (detect image)
3.70	Visually Discriminate
4.00	Visually Inspect/Check (static inspection)
5.00	Visually Locate/Align (selective orientation)
5.40	Visually Track/Follow (maintain orientation)
5.90	Visually Read (symbol)
7.00	Visually Scan/Search/Monitor (continuous)
	AUDITORY SCALE
0.00	No Auditory Activity
1.00	Detect/Register Sound
2.00	Orient to Sound (general orientation)
4.20	Orient to Sound (selective orientation)
4.30	Verify Auditory Feedback
4.90	Interpret Semantic Content (speech)
6.60	Discriminate Sound Characteristics
7.00	Interpret Sound Patterns (pulse rate, etc.)
	COGNITIVE SCALE
0.00	No Cognitive Activity
1.00	Automatic (simple association)
1.20	Alternative Selection
3.70	Sign/Signal Recognition
4.60	Evaluation/Judgment (consider single aspect)
5.30	Encoding/Decoding, Recall
6.80	Evaluation/Judgment (consider several aspects)
7.00	Estimation, Calculation, Conversion
	PSYCHOMOTOR SCALE
0.00	No Psychomotor Activity
1.00	Speech
2.20	Discrete Actuation (button, toggle, trigger)
2.60	Continuous Adjustive (flight or sensor control)
4.60	Manipulate
5.80	Discrete Adjustive (rotary, thumbwheel, lever)
6.50	Symbolic Production (writing)
7.00	Serial Discrete Manipulation (keyboard entries)

2.1 Participation

Questionnaires were distributed to 16 personnel deployed (August 2004) to the U.S. Army UAV Training School at Fort Huachuca, Arizona (E Company, 305th Military Intelligence Battalion). The majority of the personnel (14) were Soldiers from the I-14 Cavalry (Fort Lewis, Washington) who were attending a refresher course in Shadow UAV operations. These Soldiers had just returned from deployment to Iraq. The remaining two respondents were Department of the Army (DA) civilians employed by the UAV training school as UAV instructors.

2.1.1 Demographics

All subjects were male. The breakdown by ranks and military occupational specialty (MOS) is shown in table 2.

Table 2. Test subject demographics.

Rank	Civ	PFC	CPL	SPC	SGT	SSG	MOS	52DU2	33WU3	96U	CIV
	2	1	1	8	1	3		1	4	9	2

Per DA Pamphlet 611-21, the MOS 96U is the indicator for "UAV Operator," 52D is the MOS for "Power Generation Equipment Repairer," and MOS 33W is for "Electronic Warfare/Intercept Systems Repairer." The U2 and U3 designations that are part of the MOS additional skill identifiers are additional job identification information within that MOS and are reported in table 1 if they were known. Both civilians questioned had considerably higher levels of experience than any of the troops surveyed. No other demographic information was collected for the participants. The sample was based on a group of Soldiers who were available at the time of the study to survey, and no attempt was made to select a particular company from within the Army for this survey.

2.2 Instrumentation

A simple questionnaire was fashioned from the operator's field manual (often called the dash-10) for the Shadow 200 tactical UAV (TUAV). This questionnaire was based on procedures used by air vehicle operator (AVO) and mission payload operator (MPO) as well as other Shadow UAV personnel (see appendix A) in normal flight and ground operations. This questionnaire used each primary header in the operator's manual as a base for a question to the operators. Sixteen questionnaires were distributed to operators of the Shadow system. The questionnaire asked 82 questions about normal operations and 25 questions about emergency operations, all based on operator's manual procedures.

Two sub-questions were asked for every task:

- How much time was required to perform the task (in minutes or seconds)?
- How many other personnel were involved in performing the task?

In addition, every question had a section for comments for each task. This resulted in 107 questions with two required responses each or (107 x 2 x 16 = 3424) required responses plus any comments volunteered. Considering comments alone, the potential number of required responses was 107x1x16 = 1712 or the potential for 5136 total possible responses. Volunteered verbal comments totaled 124, and the vast majority were based on issues associated with emergency procedures. No attempt was made for respondents to be forced to make comments; all comments were strictly voluntary.

In addition, not all tasks were accomplished by all personnel; for example, engine mechanics and electronic repair personnel accomplished only a handful of the tasks listed in the dash-10 for AVO and MPO positions. However, the majority of personnel were 96U MOS so they participated in most of the tasks detailed in the questionnaire. The 96U MOS is somewhat of an overall classification allowing AVO and MPO duties with the same designation. Questionnaires

were completed on duty time, but no time limit was imposed. Most personnel had the questionnaire several days to a week, so there were no significant time pressures to complete the questionnaire.

All the data were fed into an Excel[1] database and then transcribed into the IMPRINT model by hand.

Workload ratings in IMPRINT were then entered by the primary author. This was accomplished because of limited time availability of the test subjects and the very time-consuming aspects of making workload ratings for every task, and subtask for every level of the model (see model flow diagrams in appendix B). The assignment of task workload ratings took many weeks for all elements of this model. An example of the numeric ratings applied to the task of "receiving the mission brief" is shown in table 3. In order to qualify that task action according to the IMPRINT model, the task would have to be rated in specific terms in accord with the McCracken and Aldrich (1984) classification scheme that was built into the model. Supplying an assessment of those tasks, the primary author applied the ratings for this particular task as shown in table 3.

Table 3. VACP rating example.

Task: Receive Mission Tasking (Mission Brief)		
Category	**Numeric Rating**	**Verbal Descriptors**
Workload Overall	7.00	Visual scan, speech, monitor continuously
Auditory	4.90	Interpret semantic content, speech
Cognitive	6.80	Evaluate judgments, consider several aspects
Psychomotor	1.00	Speech

A typical mission briefing has the majority of information presented visually (maps or drawings) and verbally (instructions, mission intent, etc.), and the verbal descriptors should intuitively match what would be expected of a normal mission briefing. The outcome for this model is therefore a mix of direct subject data and author data and contains:

- Subject-derived times for task completion,
- Subject-derived number of personnel required for the task,
- Subject-derived written comments,
- Subject matter expert (SME) (primary author) input on the specific balance of descriptors for workload tasks.

Subject data were entered into an Excel database, and for each task, means and standard deviations were calculated, and then those values were entered into the IMPRINT model. IMPRINT has the ability to accept individual values, as well as means and standard deviations for the same questions answered by many different personnel. In rare cases when there may

[1]Excel is a trademark of Microsoft.

have been a single response per question, that response was entered without any mean or standard deviation values (also allowable by the IMPRINT model).

In addition to times and workload ratings, another valuable piece of information required by IMPRINT are probabilities associated with certain tasking or task outcomes; for example, if the question were asked, "How often did the launch sequence fail because of catapult failure?", then a probability value could be entered that reflects the likelihood of that occurrence, such as a probability of 0.01 (or one time in 100). One current limitation to the VACP IMPRINT model is that exact probability values of high precision cannot be entered—only rough estimates, and those estimates can only be a probability of 0.01 or larger values. In normal reliability and maintainability accounting, the probability of a rare but significant occurrence is often very much smaller than 0.01; for example, rare events often occur at levels that reflect five or six significant digits {.00001 to .0000001}. This type of event might be an engine fire that destroys the UAV and occurs only once in 100,000 hours of operation. It is suggested that future VACP IMPRINT versions allow the inclusion of such low *p* event values.

2.3 How the Model Works

Once the IMPRINT software is loaded into a computer, the next step in the method is the creation of a network diagram. That diagram contains functions, sub-functions, and tasks that are connected by arrows that show the sequence of execution (see appendix B). In addition, the functional relationships must reflect whether more than one task is beginning at the same time and whether alternate tasks begin after a specified task with varying probabilities. An example of the first case, multiple tasks beginning at the same time, is something that could well occur when the system involves multiple crew members. An example of different tasks occurring with varying probability following a given task could reflect varying emergency procedures that might be required, depending on consequences that may occur at different points in the normal mission task operations.

In the IMPRINT model, functions and sub-functions are depicted by rectangles; tasks are depicted by ellipses. This model included 15 primary functions of the mission and 226 active sub-functions within those functions. Within each function, sub-function, and task are the values reported by the operators, derived from the SME, or estimated for the purposes of allowing the model to run (placeholder data). The source of information for functions, sub-functions, and tasks for developed systems were found in the operator's manual. The model for the Shadow 200 was developed as an operations model; thus, the key reference source was the Department of the Army (2002). Within this technical manual, the functions, sub-functions, and tasks for normal procedures are presented in chapter 8, and emergency procedures are presented in chapter 9. The overall model layout according to the operator's manual is shown in figure 1.

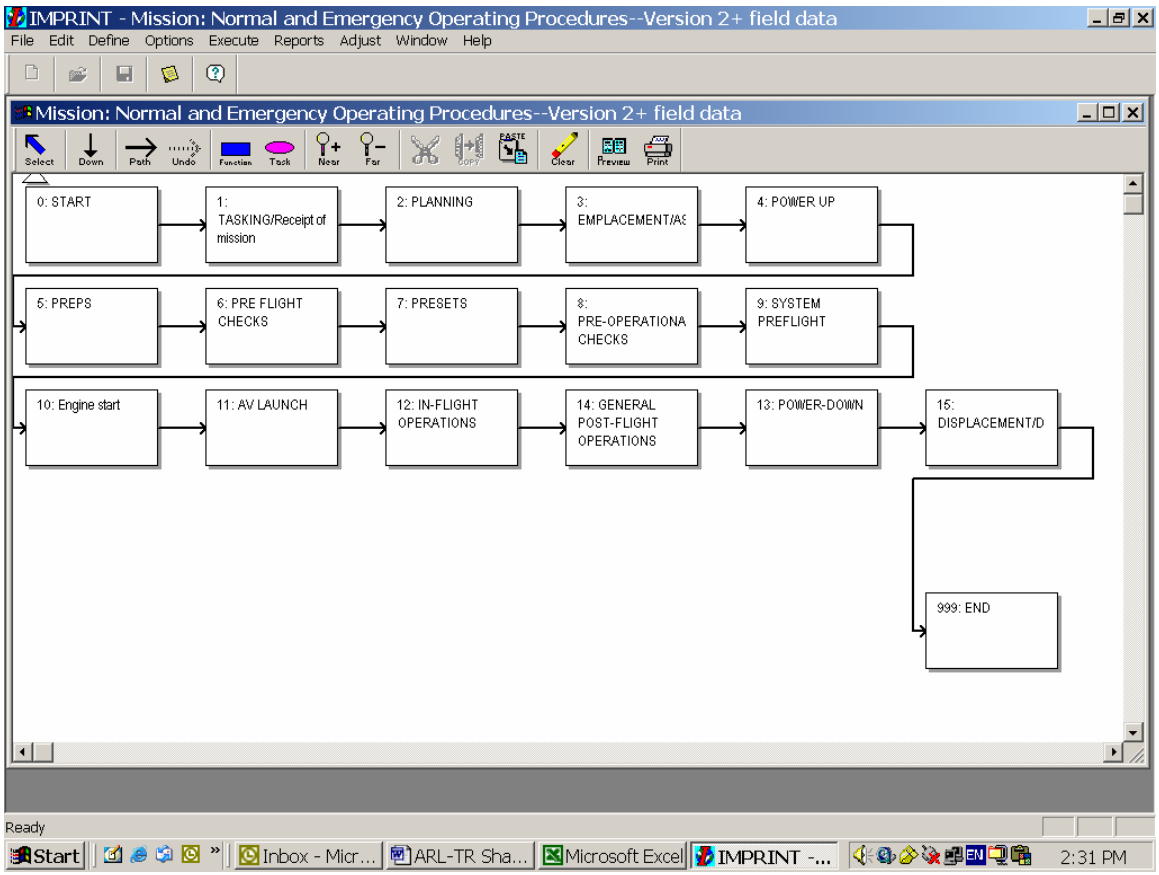

Figure 1. Overall shadow model, showing 15 functions.

The operator's manual generally contains a detailed description of how to operate the system; however, judgment of the modeler is required in defining functions, sub-functions, and tasks. In addition, the time to complete tasks, as well as the number of personnel required to complete tasks was provided by the test subjects. Comments were also solicited on a voluntary basis for any question asked. In the development of an understanding of the procedures, a matrix containing at least eight columns was developed and is shown in table 4.

Table 4. Model outline.

Functions	Sub-Functions	Tasks	Time	Visual Workload	Audio Workload	Cognitive Workload	Psychomotor Workload
15	226	Varied	Min/sec	x	x	x	x

If the procedures have many functions, sub-functions, and tasks required to complete a mission, construction of this matrix with the categories of information listed can help to build an understanding of how the system is operated. The primary area of variability was in the tasking levels since particular tasks only occur during certain situations (e.g., the task of extinguishing a fire only occurs rarely when a fire actually occurs).

In addition to the task time and number of personnel reported as necessary to the process, a number of other variables were included in the model. For the VACP workload analysis accomplished in this model, estimates were entered for task accuracy, the probability of success, and the results if the task failed.

The process of loading this matrix from a review of the operator's manual is slow because at the present time, each field must be manually entered. However, in many cases, this process can be facilitated by the copy/paste function in the Microsoft software suite.

Once the matrix was loaded, the modeler reviewed the functions, sub-functions, and tasks in detail. Some of these tasks were verified by observation of the system in operation and with discussion of accomplished operators or SMEs. For each function, sub-function, or each task required to perform that function, there should be an examination of whether it appears that it will take a substantial amount of time to complete and whether any of the workload dimensions might be relatively large. This will potentially relate to any ensuing tasks. If the answer to each of these questions is no, the same set of judgments could be used for subsequent tasks. It may be that while several tasks individually appear to have little time or workload impact, when we look across several tasks together as in the aggregate, a substantial amount of time or workload may exist. What is considered "substantial" in the modeler's judgment, to some extent will depend on how well the modeler has a real-world understanding of what the operators must do to perform the function, sub-functions, and task(s).

The approach taken in this modeling effort was to provide mean ratings of time to complete tasks as well as mean values (with their associated standard deviations) for all functions, sub-functions, tasks, and sub-tasks, based on a sampling of an operational Shadow UAV crew. As part of this modeling effort, all activities in the emplace and displace functions were observed by the primary author as they were accomplished during training at the U.S. Army UAV School at Fort Huachuca. In addition to those functions, the primary author observed several Shadow training flights from their ground control stations (GCS), and in all cases, the operator's manual was the source document for those operations. This approach was different from classical workload rating approaches such as discussed by Schipani (2003).

3. Results

As pointed out in the Background section, a major purpose of this programming effort for the Shadow 200 was to provide model coding in IMPRINT that could serve as a component piece in a larger modeling effort involving other robotic/non-UAV systems. If the earlier conclusions and those obtained with any current IMPRINT models are essentially the same, verification and validation would have been accomplished through the concurrence of results, that is, one model's output should match the later model's output. That final model could then be

transferred to FCS modelers for incorporation into the overall model. The very nature of modeling is to propose hypotheses, model them, run the simulation, and discuss the results, and as such, the purpose of the model is to create large numbers of possible answers to numerous questions asked. In the case of this model, only a few outcomes of the model are discussed as examples of what the model can generate, and those will be associated with workload.

The first of many possible hypotheses would be to derive estimates of workload for an entire crew for a Shadow mission and to derive estimates of workload for each member of that crew for the same mission. The outcomes of workload models shown in figure 2 have been translated from printed data associated with the IMPRINT model, which were then entered into an Excel database graph. The overall model diagram is shown in appendix B for clarity, but because of its complexity, not all steps can be shown in diagrammatic format without being excessively complex. Actual running of the IMPRINT program is the best way to examine the model and understand the logic of the model.

Figure 2 shows the distribution of workload, expressed as additive workload ratings for a mission of about 2.4 hours. The values on the vertical axis are merely relative and should not be interpreted as diagnostic of an exact workload value. Figure 2 shows that overall crew workload peaks at about 20 minutes into the mission (corresponding to the UAV take-off) and is then reduced for the balance of the mission but rises to a high level at the end of the mission (corresponding to the landing of the UAV). The model also shows two small spikes in the workload and one slight workload rise during the mission. Further analysis could determine the nature of those workload increases; however, the overall lesson learned is that workload increases for the team at the two critical segments of flight: take-off and landing.

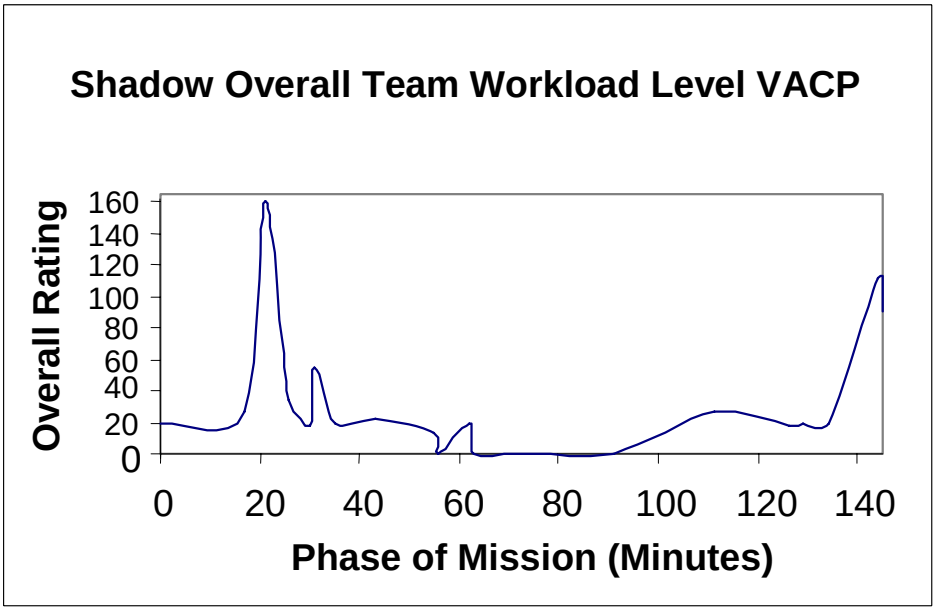

Figure 2. Shadow 200 workload, overall crew workload.

Figure 3 shows the same six-person UAV crew model (as figure 2), and it consists of an AVO and MPO (96U MOS), a mission commander (96U MOS), one engine mechanic (52D MOS), and two electronics repair personnel (33W MOS). While it is the same model as shown in figure 2, its ratings are not additive; instead, the ratings shown are individual workload values per crew position. This approach shows how individual crew workload may be balanced or not balanced among crew members, and in the future, this result could be used to allocate work, based on workload per each segment of the mission.

When we observe figure 3, the same basic pattern shown in figure 2 is present (higher workload at the take-off and landing segment, than over the duration of the mission). However, the AVO's workload is approaching a rating of 80 on landings, indicating a potential overload situation for the AVO. In contrast, the engine mechanic (52D) only appears to be working in the time frame just before take-off and does not appear to have any tasking for the rest of the mission (which would be typical, considering the mechanical work is largely done before or after the mission occurs when the UAV is not flying). Also apparent is that one 33W appears busy at 21 minutes into the mission while the other 33W is busy at 55 minutes and 145 minutes into the mission, which reflect workload that seems to be task specific.

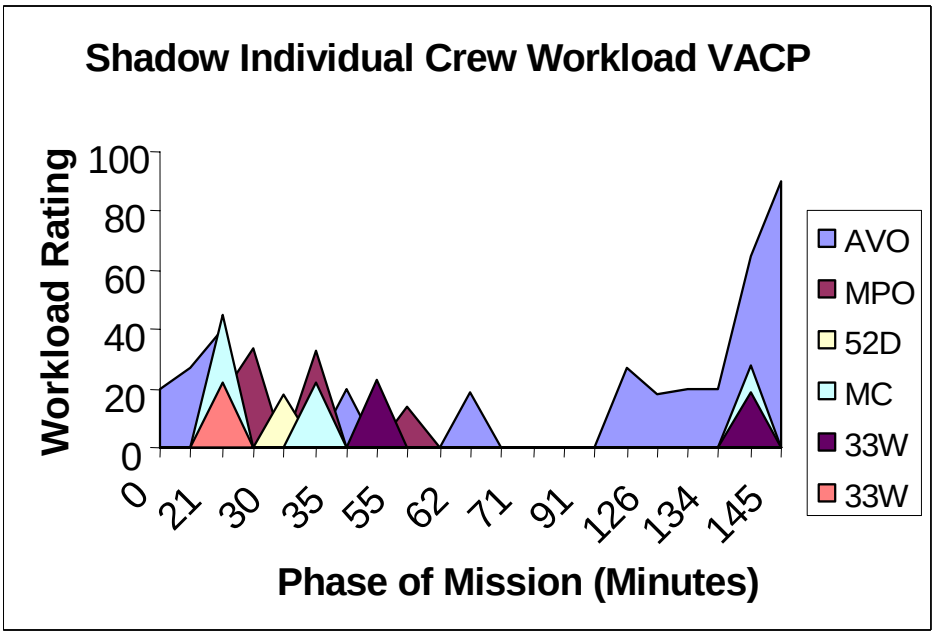

Figure 3. Shadow 200 workload estimate, individual crew workload.

Both figures 2 and 3 demonstrate the diagnostic capabilities of the IMPRINT model and the ability to differentiate workload by task, MOS, and for the overall mission. Specific workload thresholds such as overload limits can be entered into the model with a criterion such as overall VACP value or combinations of the four components of workload in any order or proportion desired. This modeling effort used several approaches, using a baseline of a straight VACP 90 rating of total workload as the threshold for "high workload" or combination scores of 7 or

higher on any or all of the VACP channels. This approach is strictly arbitrary but was chosen to reflect all the model's channels for the operators (VACP), contributing equally to overload conditions. It is very important to note that true workload overload would have to be validated not just by subjective responses but by proof of performance decrements. Performance data were not collected for this simulation; however, future simulations should consider the modeling of performance decrement as a valuable adjunct that addresses the validity of the subjective ratings provided. In addition, a verification and validation effort could be conducted following the approach detailed in Allender et al. (1995) and Mitchell (2000).

4. Discussion

In the original Shadow 200 Micro Saint model coding (Walters et al., 2002), it was assumed that the system required 18 Soldiers to man; however, the fielded Shadow UAV now requires 22 Soldiers, and because of numerous "add-on" functions, Soldiers have had to assume changes in workload and include overlapping functions, sub-functions, and tasks. In early discussions for previous models, those SMEs questioned whether the current modeling effort was, like the original, designed to provide input to system manning requirements. They also added that with the then current tasking levels, the system could use 28 or more Soldiers. In discussions with SME instructors at the Army's UAV training facility, they indicated that system supervisors are always adding functions (at least documentation functions) to the list of tasks that Soldiers must already perform. This anecdotal information about workload and manning levels that was obtained by the second author was confirmed months later from different SME personnel from the same organization by the primary author.

Although additional functions for individual Soldiers are constantly being considered or added, a detailed validation and verification for the earlier model versus this late model is probably the focus of an additional, ensuing research effort.

Operation of the model was tested with 500 trial repetitions, and the model ran the entire series of 500 trials without stopping. Additional trials of 1000 or more repetitions could be tried to assess the variability of the model with increased repetition. The greater the number of runs, the more diverse the stochastic range of outcomes will be. The model is sensitive to assumptions, however, and if a logical flow cannot be maintained through the model because of faulty assumptions, then the model will run in an infinite loop and not execute properly. If properly set up and run, a typical model will take only a few minutes to cycle. The 500 repetition runs of this model took approximately 10 minutes to run on a conventional Dell Pentium[1] computer.

[1]Dell is a trademark and Pentium is a registered trademark of Dell, Inc.

It is strongly emphasized that this model is still primarily a modeling outline or test bed that can and should be populated with additional operationally derived data that can be manipulated to achieve various realistic testing of hypothesis outcomes. The complexity of the model precludes a simple "yes or no" response as to whether it can predict any certain series of outcomes with highly realistic final values. Much of the data for this model was derived by approximation (such as the probabilities associated with mechanical functions such as engine loss, fires, and many other emergency procedures). For more refined modeling results, those estimated values, which are currently acting as placeholders, should be replaced with actual operational data values derived from combat missions in order to provide realistic input to the model that will, in turn, result in realistic simulation results.

When we check through the model and compare the Excel questionnaire database information (which is realistic and based on actual operator experience) to estimates of probabilities of rare events, we see that a comparison could be arranged between actual values and estimated values. It is believed that this study's questionnaire data may be used as are since the sample was randomly acquired, operationally representative, and recently collected. This model is considered as generic for all tasks and was based on the recall of the operators. For validation, these data should be run against several missions in order to determine the fidelity of the model. Once again, this is a discrete event, stochastic model, that is providing estimates of outcomes, and those estimates must be compared to additional data in order to validate this model's assumptions and outcomes.

Future studies should also focus on operator workload ratings (as opposed to author or SME assigned workload ratings) in order to increase the content validity of the model. One cautionary note is that the McCracken and Aldrich (1984) approach, while intuitive to psychologists, is not necessarily intuitive to UAV operators. The classification scheme that breaks down workload using terms such as cognitive and psychomotor must be defined and explained in layman's terms for the users, the majority of whom for this study were junior enlisted personnel who do not have college degrees, much less formal training in cognition or psychology.

The acceptability of any rating system must consider the user population and it is unlikely that anyone in this particular user population could adequately describe the terms cognition or psychomotor in operational terms. However, it is believed that any user group, if given training in the concepts, could understand the terminology, and complex verbal descriptor continuums used in the IMPRINT workload model.

5. Conclusions and Recommendations

This new Shadow UAV model has demonstrated utility in simulating missions for the crew overall as well as for individual positions. Workload can be predicted quite well by MOS, by

task, or overall. An additional study could be performed in order to complete a full model validation and verification, by a comparison of this model's results to a random sample of actual missions, using the operational missions as templates for entering data into the model. It is further emphasized that any mission, regardless of tasking, still consists of the same basic building blocks drawn from the operators manual, and thus the structure chosen for this model can serve as a platform for further, more mission-detailed scenarios.

5.1 Limitations and Future Directions

Further manipulations of the model could occur when effects for fatigue, chemical-biological operations, sustained operations, or other manning variations are considered. While this may require using a different approach or a more advanced IMPRINT model than the one chosen, the basic structure could be imported into that newer model which would have those functions. While the original Micro Saint models had fatigue and circadian rhythmicity functions built into the programs, this model did not include those functions.

The utility of this particular Shadow UAV model is that it is relatively universal and can be suited to any type of mission if the focus is on task accomplishment based on the operator's manual. In the future, additional modules could be set up to look at maintenance specific functions, such as for the engine mechanic, or for other operators such as the 33W technicians. Two other models that could be used are the IMPRINT goal-oriented model and the IMPRINT advanced workload analysis model, both of which are dissimilar to the VACP model chosen for this report; those models are themselves being revised (Allender, personal communication, September 20, 2005). Finally, it is recognized that all modeling systems are evolutionary in nature (Allender, Archer, Kelly, & Lockett, 2005); thus, the development of models is based on the collection of new system data, such as the Shadow UAV model, and those data can help transition existing models into improved models, as the proposed systems upon which they model become operational.

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Appendix A. Questionnaire Used to Collect Shadow UAV Data

SHADOW UAV Operations Survey

Name_____

MOS_____ Rank_____

Approximate number of hours you have been assigned to this UAV_____.
NOTE: If you have been assigned to this UAV for very many hours, please put number of YEARS assigned to UAV_____

Please list the amount of time it takes **in minutes or seconds** to complete the following UAV tasks.

(NOTE: If it takes hours to complete certain tasks, list the number of hours and make a note in the comments section.)

If you have not done this task, mark an X in the time required box.

Tasks	Time Required	How many other personnel involved?	Comments
1. Receipt of mission			
2. Mission brief			
3. GCS emplacement			
4. Portable Ground Control Station (PGCS) emplacement			
5. Portable Ground Data Terminal (PGDT) emplacement			
6. RVT emplacement			
7. Arresting gear emplacement			
8. Arresting net emplacement			
9. Take-off and landing systems (TALS) emplacement			
10. Launcher emplacement			
11. Rotation of launcher for wind direction change			
12. AVT emplacement			
13. EPE emplacement			
14. Assemble AV			
15. EPE power up			
16. GCS power up			
17. GDT power up			
18. RVT power up			
19. Prepare EPE			
20. Prepare GCS			
21. Prepare GDT			
22. Prepare PGCS			
23. Prepare PGDT			

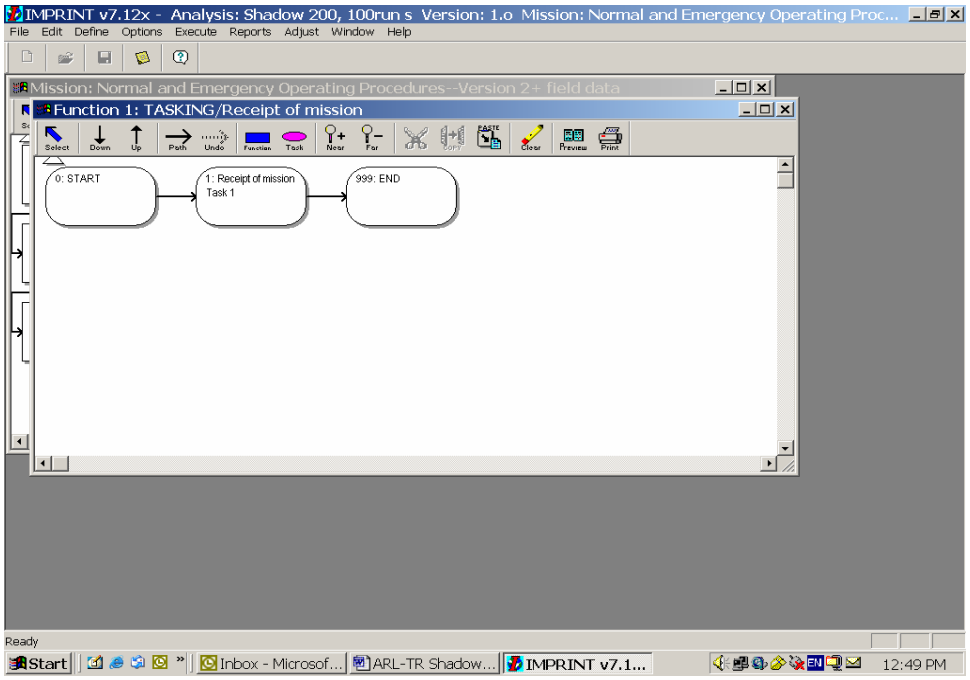
24. GCS pre-flight check			
25. GDT pre-flight check			
26. AV pre-flight check			
27. PGCS pre-flight check			
28. PGDT pre-flight check			
29. GCS preset			
30. PGCS preset			
31. C4I IP addresses baseline			
32. Map loading baseline			
33. RVT pre-operational check			
34. Launcher pre-operational check			
35. TALS pre-operational check			
36. AV pre-flight			
37. GCS pre-flight			
38. GDT pre-flight			
39. PGCS pre-flight			
40. PGDT pre-flight			
41. TALS pre-flight			
42. Launcher pre-flight			
43. AV engine startup			
44. Mount AV on launcher			
45. Remove AV from launcher			
46. Pre-launch			
47. AV launch			
48. In flight target data collection			
49. Artillery adjustment			
50. RVT operations			
51. Crew changes in flight			
52. AVO responsibilities			
53. MPO responsibilities			
54. Control station transfer			
55. AV recovery			
56. AV engine shutdown			
57. System turn around			
58. Preparing arresting gear for next recovery			
59. Inspect AV			
60. Clean and prepare AV			
61. Fuel AV			
62. Defuel AV			
63. Re-launch AV			
64. AVO post flight operations			
65. MPO post flight operations			
66. GCS power down			
67. GDT power down			
68. PGCS power down			
69. PGDT power down			
70. RVT power down			
71. EPE displacement			
72. AV disassembly			
73. GCS displacement			
74. GDT displacement			
75. PGCS displacement			
76. PGDT displacement			
77. RVT displacement			
78. AV displacement			

79. Launcher displacement			
80. TALS displacement			
81. Arresting gear			
82. Arresting net displacement			
Emergency Tasks	Time Required	How many other personnel involved?	Comments, how often does this happen; example, one time per 10 flights? One per 100 flights? Give an example of a percentage of this events occurrence. If a particular emergency has never happened to you please say so.
1. Fire on ground			
2. Air vehicle fire on launcher			
3. Launcher failure			
4. TALS recovery failure			
5. Air vehicle generator failure			
6. Engine failure below 2000 feet above ground level (AGL)			
7. Engine failure above 2000 feet AGL			
8. Primary and secondary no report			
9. Uncontrolled flight			
10. Carburetor icing			
11. Global Positioning System failure			
12. Stuck throttle (high revolutions per minute)			
13. Stuck throttle (low revolutions per minute)			
14. TALS abort below the decision point			
15. AV high engine temperature			
16. (P) GDT comms fail			
17. In-flight servo failure			
18. Software lockup			
19. Dual uplink failure			
20. Single uplink failure			
21. VERSA modulareurobus (VME) failure			
22. GCS electrical power failure			
23. General data does not match AV report			
24. Return home menu does not match AV report			
Any other emergencies that you have experienced?			

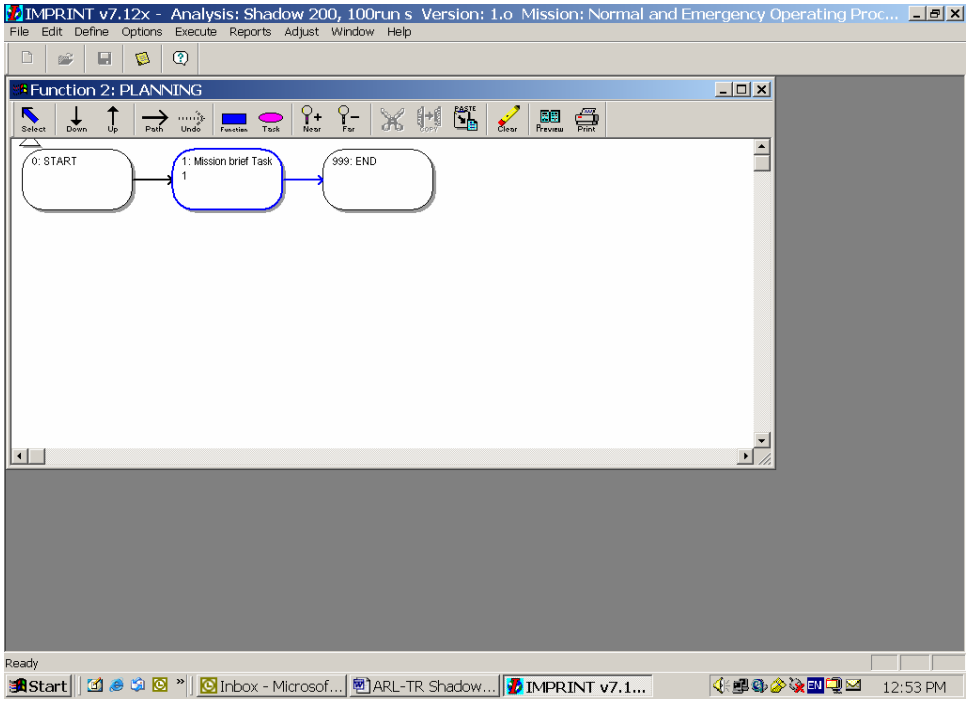
INTENTIONALLY LEFT BLANK

Appendix B. Model Details by Function (15 functions total)

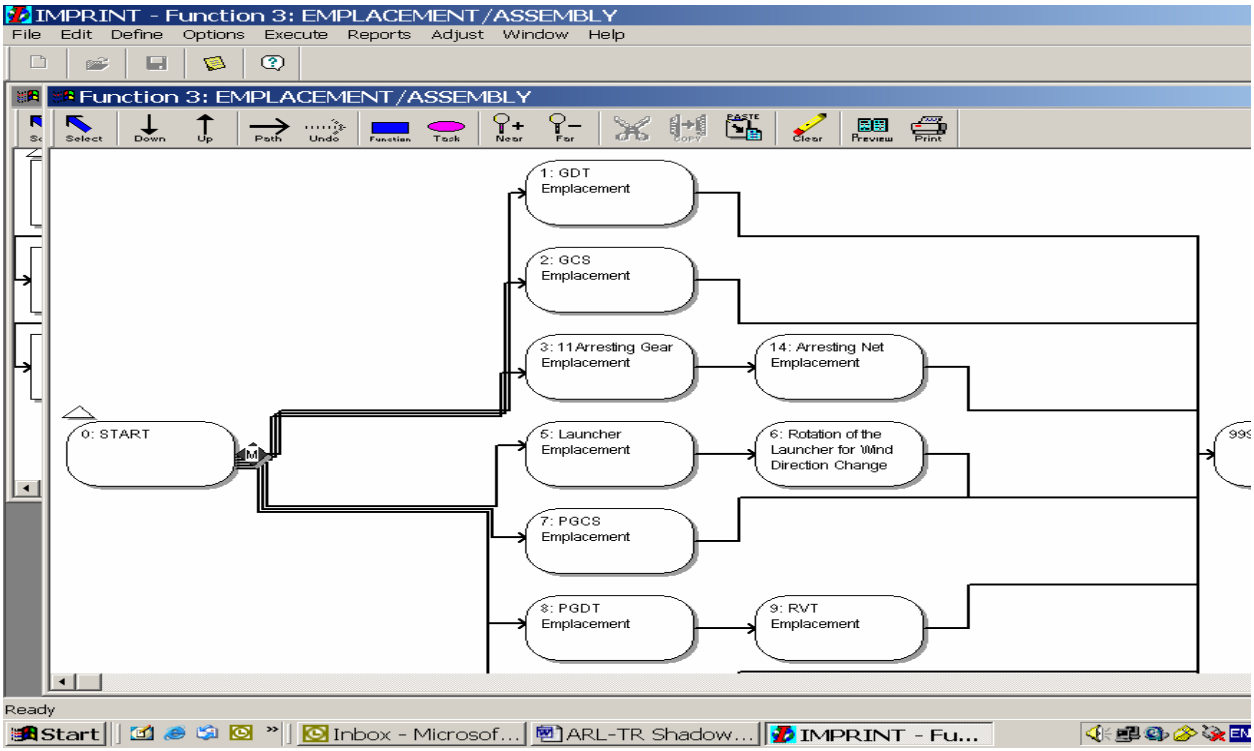
Function 1. Receipt of Mission



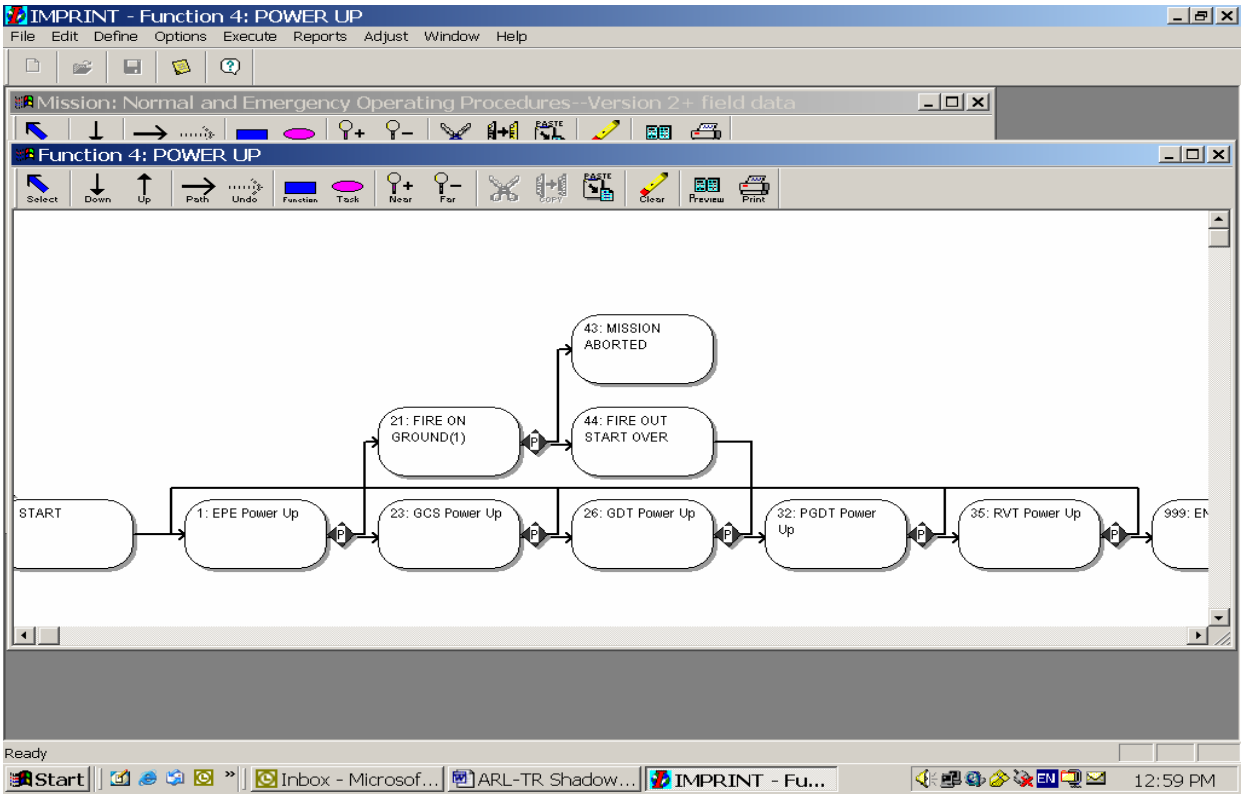
Function 2. Planning



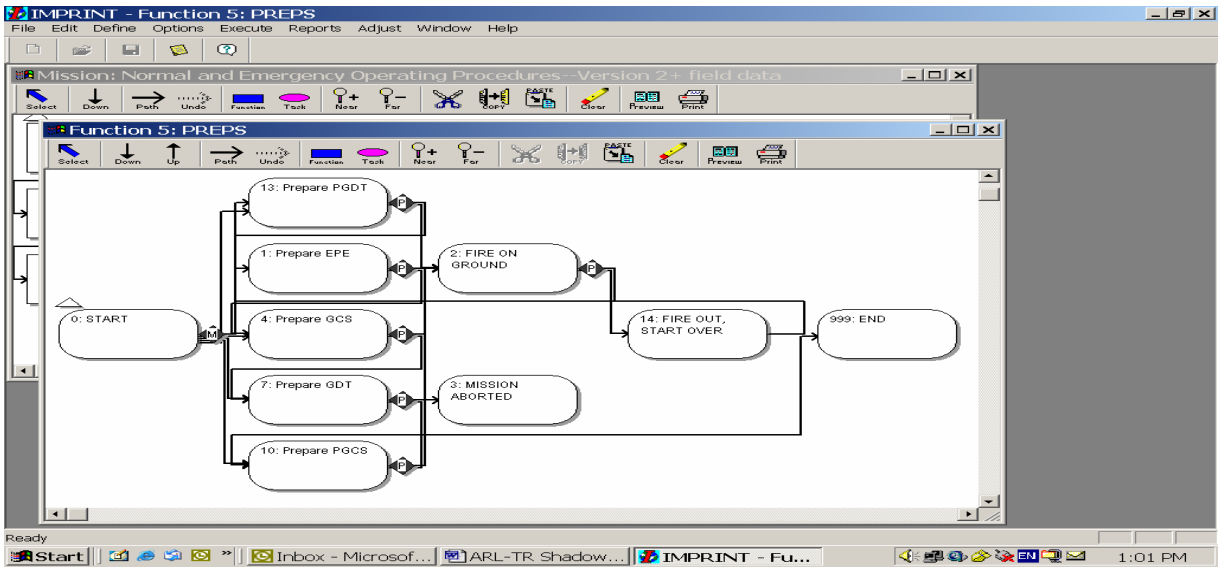
Function 3. Emplacement (not all tasks shown)



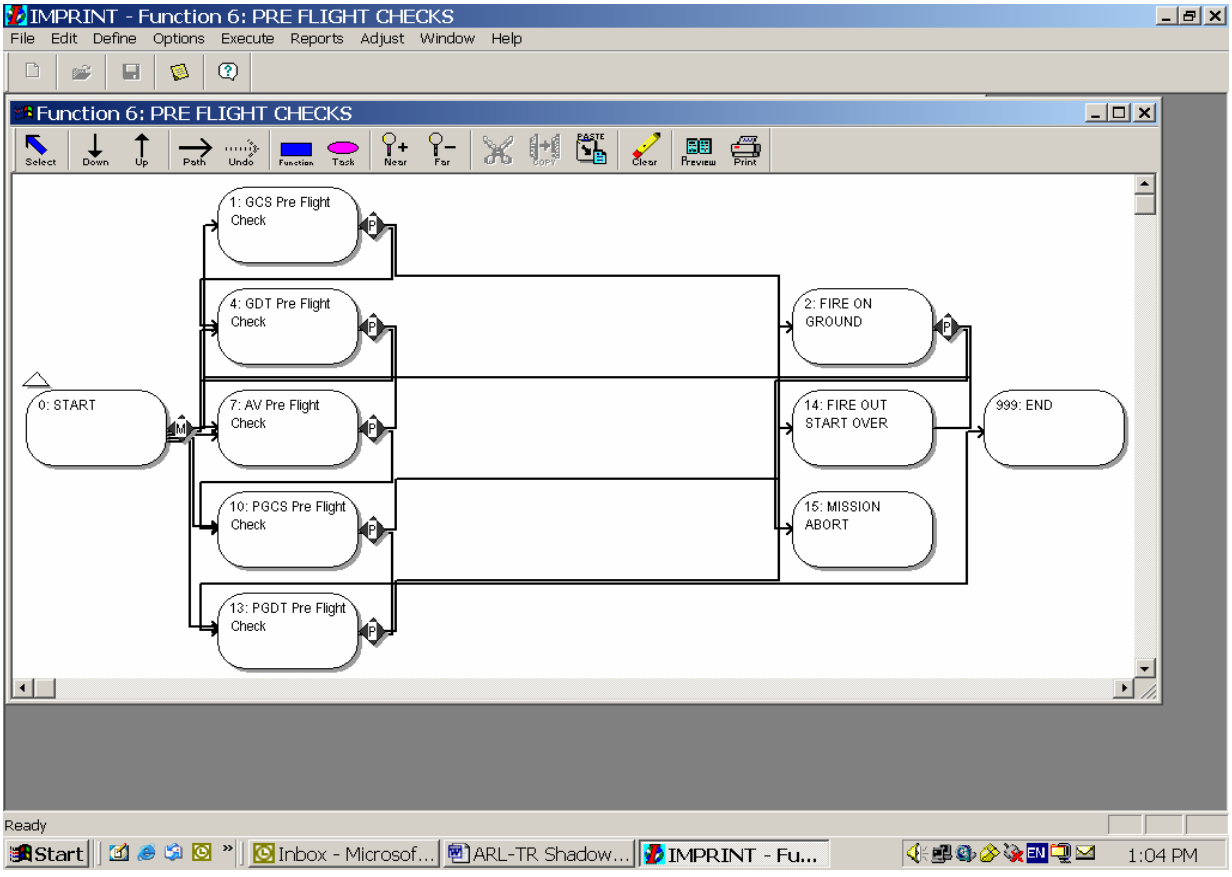
Function 4. Power up (not all tasks shown)



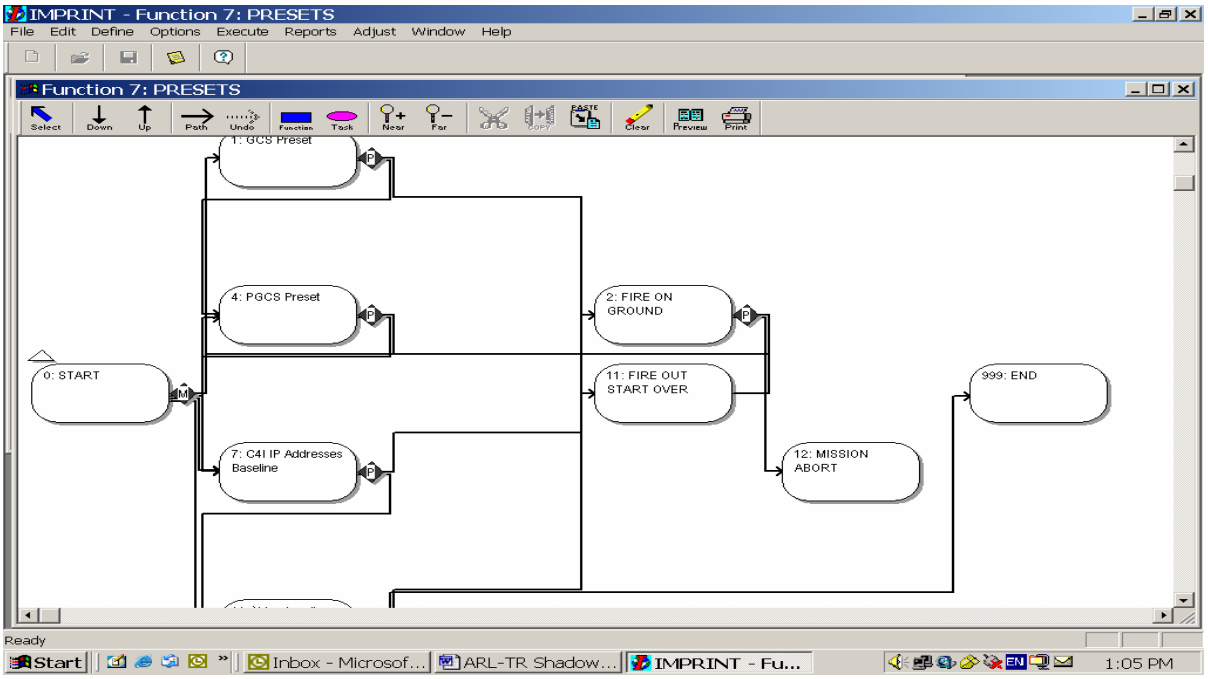
Function 5. Preps (mission preparation)



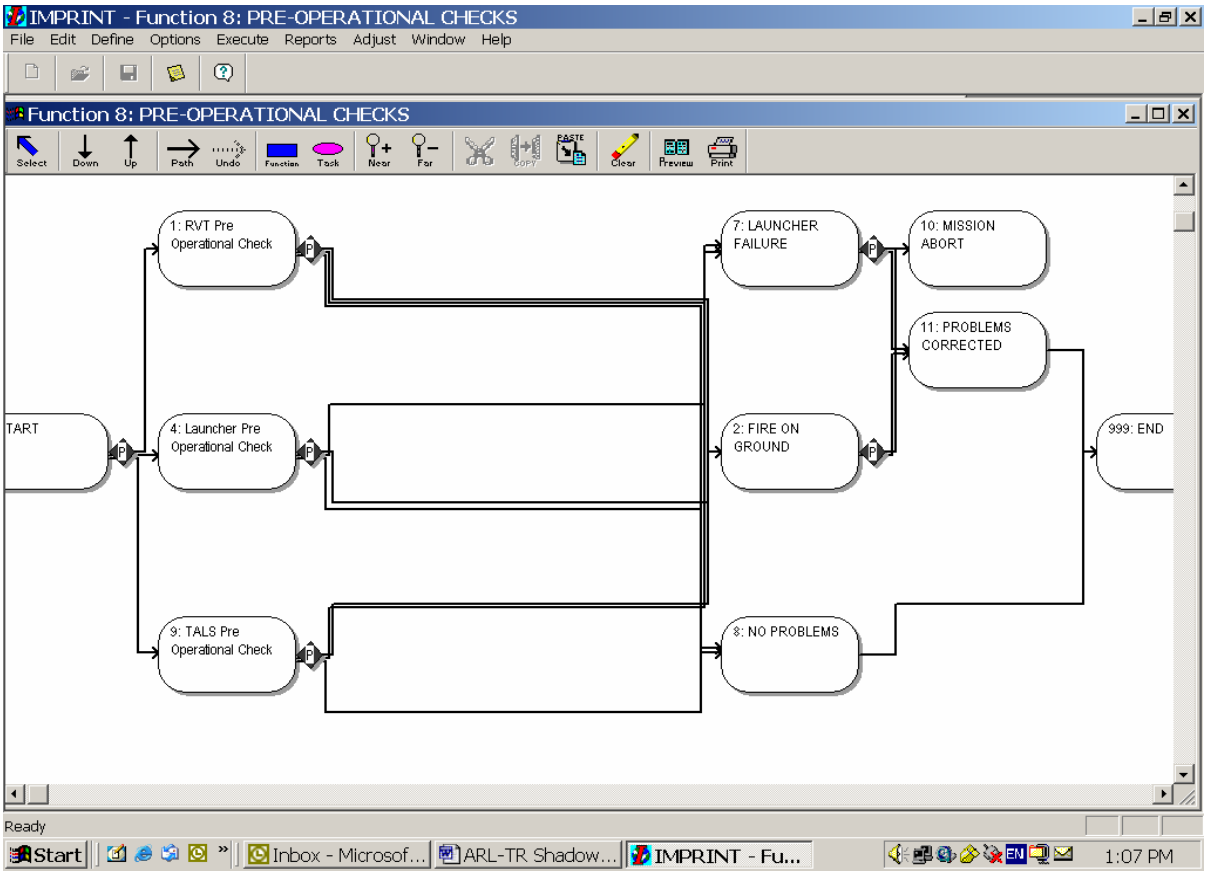
Function 6. Pre-flight Checks



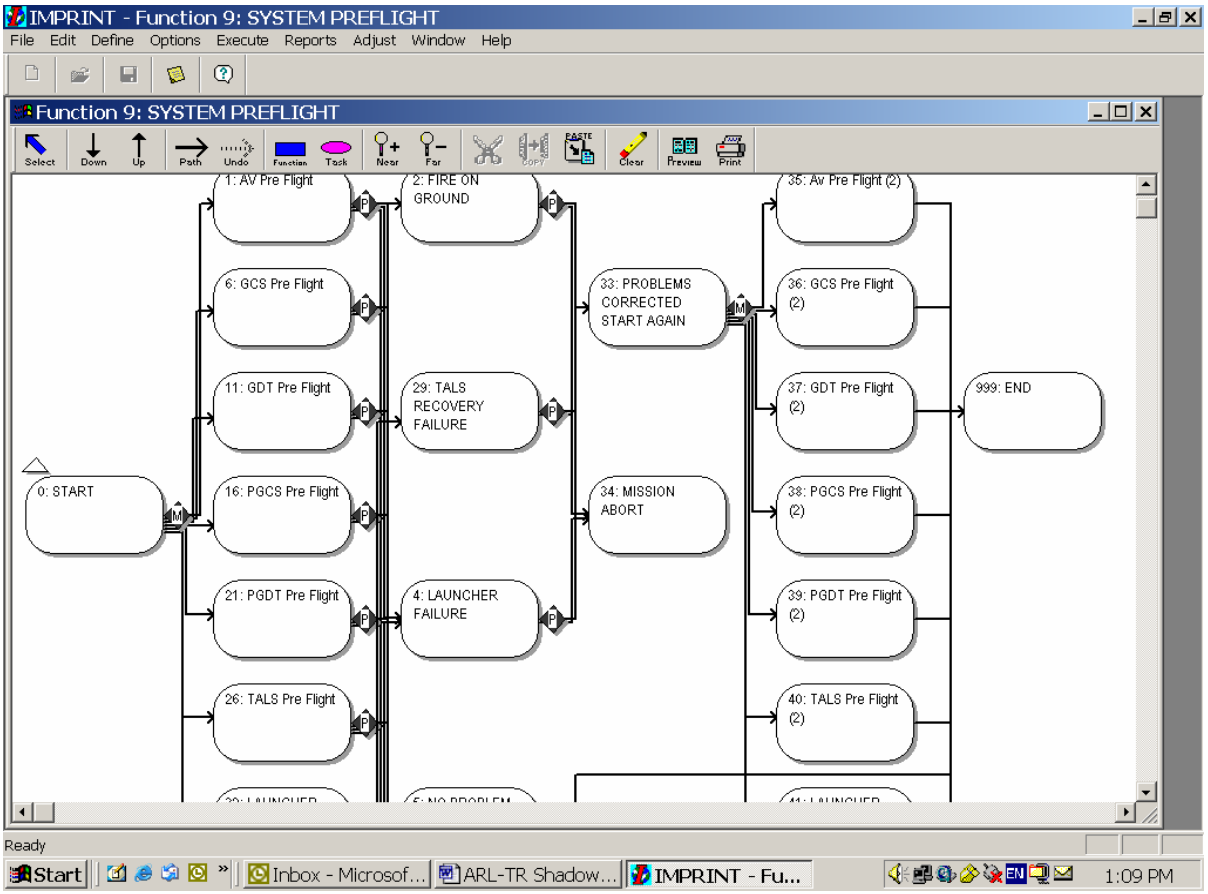
Function7. Presets (not all tasks shown)



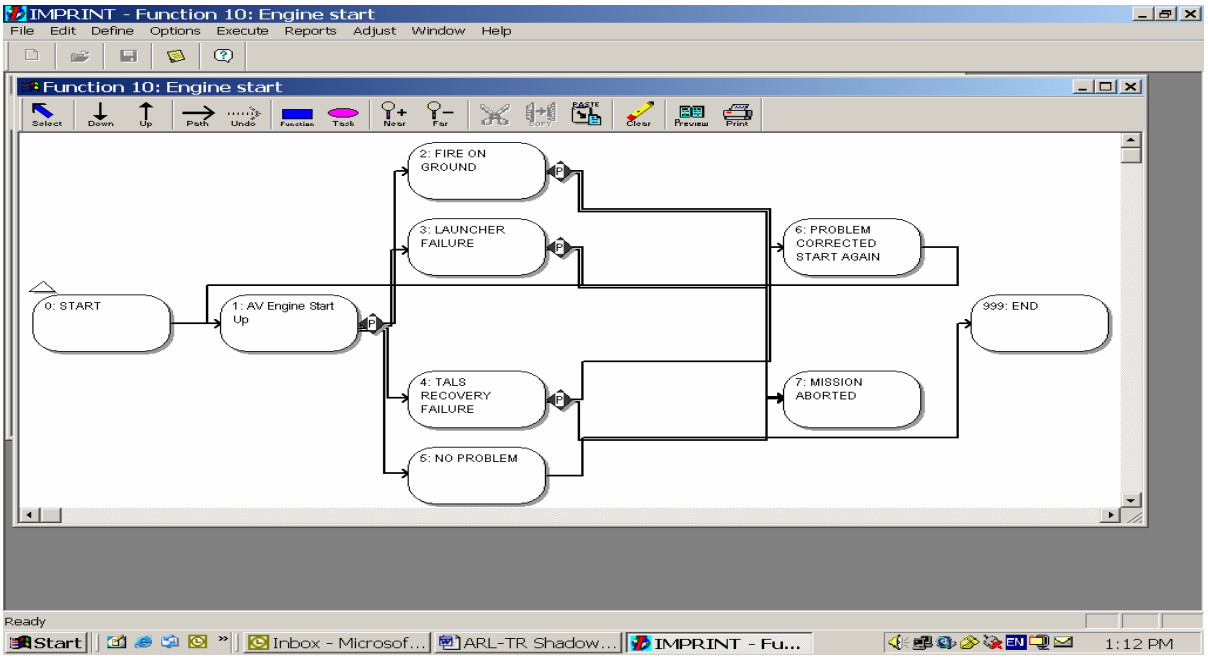
Function 8. Pre-operational Checks



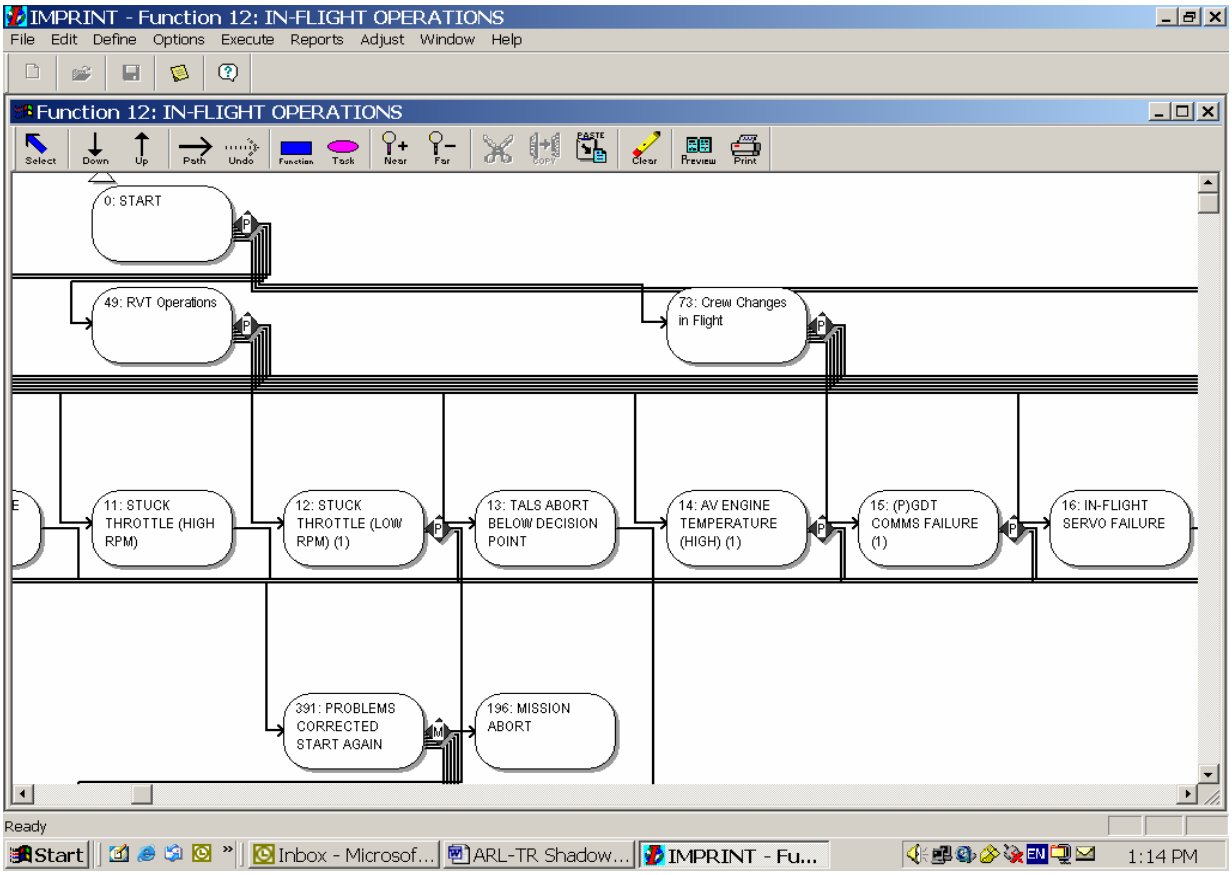
Function 9. System Pre-flight (not all tasks shown)



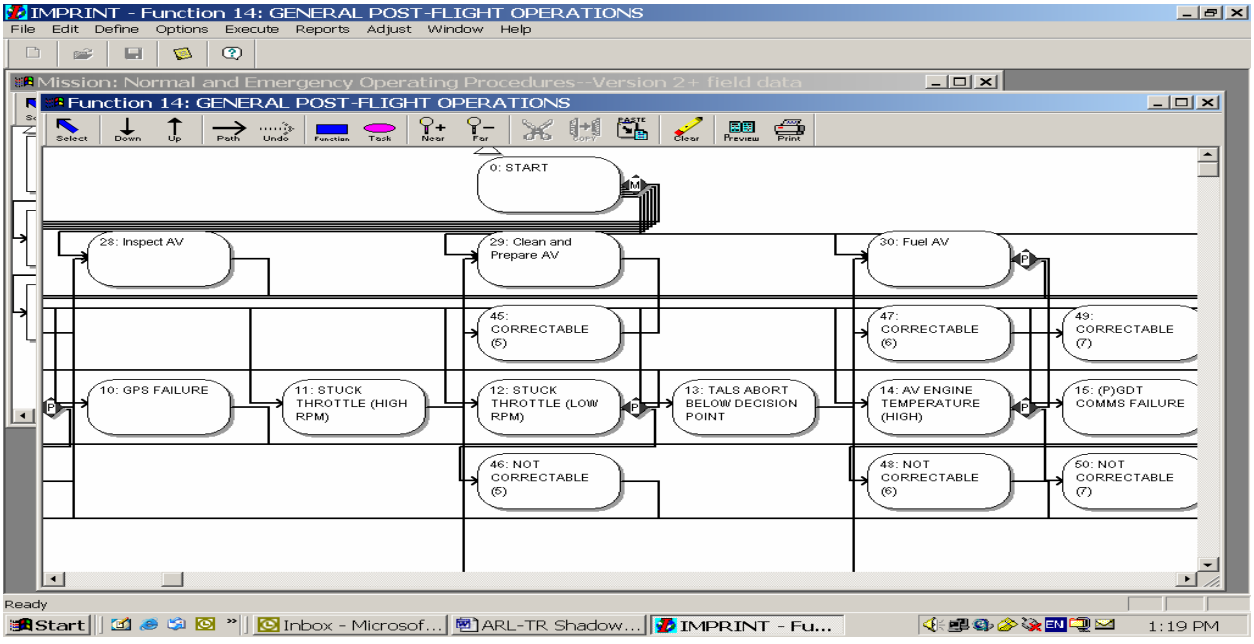
Function 10. Engine Start



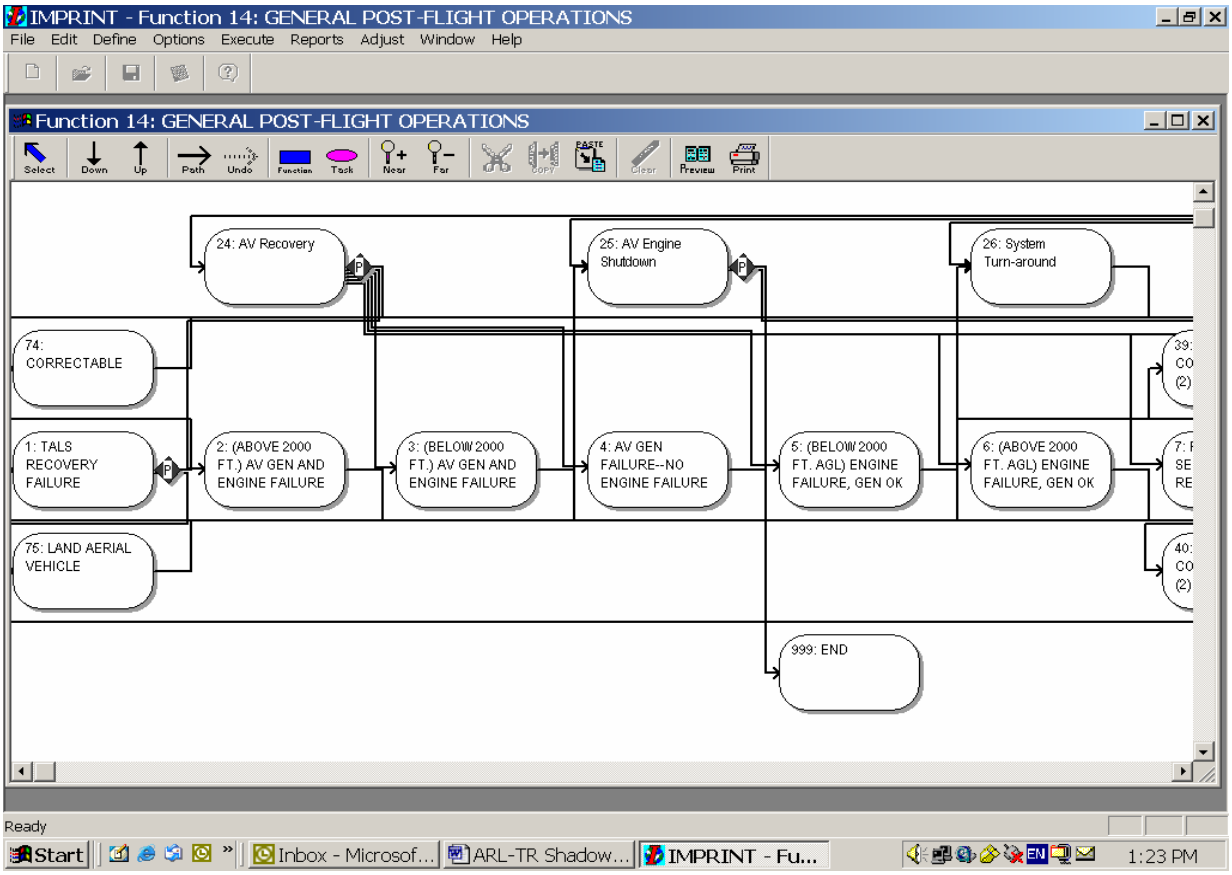
Function 11. AV Launch (not all tasks shown)



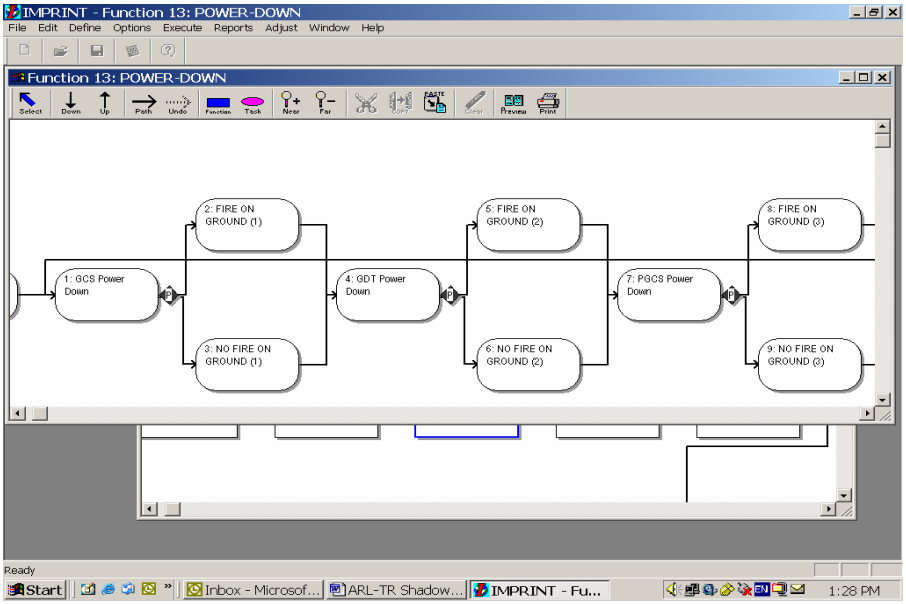
Function 12. In-flight Operations (not all tasks shown)



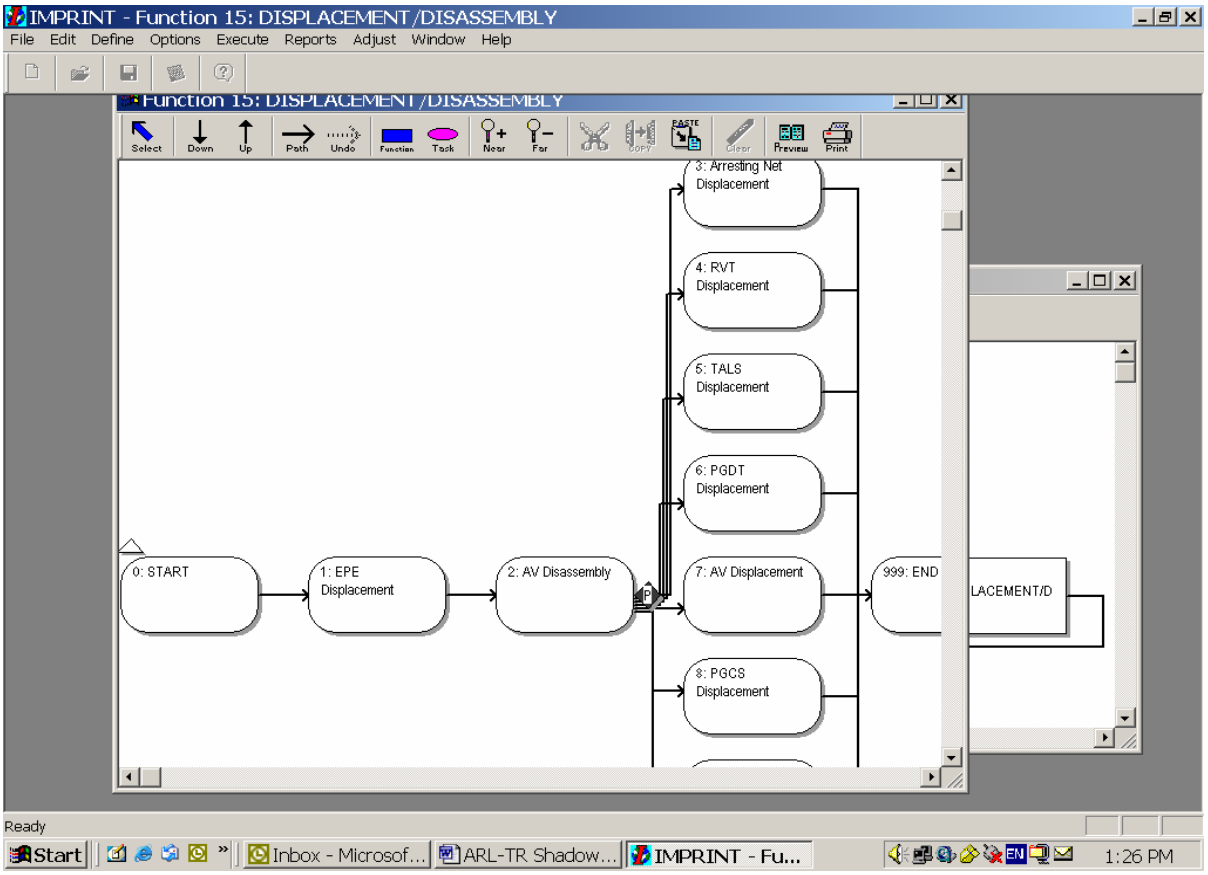
Function 13. General Post Flight Operations (not all tasks shown)



Function 14. Power Down (not all tasks shown)



Function 15. Displacement (not all tasks shown)



Acronyms

ARL	U.S. Army Research Laboratory
ATO	Army Technology Objective
AV	air vehicle
AVO	air vehicle operator
ER/MP	extended range/multipurpose (UAV)
FCS	Future Combat Systems
GCS	ground control station
IMPRINT	Improved Performance Research Integration Tool
IOT&E	initial operational test and evaluation
MOS	military occupational specialty
MPO	mission payload operator
SME	subject matter expert
TUAV	tactical unmanned aerial vehicle
UAV	unmanned aerial vehicle
VACP	visual, auditory, cognitive, and psychomotor

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