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Automation, CRM and Distributed Cognition: an Exploration of the Defense Mechanism in the Cockpit

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AUTOMATION, CRM AND DISTRIBUTED COGNITION: AN EXPLORATION OF THE DEFENSE MECHANISM IN THE COCKPIT

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What is the mechanism that allows aircraft flight crews to achieve such an astounding safety record despite the hazards they encounter? In this paper, we discussed the topics of aviation safety from a broad theoretical framework, which generally relate to these three topics: Automation, Crew Resource Management, and Distributed Cognition. We outline the preliminary results of a study surveying 38 reports from the Aviation Safety Reporting System. In this survey, the reports were given three classifications, the problem-based classification, the optimal-solution-based classification and the actual-solution-based classification. Some interesting findings were shown by studying the correspondences between three classifications. Based on the findings, an integrated defense mechanism with the contributions of automation, CRM, and distributed cognition was explained against the external and internal threats found in an aircraft cockpit.

Introduction

In 2000, 629 million passengers boarded airplanes at U.S. airports, yet the number of fatalities reported from passenger aircrafts accidents was approximately two hundred. Generally, aviation is considered a highly complex activity, with a hazardous and multifaceted threat environment; yet, air carriers consistently operate at a high level of reliability and safety. Why? What is the mechanism that allows aircraft flight crews to achieve such an astounding safety record despite the hazards? In previous studies, experts discussed the topics of aviation safety from a broad theoretical framework, which generally relate to these three topics: Automation, Crew Resource Management, and Distributed Cognition.

Automation

Automation involves the substitution of automation components for tasks that the machine may perform more efficiently than humans, or tasks which humans are incapable of performing safely or at all (Wiener, 1985). Cockpit automation is a typical example of a complex control environment. Every day thousands of flight crewmembers operate aircraft utilizing a variety of automated devices. These devices include everything from traditional autopilots and flight directors to elaborate flight management systems, aircraft performance management systems, and a host of automatic warning and alerting systems.

In the quest for safer and more efficient flight, microprocessor technology has enabled the rapid advance of cockpit automation, the principal rationale being the assumption that the reduction of the flight crew's routine tasks and mental cognitive activities will reduce potential problems in the cockpit (Sarter & woods, 1994). This allows more time to supervise the flight operations effectively. Cockpit designers are incorporating more and more automation into the cockpit in an attempt to address human limitations; with their ultimate goal of automating the hazards out of the cockpit.

Overall, the movement toward cockpit automation has undoubtedly enhanced aviation safety, however to some extent it has become evident that automation doesn't always replace the pilot's in the cockpit, instead it changes the nature of their tasks, and therefore new sources of cockpit error have been created (Parasuraman & Riley, 1997).

Crew Resource Management (CRM)

Personnel-related causes or factors were cited in 89.8% of all general aviation accident reports for 1999 (NTSB, 2003). This realization led to the development of many programs that are used to improve what is called crew resource management (CRM). These programs aim at preventing aviation accidents by enhancing team performance through training. However so far, CRM is not defined explicitly. More generally Salas, Prince, Bowers, et al. (1999) conceptualized CRM as a "family of instructional strategies that seek to improve teamwork in the cockpit by applying well-tested training tools (e.g., simulators, lectures, videos) targeted at specific content (i.e., teamwork knowledge, skills and attitudes)".

Because of this diversity, there are widely varying ideas about what constitutes CRM throughout the aviation community. Some CRM focused heavily on attitudes toward teamwork, pilot personality, and social interactions. Other programs focused mainly on behavior skills. As such, different labels, descriptions, and representations are used to define those skills. Evidence of the effectiveness of CRM training was obtained by many researches. For example, Continental Airlines' Error Management training program, which is a CRM training program, was an effective accident prevention tool for helping cockpit crew identify, respond to, and resolve mistakes before they become a threat to flight safety.

Although much progress was made in the previous CRM training applications and researches, there are still some topics needed to be explored. This will require further study of the cognitive processes underlying team situation assessment, team situation awareness, and team decision-making, and the theoretically driven and practically relevant principles, guidelines, interventions, and tools are still much-needed resources.

Distributed cognition

Distributed cognition is an important socio-psychological phenomenon of the safety system in the cockpit (Hutchins & Klausen, 1990). Three properties of distributed cognition make valuable contributions to aviation safety. First, the overlapping communication makes the storage and dissemination of information flexible, in that the efficiency of receiving and transferring information is not only influenced by the personal skill and expertise, but it also utilizes the crew's capacity to share information in the distributed networks.

Second, the creation of artifacts driven by distributed cognition is another practical contribution to aviation safety. In the advent of new technology, a significant number of powerful external symbolic devices and material memoranda are designed. Distributed cognition is viewed as the interactions between internal and external representational structures. In the cockpit, increasingly more information is arranged by an external representational structure, which is designed to conserve the limited resources in human working memory.

Distributed cognition's third contribution to aviation safety is that its propagation reconstructs the cockpit culture on a deeper cognitive level that can be seen as an overall improvement in the level of situational awareness and aviation safety. It takes a culturally constituted functional group as its unit of analysis, rather than an individual mind. In doing so, aviation safety and efficiency are fostered in terms of breaking through the individual constraints and generating the positive behavior pattern of cooperation and coordination among the flight crew. As such, the flight crew as a whole has a greater awareness than the sum of its parts.

Initial thought of a defense mechanism in the cockpit
So far the contributions of automation, CRM, and distributed cognition to the aviation safety have been discussed separately. There has been no model or theory proposed to integrate all these contributions simultaneously. In this study, we are interested in exploring a defense mechanism against threats to safety in the cockpit, by integrating all three coping strategies driven by automation, CRM, and distributed cognition. Due to the diversity of their contributions in detecting and solving problems in the cockpit, we speculate that the efficiency of this kind of defense mechanism will be greater than those concerned with only single coping strategy. The benefit of this defense mechanism is to show how each coping strategy mutually supports the others by overcoming the limitations of each, which are discussed in this section.

Survey

Database and analysis
The method of this study was an archival data analysis. The data used in this study was obtained from the 50 ASRS reports found in the CRM Database Report Set dated October 9, 2003. To decompose these reports into meaningful classifications, five reviewers reviewed each case separately, and then discussed all fifty cases as a group. By consensus, the reviewers decided that 38 of these cases provided sufficient information for subsequent analysis. Each of these 38 cases used were analyzed according to three classifications which are discussed below. By studying the correspondences between three classifications, the defense mechanism with the contributions from automation, CRM, and distributed cognition was explained. Descriptive statistics were used to get some interesting findings
Three classifications

In each of the 38 cases, the incidents as reported by the flight crewmembers were given three classifications. The first classification - the problem-based classification – which defined the two groups of operational areas that caused the majority of the incidents reported in the ASRS Database. These two groups are the human performance errors (HPE) or external physical threats (EPT) and were proposed in studies by Shappell and Wiegmann (2004), and Gordon, Flin, and Mearns (2001). Within each group the types of problem were defined as the following (see Table 1).

Table 1. *The first classification*

General groups	types of Problem
HUMAN PERFORMANCE ERRORS (HPE)	Tactical decision error
	Perceptual error
	Communication failure
	Violations
	Misuse of Procedures
	Manual control failure
	Misuse of Checklists
EXTERNAL PHYSICAL THREATS (EPT)	Environment
	Weather
	Airspace structure
	Aircraft
	Maintenance
	Others

The second classification - the optimal-solution-based classification - is based on how the problems in the ASRS reports surveyed should have solved as reported by flight crewmembers. As proposed in the previous section, Automation, CRM, and distributed cognition each had different characteristics that benefit aviation safety, and their classification criteria were defined based on the following characteristics:

(1) Flight crew should have used automation to decrease workload and stress therein to solve the specific problem in the selected case (optimal-AUTO);
(2) Flight crew should have used CRM skills and strategies enhanced by training, minimize the resource expenditure and eliminate the human error therein to solve the specific problem in the selected case (optimal-CRM);
(3) Flight crew should have used an efficient distribution of cognitive activities throughout the cockpit to increase the information redundancy therein to solve the specific problem in the selected case (optimal-DC);
(4) Flight crew should have used other strategies to solve the specific problem in the selected case (optimal-other).

The third classification - the actual-solution-based classification - is based on how the problems in the ASRS reports surveyed were actually solved as reported by the flight crewmembers. This classification maps directly to the second classification, and its classification criteria is defined as follows:

(1) The flight crewmembers actually used automation to decrease workload and stress therein to solve the specific problem in the selected case (actual-AUTO);

(2) The flight crewmembers actually used CRM skills and strategies enhanced by training to minimize the resource expenditure and eliminate the human error therein to solve the specific problem in the selected case (actual-CRM);

(3) The flight crewmembers actually used an efficient distribution of cognitive activities throughout the cockpit to increase the information redundancy therein to solve the specific problem in the selected case (actual-DC);

(4) The flight crewmembers actually used other strategies to solve the specific problem in the selected case, or the problem was not solved (actual-other).

Results

The correspondence between the problem-based and optimal-solution-based classifications

Figure 1 shows the correspondence between the first, the problem-based classification, and the second, the optimal-solution-based classification. It revealed that HPEs, as well as EPTs, were extensively distributed throughout all levels of optimization-based solution classification. Overall, a review of the ASRS reports in the survey showed there were slightly fewer problems involving EPTs than HPEs, except that the number of HPEs that should have been solved by using an efficient distribution of cognitive activities relatively was higher than the number of EPTs. Furthermore, there were more EPTs that should have been solved by strategies other than automation, CRM and distributed cognition, than HPEs that should have been solved by these same strategies. However, in total the unsolved problems were much fewer than those that were solved.

Figure 1: The correspondence between the problem-based and optimal-solution-based classifications

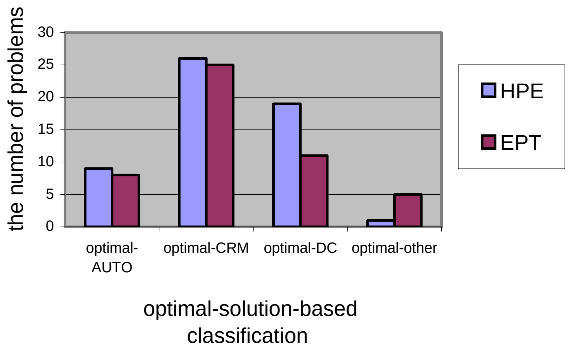
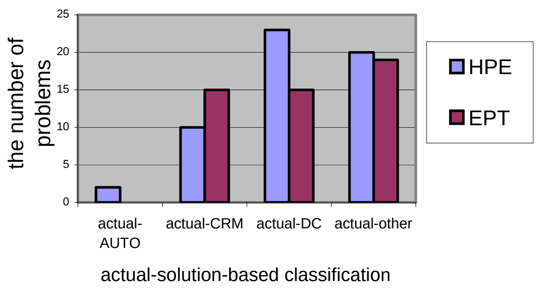


Figure 2: The correspondence between the problem-based and actual-solution-based classfications



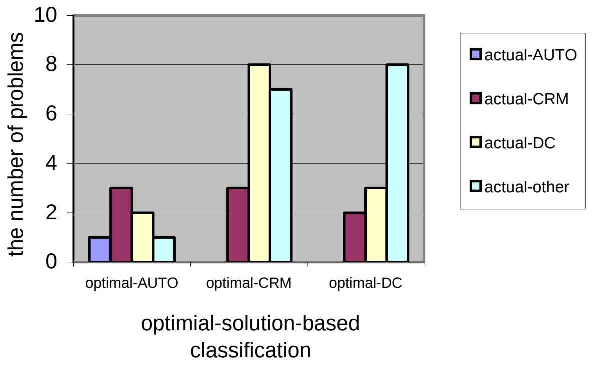
The correspondence between the problem-based and actual-solution-based classifications

Figure 2 shows the correspondence between the first, the problem-based classification, and the third, the actual-solution-based classification. Only two problems were solved by using automation. Meanwhile more HPEs were solved by using an efficient distribution of cognitive activities, than by using CRM strategies and skills. However, when the EPTs were eliminated, the benefits from distributed cognition were not different then those from CRM. These findings suggested that distributed cognition was powerful enough to solve more HPEs rather than EPTs, but CRM appeared to be effective in solving as many HPEs as EPTs. On the other hand, a certain amount of HPEs, as well as EPTs were solved by chance or even worst, were not solved.

The correspondence between the optimal-solution-based and actual-solution-based classifications

Figure 3 shows the correspondence between the second, the optimal-solution-based classification, and the third, the actual-solution-based classification. Most problems that should have been solved by using automation were solved by the use of effective CRM skills and strategies; most problems that should have been solved by effective CRM skills and strategies were solved by the flight crew operating at a high level of distributed cognition; and finally, most problems that should have been solved by distributed cognition were solved by using some other strategy, than automation, CRM, or distributed cognition; or they were not solved at all.

Figure 3: The correspondence between the actual-solution-based and optimal-solution-based classifications



It should be noted that if any problem was actually solved by the optimal strategies, these problems might not have been reported to ASRS. Therefore it is not always possible to determine how many incidents were actually solved by the flight crewmembers using the optimal strategy, from review of the ASRS reports alone. Except for the problems which were actually solved by the optimal solutions, figure 3 shows the distribution of the alternatives of the optimal coping strategy which solved the problems. Moreover, the proportion of these problems classified as “actual-other” formed a continuum, with the least number occurring when they should be solved by using automation, followed by CRM, and then distributed cognition.

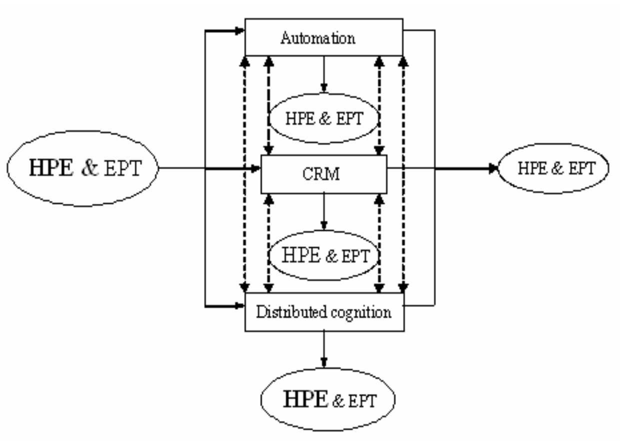
Discussion

Based on the correspondences among the three classifications, some interesting findings were shown to be relevant to our initial thought of an integrated defense mechanism in the cockpit. Overall, we believe that the power of a defense mechanism supported by automation, CRM and distributed cognition is strong. Almost 95% of problems in the cockpit could be solved by at least one of these coping strategies. Meanwhile, the three coping strategies are more effective to detect and solve HPEs than EPTs, especially for distributed cognition. Human errors caused nearly 80 percent of corporate aviation accidents during 1992-1997 (Hinson, 1997). Therefore, it is possible that this integrated defense mechanism could address the threats that cause the most types of aviation accidents.

The most important finding of this study is the correspondence between the second, the optimal-solution-based classification, and the third, the actual-solution-based classification. Except for the problems which were actually solved by the optimal solutions, most problems that should have been solved by using automation were solved by the use of effective CRM skills and strategies; most problems that should have been solved by effective CRM skills and strategies, were solved by the flight crew operating at a high level of distributed cognition; and finally, most problems that should have been solved by distributed cognition were solved by using some strategy, other than automation, CRM, or distributed cognition; or was not solved at all. This suggests that the coping strategies driven by automation, CRM, and distributed cognition, not only contribute to aviation safety individually, but may also compensate for the limitations of the other strategies.

Based on the findings above, we purpose a simple model of our integrated defense mechanism (see Figure 4). In this model, the issues represent the results of the survey in this study. The circles in the left and in the right represent the input of problems and the output of unsolved problems respectively. The links between the circle in the left and the squares demonstrate that the flight crews choose the appropriate coping strategies for the problems. In the middle, the links between the circles and squares represent the throughput of each coping strategy and the dashed links between the squares show the redundancy in the integrated defense mechanism; in that even if the flight crews does not choose the appropriate coping strategies for the problems, it still can be solved by using other strategies.

Figure 4: An integrated defensive mechanism in the cockpit



Notes 5: The circle and square represent the problem and the coping component respectively. The font of the words in the circle represents the amount of the problems.

In fact, the results showed that the flight crewmembers did not always recognize the benefits of the integrated defense mechanism as they usually did not use the appropriate coping strategies to solve the problems, or it went unsolved. This fact suggests that right now, our integrated defense mechanism is not being utilized efficiently to maximize aviation safety. There is a gulf between what the optimal solution was and what the flight crewmembers actually use to solve the problems. So, what can we do to eliminate this gulf, and thus increase aviation safety? Based on our findings, we recommend that to maximize the benefit of the defense mechanism in each cockpit, the coping strategies driven by automation, CRM and distributed cognition should be considered simultaneously to an increase in aviation safety, and further research into this theory is needed.

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A COMPARISON OF SAINT WITH IMPRINT AND MICRO SAINT SHARP

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SAINT was a hybrid modeling and simulation language developed in FORTRAN for main frame computers that allowed simulation of human activities in the context of system operation. MicroSaint was initially developed in the C language, specifically for Personal Computers (PCs), mimicking much but not all of what was in the original FORTRAN version. IMPRINT Version 7 uses Micro Saint IV as its underlying computational engine. MicroSaint Sharp is based on the C# programming language and will be the computational engine underlying IMPRINT Version 8. Representational capabilities of these various modeling techniques are compared to illustrate what improvements have been made and what has been abandoned in the progressive development of these analysis tools.

Introduction

SAINT is an acronym standing for Systems Analysis of Integrated Networks of Tasks. As a modeling tool, it uses a general activity network to represent procedural and decision making tasks, including parallel activity chains by one or more operators. The associated software executes a Monte Carlo simulation of the activity network, generating statistics on activity duration, time of task sequence completion, number of task repetitions, and other descriptive measures. There are numerous similar diagramming techniques, such as: DeMarco Data Flow Diagrams (Yourdan and Constantine, 1979), Petri Nets (e.g., Desrochers and Al-Jaar, 1995), and PERT charts (Moder, et al., 1983). While PERT uses an activity-on-branch representation, SAINT uses an activity-on-node representation.

Background

The original impetus for developing SAINT was the Siegel-Wolf two-man operator simulation model (Siegel and Wolf, 1969), used in a study of F-106 nuclear vulnerability / survivability (Chubb, 1971). Task times were assumed to be normally distributed with some specified probability of success. Failed tasks led to repetition of the task. Average and standard deviations of the nominal task durations were adjusted to reflect the impact of time stress, as determined from time available versus time required. It was recognized that: 1) engineers were reluctant to use a model developed by psychologists, 2) there were other distributions of task times that might better represent certain activities, 3) the branching structure logic was simplistic, and 4) there was no representation of system dynamics that might drive human performance. To be effective, it was believed the best approach was to use simulation technology that engineers were taught to use and then incorporate human factors considerations into that technology. Such was the goal for SAINT.

SAINT Development

SAINT was developed using elements of GERT (Pritsker and Happ, 1966 and Pritsker and Whitehouse, 1966), a FORTRAN simulation language used by industrial engineers to model discrete systems, later adding elements from GASP IV (Pritsker and Hurst, 1973) that also allowed representation of continuous system dynamics (Cellier,1982). For a more detailed overview of the initial SAINT modeling and simulation capabilities, a list of preliminary applications, and references to documentation see Seifert and Chubb (1978).

Subsequent Applications and Developments included modeling of the B-1A Electronically Agile Radar (EAR) to determining the characteristics of time-sharing between forward looking terrain tracing and horizontal ground mapping modes. Additional branching logic and other modeling improvements were also made under the Cockpit Automation Technologies (CAT) program (Hoyland, et al., 1988). SADT (Marca and McGowan, 1988) was also shown to provide a good top-down, front-end analysis technique consistent with later developing the SAINT activity networks (Chubb, 1989).

Deficiencies and Shortcomings of SAINT included a lack of graphics capability to represent network models, complicated symbology for network diagramming, particularly the types of branching logic, and the general lack of technical support. While the source code was delivered with no restrictions on data rights (therefore available in the ‘public domain’ and releasable to any requester), there were no formal provisions for giving users any technical support if they encountered difficulties in their use of SAINT. SAINT was designed as a batch program for a large, main frame computer, and all data was in alphanumeric form using punched cards. Micro Saint (Laughery, 1985) changed that, substantially.

Micro Saint Development

Micro Saint was developed by Micro Analysis and Design (MA&D) as part of the Army's Chemical Defense program and made four major improvements: 1) it was hosted on personal computers (PCs), b) it included graphical representations of the network model, 3) it simplified the representation of branching logic, and 4) data entry was easier and less error prone. Micro Saint was initially programmed in the C programming language, which permitted capabilities not readily available to FORTRAN programmers. Network graphics were animated to indicate which task(s) were being executed as the sequence unfolded. In addition to helping users better understand the task-flow, it also helped 'debug' incorrectly implemented models. There was no attempt to include all the distribution types or types of branching logic found in SAINT, nor did Micro Saint include SAINT's continuous-time modeling of system dynamics.

The most recent version of Micro Saint is based on C#, not C or C++. This new language offers more programming power and additional capabilities (Bloechle and Schunk, 2003). The ability to build enhanced animation of models has also been added, as well as permitting the development of better web-based applications. However, developing advanced animations may, by itself, take as long as developing the model and Micro Saint simulation. It has a distinct cosmetic advantage in promoting a model and its use, but does little technically – the underlying model is the same. An add-on optimization package is also available for analyzing the output from a series of model runs.

Micro Saint is a proprietary product and therefore not in the public domain. However, MA&D does offer an academic discount for both student and the 'industrial strength' versions of Micro Saint. They also provide excellent training in their product (as well as appropriate courses in the use of IMPRINT).

IMPRINT Development

IMPRINT (Anonymous, 2003 a & b) is a tool developed by MA&D for the Army that helps satisfy part of the MANPRINT requirements Booher (1990). Version 7 uses Micro Saint IV as its underlying computational engine. Version 8, currently under development, will use Micro Saint Sharp as its underlying computational engine, providing some new / enhanced modeling capabilities for IMPRINT that are not treated in this comparison. The Army prefers Law and Kelton (2000) as their basic reference text on simulation and modeling.

IMPRINT has its own graphical user interface and may be used to look at both operator (e.g., individual missions) and maintainer (e.g., sustained combat operation) applications. There are now three levels or modes of modeling that are increasingly complicated and demanding of user input data. All three have 'standard' outputs built-in.

The simplest model implementation permits workload assessments of hierarchical task network models using the McCracken-Aldrich model (1984). The advanced workload assessment mode, restricts the modeling to a single level of task representation, but allows parallel tasking and uses the North model of workload (1989).

The most complex use of IMPRINT uses techniques originally developed under the CART program (e.g., Brett, et al., 2002). This permits goal-directed task modeling that better represents the way in which most missions are accomplished. More recently, the interface of IMPRINT and ACT-R has been explored as well (Kelley and Scribner, 2003).

Both the advanced workload and CART-related modes of IMPRINT give the user access to more powerful modeling tools but fall short of requiring a complete understanding of the full complexities of Micro Saint. This structured support of increasingly more complex models allows new users to systematically develop their modeling expertise.

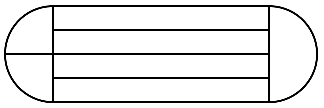
While the documentation does not completely support the user's needs, the Army has made provision to give technical support to new users, something the Air Force did not do for SAINT. This substantially enhances IMPRINT's utility. IMPRINT is a non-proprietary product, supplied free of charge to 'qualified' users – typically organizations with Department of Defense contracts. The point of contact for making a formal request is: Mr. John Lockett, Army Research Labs, Aberdeen, MD.

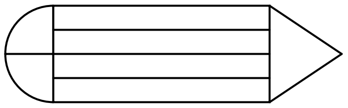
Other Comparisons

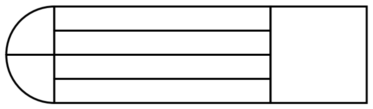
Comparisons can be made on at least four levels: graphic modeling of activities, common features, unique features, and the user interface, for both input and output.

Graphic Modeling

SAINT provided no assistance in developing the network diagrams. A symbol set (Figure 1) was specified for representing task networks, but the diagrams had to be done manually. SADT tools later made this easier to do, but the translation into SAINT was neither direct nor automatic. Micro Saint and IMPRINT both provide facilities for creating the network diagrams.


Deterministic Node: Take ALL Branches Out


Probabilistic Node: Take One and Only One Branch, Based Upon the Relative Frequency Specified


Conditional Node: Take ALL Branches for Which the Stipulated Condition Is Met

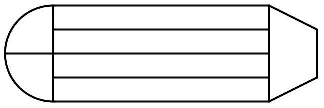

Conditional Node: Take 1st Branch for Which the Stipulated Condition Is Met

Figure 1. *SAINT Symbols.*

The first node in a network starts the task sequencing; subsequent nodes are 'triggered' upon completion of one or more preceding task(s). Directed arrows point from one task node to the task(s) node(s) which follow, and the specified branching logic is applied to determine which path(s) are to be taken. Information packets follow along those paths (like tokens in Petri Nets). These packets are a vehicle for transmission of local information from one task to another (e.g., the level of stress, the value of a control setting, or other definitions for a variable's value). Subsequent tasks can then examine the values of variables passed in a packet. The value can then influence either the time taken by that task, some variable manipulated in the performance of the task, or some condition tested to determine branching out of the task. Micro Saint retained this capability. It provides a very powerful modeling tool.

When any one task completes, one or more of the subsequent tasks may be released for execution, depending on the precedence requirements or release conditions specified for each task. At some point, a terminating node is reached which ends the simulation and initiates the generation of summary statistics for a series of runs / iterations.

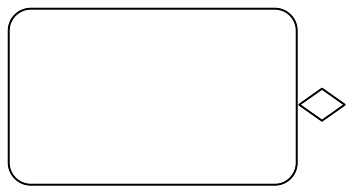
When a continuous system's dynamics were modeled, SAINT would also generate a 'strip chart' recording that showed the level (value) of each continuous variable over time, from the start of the simulation to its termination: the time trajectory for each state variable of interest.

The semi-circular left side of all blocks had an upper and lower half specifying what precedence constraints had to be satisfied (what number of preceding tasks had to be first completed before this task was started). In the upper half, one specified how many of the incoming 'signals' had to be present before the current task could be 'released for execution the first time it was performed. The lower half specified how many had to be present before subsequent releases.

Micro Saint did not distinguish between first and subsequent task execution precedence constraints. Task release could instead be specified on the basis of a specified variable, which if 'true' when tested, the task would be released. IMPRINT allows this same representation.

Also, Micro Saint did not use alternate shapes to represent branching alternates. Instead, a dialogue box is presented for the user to select what type of branching is desired. Conditional 'take first' branching is not one of the options however. Prioritized branching can be accomplished through setting and testing variables instead. This scheme simplifies the diagram, leaving details to be specified in terms of data inputs. IMPRINT does the same.

Micro Saint IV and IMPRINT use two different shapes to model functions and tasks. Tasks are always a decomposition (more detailed representation) of functions. Figure 2 shows the older Micro Saint symbology, also used in IMPRINT. Micro Saint Sharp is similar but slightly different. A Node may be either a task or a network of tasks. That network can be either a set of tasks, set of networks of tasks or some combination: a powerful hierarchical approach to modeling complex systems.



Function and Decision Block

Task and Decision Block

Figure 2. *Micro Saint Symbology.*

By clicking on either the function or the task blocks, the user will bring up the dialogue box that permits entering data associated with the selected function or task. Correspondingly, by clicking on the diamond to the right of each box, the user calls up the dialogue box for specifying the desired branching logic. While this notation simplifies the diagram, it effectively hides the nature of the branching logic.

SAINT did not preclude hierarchical decomposition of task networks, but neither did it facilitate that kind of modeling. Micro Saint distinguishes between upper level functions and the lower level tasks that then support or implement those functions: a network of tasks at one level can appear as a single task at another level. IMPRINT does this too, but in a more limited fashion (a single function layer and a single task layer). However, when using the Advanced IMPRINT workload assessment technique, only a single task layer is allowed, but parallel paths are permitted. The CART-based mode adds yet another consideration: goals drive which functions may be activated at any one time. Several functions may be ongoing at one time, along with their associated tasks. This allows better representation of mission scenarios, but it also is a more complicated form of modeling and typically requires attention to detail and more time in debugging the implementation.

Common Features

SAINT, Micro Saint, and IMPRINT all provide modelers with a wide variety of statistical distributions for representing the duration of tasks or other activities. All three techniques also offer users flexible ways to adjust the parameters of those distributions to reflect the impact of a wide variety of moderators or stressors that change the character of behavior, either in terms of the duration of the task or in the branching that occurs when a task is completed.

Unique Features

System dynamics portray the states of a system (e.g. airplane) continuously over time. The first example used in SAINT was aerial refueling of a B-52 by a KC-135. What was critical was representing the vertical and longitudinal separation between the two airplanes as the pilot changed yoke and throttle settings. Those discrete tasks changed acceleration characteristics, which affected the speed and vertical velocity of the bomber with respect to the tanker, which in turn altered the position of the bomber relative to the tanker (their separation).

While SAINT provided symbols for modeling discrete activities, continuous processes can also be diagrammed, but SAINT assumed users would use either analogue computer techniques (integrator symbols, logic gates, etc.) or the ‘flow rate and level’ symbology used by Forester (1961). For simulation, the differential equations portraying system dynamics are expressed as difference equations for integration of rates to get states. Neither Micro Saint nor IMPRINT provide this capability directly.

IMPRINT on the other hand has a built-in ability to reflect the effects of task accuracy (or, conversely, failure) on performance. This feature appears intuitive on the surface, but users should carefully examine this function to be sure what they think it does is what is actually happening. While the explanations provided seem clear, the user would do well to empirically test a simple model to be sure what they expect will happen actually occurs. Otherwise, they need to reinterpret how this function really works!

The User Interface

SAINT required punched card input, and a single typing mistake meant punching a new card and perhaps rerunning the program. Pre-defined outputs were generated on pre-punched computer paper, not regular 8 ½ x 11 inch sheets. The horizontal format provided more space for printing output, but storage of massive output listings was then awkward.

Micro Saint was designed to operate interactively using a PC’s display screen. Modifications to input could be made more easily, and turn-around for modeling improved greatly. Results could be displayed before printing, so less paper was wasted, and printers started using more conventional sizes of paper. Considerable flexibility is provided to the user in generating output products, including animation.

IMPRINT is more restrictive and directive than Micro Saint and has its own unique user interface, but that also permits more rapid model development with that standardization. The three different IMPRINT modes do have differences in both the input and output interfaces available to users. Each is tailored to the specific mode being exercised, and animation is not provide except in its simplest form: seeing which task(s) get executed. However, this can be quite useful in debugging model implementation.

IMPRINT addresses two important kinds of application: a) system modeling of an individual performing a specific mission, and b) a series of ongoing engagements where the break and fix rates of malfunctioning equipment determine the ability to sustain combat operations. Each use of IMPRINT has its own special characteristics, data input requirements, and output reports.

Conclusions

While SAINT started with the objective of providing engineers with tools that would permit system modeling that also treated human factors, Micro Saint made this approach to simulation and analysis more practical for both engineers and human factors specialists, and IMPRINT tailored the Micro Saint technology to specific needs of the human factors engineer in systems acquisition programs. Micro Saint Sharp has provided a significant advance over the older versions of SAINT but without incorporating its continuous / combined modeling capabilities. While IMPRINT is a bit more restrictive than Micro Saint, it handles workload well, has been extended to treat the degrading effects of a variety of stressors, and addresses some of the impacts training and the lack of practice can have on performance. Version 8 of IMPRINT, now under development, will incorporate some of the features found in Micro Saint Sharp and should therefore be an even more powerful and flexible tool for modeling and analyzing human performance in the context of mission simulation.

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