

# **ABNORMAL SITUATION MANAGEMENT IN PETROCHEMICAL PLANTS: CAN A PILOT'S ASSOCIATE CRACK CRUDE?**

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## *Abstract*

Abnormal Situations comprise a range of process disruptions in which petrochemical plant personnel must intervene to correct problems with which the control systems can not cope. Preventable losses from abnormal situations cost the U.S. economy at least \$20B annually.

The Abnormal Situation Management (ASM) Joint Research and Development Consortium (Honeywell, the seven largest U.S. petrochemical companies, and two software companies) was formed to develop the technologies needed to allow plant personnel to control and prevent abnormal situations. The Consortium is working on a NIST-funded, 3.5-year, \$16.6 million program to demonstrate the technical feasibility of a collaborative decision support system (called AEGIS) for helping operations personnel deal with abnormal situations.

Many of the issues faced in the development of AEGIS have also been faced in the research and development of associate systems for military aviation domains, especially the U.S. Air Force's Pilot's Associate (PA) and the U.S. Army's Rotorcraft Pilot's Associate (RPA). Honeywell intends to apply associate technologies as vigorously as possible to the ASM problem. The two domains have a number of features in common, which we hope will permit significant technology transfer in both directions.

This paper describes the similarities of and differences between the technical and organizational domains in which Abnormal Situation Management and the PA and RPA systems must operate, and assesses the issues thus raised. Finally, we describe our approach to resolving these issues and assuring successful demonstration of the feasibility of associate technology in this new domain.

## **The ASM Problem**

Preventable losses from Abnormal Situations—unexpected process disruptions—cost the U.S. economy at least \$20B annually—about half of that in direct losses to petrochemical companies themselves. Petrochemical plants use distributed control systems to simultaneously control thousands of process variables such as temperature and pressure. The human role in process control is to monitor these highly automated systems, maintaining situational awareness in order to make accurate and timely control decisions while avoiding information overload.

Increased demands for higher efficiency and productivity in these industries are resulting in tremendous increases in the sophistication of process control systems through the development of advanced sensor and control technologies. However, these sensor and control technologies have not eliminated abnormal situations and will not in the future. Consequently, operations personnel continue to intervene to correct deviant process conditions. As petrochemical plant automation technology increases in sophistication, operators are faced with increasingly complex decisions. As in aircraft, the consequences of an error—an overlooked anomaly, a nonoptimal response, or a delayed

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reaction—is always associated with a cost, and can ultimately contribute to catastrophe.

Unlike most combat aircraft, however, the operator rarely has personal and immediate access to the complete set of information or control actions which s/he may need to make a decision and effect an action. Operators work in teams with maintenance and field personnel, coordinating their movements around the plant site to confirm gauge readings, operate valves, investigate leaks, etc. Field personnel in turn make the operator aware of conditions which may not be readily apparent at the central console .

Sufficient information and resources are usually available to support appropriate and timely responses, provided the operations team is able to identify the problem and develop an effective, coordinated response. While the pressure to make real-time decisions is usually (but not always) somewhat more relaxed than it is in combat aircraft, operators may have to deal with far more information, presented in far more detail, and which develops slowly over longer period of time. Sorting out relevant diagnostic information and making appropriate decisions is at least as difficult as it is for the military aircraft pilot, and the worst case consequences of an error (in terms of losses in property and human life) are, unfortunately, also comparable in scope.

The persistent paradox in supervisory control, regardless of the domain in which it is practiced, is that as automation technology increases in complexity and sophistication, operations professionals are faced with increasingly complex decisions in managing abnormal situations. In the industrial processing domain, the problem is aggravated because of the need for the coordination of multiple operations personnel, and because the sophistication of user support technologies has not kept pace with the task demands imposed by abnormal situations. Thus, collaborative decision support technologies must be developed to significantly improve abnormal situation management practices.

The Abnormal Situation Management Joint Research and Development Consortium, led by

Honeywell, is engaged in is a multi-year effort to develop a system to provide collaborative decision support. This Abnormal Event Guidance and Information System (AEGIS) can be thought of as an associate system for petrochemical operations, and is indeed motivated by many of the same issues that drive the work on Associate Systems: advanced sensor integration and interpretation to support improved situation assessment, automated planning assistance to provide help in addressing abnormal situations, information management to support increased situational awareness and avoid information overload, adaptive aiding to improve the effectiveness of the operators actions and to free him or her from mundane tasks in order to focus on functions which only the human can do.

AEGIS must ensure that operations personnel receive information appropriate to their needs, while at the same time enabling appropriate members of the operations staff to collaborate to solve the problem as a team. Individual needs vary as a function of a large number of variables: the current situation, the task being performed, individual preferences and styles—and others yet to be determined. In order to serve these needs, we need to carefully assess the information requirements, not just for the current job functions present in existing plants, but for the job functions that will evolve as better decision aids become available and operators receive more support.

Many of the issues faced in the development of AEGIS have also been faced in Pilot's Associate (PA) work over the past ten years, and Honeywell intends to apply PA technologies as vigorously as possible to the ASM problem. Our initial approach to seeking opportunities for technology transfer involved comparing the problem domains these programs are attempting to address.

### **Comparing Problem Domains**

Some key comparisons between the problem domains of AEGIS and PA systems are summarized in Table 1. The most significant differences between the domains are due to the

number of users, the predictability of the problems to be encountered (especially, the effectiveness of potential solution attempts), and the variability of the hardware being supported by the supervisory control system.

*Number of users*

While the PA program concentrated on providing associate-style assistance to a single pilot in an advanced fixed-wing aircraft, and the RPA program is developing an associate to aid both members of a dual-crew attack/scout helicopter, successful transfer of the associate approach to AEGIS will require us to extend the approach to cover a geographically dispersed operations team of perhaps dozens of individuals who must work collaboratively to solve the problem.

*Characteristics of the problems typical of the domain*

The problems encountered by AEGIS aren't oppositional—they don't intelligently resist solution, and so the anticipation of countermeasures is not required—but they are challenging nonetheless. Process upsets can arise very slowly (over a matter of hours, days, or even months) and they may similarly require a long time to resolve. The processes are often too complex to model, and are therefore poorly understood and difficult to predict in an empirical sense. Finally, the sheer scope of processes makes the enumeration of potential problems difficult: the number of physical variables, their interactions, and the unpredictable influence of dozens of operations personnel ensure that

problems continually occur which have been unanticipated by the process engineers as well as the operators.

*Variability of hardware to be supported*

We will have to be able to create, rapidly and at low cost, as many unique associate systems as there are petrochemical installations, because no two plants are alike—they're not even very similar. And, we will have to support a variety of process control technology and software, from that installed ten years ago to systems now on the drawing boards.

*Do these differences matter?*

While the differences associated with the problem domains listed in Table 1 and described above seem significant, they do not all affect the design of the solutions to the same degree.

For example, while the problems faced by Associates in their respective domains have different characteristics, they raise similar issues for Associate designers: How do we construct a system to be helpful to users when we do not understand the problem thoroughly, can not predict the specifics very well, and can not ensure that unforeseen aspects of the problem space will render the Associate useless in some specific scenarios?

Similarly, while petrochemical plants are more variable in their configuration than military aircraft, that variability isn't the only relevant aspect of the problem space to consider: Process plants produce the same products day after day, but aircraft are used for a diverse set of missions.

<b>Domain Characteristic</b>	<b>Pilot's Associate/RPA</b>	<b>ASM (AEGIS)</b>
<b>Number of primary users</b>	1 or 2	5 to 15
<b>Autonomy of any one user</b>	Very high	Limited
<b>Physical variables to monitor</b>	100s	1,000s - 10,000

<b>Critical time interval for decision</b>	Seconds to minutes	Seconds to hours
<b>Ability to methodically enumerate possible problems ahead of time</b>	Limited by enemy, perhaps 25%	Limited by combinatorial expansion
<b>Ability to predict outcome of various solution attempts</b>	Limited (enemy actively thwarts solutions)	Good (limited by unpredicted failure cascades)
<b>Typical user education/training</b>	Unequaled	Varies
<b>Understanding of problem physics ahead of time</b>	Very Good to Excellent	Good (Limited by complexity)
<b>Acceptance of new technology</b>	Good	Poor to Excellent
<b>Level of current technology</b>	Very good to excellent	Fair to very good
<b>Level of integration required</b>	Extremely high	Extremely high
<b>Homogeneity of user population</b>	Very high	Not dependable
<b>Homogeneity of equipment</b>	High	Nonexistent
<b>Homogeneity of activities</b>	Moderate	High
<b>Typical duration of continuous associate usage</b>	2-12 hours	Continuous
<b>Acceptable initial cost of system</b>	\$10M?	\$10K-\$1M??
<b>Computational resources</b>	Limited by space/weight available and/or bandwidth	Limited by cost
<b>Frequency of associate intervention in user activity</b>	continuous in mission	Sporadic. Mostly in Abnormal Situations (4X per week?)
<b>Autonomy of associate</b>	pilot is in charge	Must vary according to situation, company and supervisor policy, and operator preference.

**Table 1. Comparison of AEGIS Problem Domain with those of PA and RPA**

Thus, by focusing exclusively on the problem space, we may unconsciously limit the potential for transferring learning between these problem domains. These considerations have led us to seek technology transfer opportunities by comparing the approaches the various Associates are employing to solving their respective problems.

### **Comparing the Solution Approaches**

Some key comparisons between the solution approaches for AEGIS and PA systems are summarized in Table 2. It is readily apparent that, despite the just-discussed similarities in their respective problem spaces, the two programs are approaching their respective problems in very different ways.

We think that there are two primary drivers of these differences. First, there are no autonomous users of an AEGIS system, and the entire solution is therefore being driven by the need to support the collaboration of its users. The second driver of the AEGIS approach results from the cost requirements of the civilian business culture. This influence is apparent in several areas: Since the cost of an ASM system will have to be rigorously justified, the resources available to the system developers and maintainers are significantly constrained.

These constraints are driving the ASM program toward open systems architectures, the use of off-the-shelf components, and intelligent system configuration and engineering aids. In addition, AEGIS will have to provide for its own needs in the areas of training, operations support, and maintenance functions.

The PA approach thus takes advantage of the users' autonomy, and the relative availability of development resources, and relies on a collection of well-specified, highly-coordinated special purpose modules.

The AEGIS approach is to provide access to an application infrastructure and information sharing environment in a way that permits economical development of applications that share the tasks in providing an overall solution.

The AEGIS system must also provide for the training and support infrastructure that the PA approach can take for granted. The assumption is that if the infrastructure is available, the market will provide applications to expand the capabilities of the initial system. While this assumption is untested, repeated experience in other domains (e.g., personal computer operating systems, laboratory instrumentation busses, global positioning system applications) supports this general approach.

### **Technology transfer from PA to AEGIS**

Since AEGIS has had to focus on infrastructure and the provision of an open (and therefore to some extent content-free) architecture, we are not borrowing very much from the PA architectural approach. We are, however, using as much of PA's application knowledge as we can. For example, we have built upon the PA approach to decision support, information management, and planning.

The AEGIS approach to information management, in fact, is almost identical to that of PA: We believe that there are four types of knowledge needed by both decision support Associates in order to correctly sift and present information.

#### *Knowledge of context*

First, Associates must have an understanding of the current context including the plans, goals and tasks in which the human operator(s) are engaged. Advanced Associate systems may be given the authority to allocate some tasks to various operators (animate or inanimate) in an effort to manage task and information overload. But in order to unload the operators, the Associate needs to be able to determine when they are overloaded to begin with.

<b>Approach Characteristic</b>	<b>Pilot's Associate/RPA</b>	<b>ASM (AEGIS)</b>
<b>Number of users supported</b>	1 or 2	5 to 15
<b>Hardware</b>	Custom	COTS layered on Custom
<b>Software Operating System</b>	Custom	COTS
<b>Architectural Approach</b>	Multiple special-purpose modules, rigorously coordinated, custom-developed .  Maximum possible sophistication in all modules.	Enabling Infrastructure for distributed applications; open architecture, published APIs, information sharing.  Sophistication varies according to cost-effectiveness.
<b>Approach to Problem Diagnosis</b>	Custom knowledge-based module and cockpit information manager	Multiple diagnostic applications, evidence aggregation, multiple user interface applications
<b>Approach to User Interaction</b>	Cockpit Information Manager, rigorous application of interaction protocols  Pilot is in charge	Information presentation infrastructure supporting multiple user interface applications, customized interaction styles  Autonomy varies according to plant policy
<b>Supporting Technologies</b>	Embedded in System	Training  Operations Support  On-line Information and Documentation Systems
<b>Expected availability and frequency of use</b>	Always available, continuously in use	Always available, user interface continuously in use, AEGIS services in use infrequently (on an as-needed basis)

**Table 2. Comparison of AEGIS Solution Approach with those of PA and RPA**

*Knowledge of information requirements*

Second, the system must also have knowledge about the kinds of information needed in various contexts to perform various tasks. It is usually not appropriate to present detailed maintenance information about malfunctioning avionics to pilots in the heat of a mission, but it may be appropriate to present information on how to reconfigure the avionics system to manage the problem.

*Knowledge of presentation resources*

Third, the system needs knowledge about the available information presentation resources (e.g., display surfaces and display formats that can be presented on them, acoustic channels, etc.) and these must be represented such that their capabilities for providing information needed by tasks is clear or derivable. The Associate must not interrupt radio messages with voice

annunciation, nor present information requiring color on a multipurpose, but monochrome, display.

#### *Knowledge of information priority*

Fourth, the system must have a mechanism for selecting and prioritizing information for presentation for the limited human and machine resources available. This fourth type of knowledge may include representations of the degree of "fit" between information needed and information provided, individual differences and personal preferences of specific operators, the capacity of specific I/O devices in the operator's crew station, and the processing capacity of the human operator.

We have developed methods for acquiring, representing and using all of these types of information on the RPA program, and have developed a CIM prototype which is currently being evaluated and refined for use on the RPA aircraft. We should be able to transfer the bulk of this approach to the AEGIS effort.

#### **[Potential] Technology Transfer from AEGIS to PA**

We believe that the PA efforts may benefit from AEGIS work in three key areas. In two cases, these opportunities result from the fact that the PA and AEGIS efforts share requirements, but are addressing them with different priorities.

Just as AEGIS can benefit from the early PA focus on information management issues, we believe PA can benefit from AEGIS focus on supporting collaboration among multiple users, and from the AEGIS work in the development of a distributed architecture that supports independent applications to collaborate to solve the problem as a whole. The other technology transfer opportunity for PA stems from the AEGIS effort to coordinate all of its operator interaction within a single consistent interface.

#### *Collaboration support*

PA efforts have heretofore not been overly focused upon supporting the collaboration of

multiple users, but we know that it is only a matter of time before collaboration support becomes a necessary component of PA. For example, suppose a flight of aircraft is assigned to a mission with multiple targets and multiple threats. The PA system might well be expected to dynamically coordinate the efforts of the entire flight to complete as many of the mission priorities as possible.

The need to support collaboration entails the expansion of the information management model of PA to incorporate knowledge of what other users are doing, and the modification of the existing four types of knowledge that the information management system must understand to include the impact of having additional operators available—both as problem-solving resources and as information processing burdens.

#### *Distributed architecture*

The second major opportunity for technology transfer from AEGIS to PA, as we see it, results from the distributed, open architecture design being pursued by AEGIS. The AEGIS effort of course has the potential to greatly reduce the fielded cost of Associate technology, but it may also contribute greatly to reducing the systems maintenance effort, enabling frequent updates to the technology, and, eventually, perhaps, to enabling PA to evolve into less expensive, more open, more distributed and therefore more redundant and fault tolerant system.

#### *Unified user interface*

The demands of process control, and in particular the need to interact with hundreds of instruments without adverse impact on the operators' awareness of the overall state of the plant, led the designers of distributed control systems to develop the "single window to the process" concept. This design principle requires us to ensure that all interaction with the process take place in a unified, consistent, and comprehensive user interface. As new capabilities are added to the process control

system, they are required to be integrated into the existing user interface environment.

The pilot's environment has evolved differently, in that as new capabilities became available to support various aspects of an ever-more-sophisticated mission, the cockpit has accreted new interfaces: Flight management, weapons management, radar systems, flight control, communication, aircraft status—each of these has a separate user interface personality, integrated to differing degrees with the rest of the cockpit systems. For example, some systems share a display, but use it in different ways. Some systems have dedicated interfaces, but they are not consistent with the interfaces of other systems.

It may be argued that the functionality being supported by these systems is too sophisticated (or critical, or specific, etc.) to enable integration into a consistent framework, but we are not convinced: Industrial systems designers face challenges of equivalent complexity.

It *is* the case that the pilot interface has evolved over fifty years, and the introduction of new technology into the digital control room has benefited from the lack of such tradition. Nevertheless, we believe that the multiplicity of cockpit systems is reaching a point of diminishing returns, and that cockpit integration—in the user

interface sense—is the next best opportunity to significantly improve pilot performance, decrease training requirements, reduce incidents, and further the goals of the aviation community.

In some respects, the greatest potential technology transfer from AEGIS to PA may be of approaches, methodologies, and architectures to address this problem of user interface integration into a single, consistent framework.

## Conclusions

The AEGIS system is addressing, from a user's perspective, the same issues that the PA programs have been working on for some time: The management of time-critical and unpredictable problems in complex, high-value, safety-critical systems. Despite the differences in the specifics of the problem domains, success while require the many of the same issues to be addressed.

The programs are being driven to address these requirements in a different priority order, and therefore there is significant potential for technology transfer in both directions. We intend to take advantage of our participation in both of these efforts to vigorously pursue the opportunity to help the programs benefit from each other.



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**Dr. Chris Miller:** Principal Research Scientist, Honeywell Technology Center (PhD, MA, Cognitive Psychology, University of Chicago; BA, Experimental Psychology, Pomona College). Dr. Miller is currently the Principal Investigator for Honeywell's portion of the U.S. Army's Rotorcraft Pilot's Associate program. Honeywell's objective in this program is to develop and implement an information management system to coordinate information and task flow between two crew members and advanced automation systems in a next-generation scout/attack helicopter. Dr. Miller is a key contributor to the overall system architecture and information management subsystems in the Abnormal Situation Management Program. Dr. Miller was the Principal Investigator on Honeywell's Learning Systems for Pilot Aiding (LSPA) program for the U.S. Air Force. This program pioneered the use of machine-learning techniques to automatically acquire new tactical plans and pilot information requirements from observations of pilot's flight.

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