o Parallel processing. This is one of the potential means for increasing the speed of the expert system.

o Human interface. The problem of how the expert system can deal with the human elements, especially in real-time situations, in which there is limited time for "discussion" is a severe problem in air traffic applications.

o Capture of knowledge. The techniques for capturing knowledge are still not well developed.

Much time was spent in developing a concise and well-reasoned list; this list seems to portray some agreement on what the AI community should be doing.

The group strongly supported the concept of starting small. There is frequently a tendency to ask for a largo, tightly specified system which will be delivered in ten years and will do everything. This is quite contrary to the spirit and practice of development of expert systems where you start with something that works, but probably not very well. Then you play with it until you like it better.

The general precept of software engineering these days is to develop complete specification before the first line of code is written. This is not the way most software is developed. Expert systems methodology makes explicit the old cut-and-try approach by which most software for all purposes is developed. These days both approaches have strong and highly principled defenders.

Another point that should be noted is the interplay between research and applications. The panel felt that they must move together and that research should, at least in part, be motivated by what is needed for applications.

INDIVIDUAL INPUTS

Participants in the workshop were invited to submit written comments or papers on the issues discussed at the workshop for inclusion in the report of the workshop. The following represents the material received.

INDENTIFICATION AND DEVELOPMENT OF ARTIFICIAL INTELLIGENCE APPLICATIONS IN AIR TRAFFIC CONTROL AUTOMATION

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The significant increases in the level of automation of the United States air traffic control system currently being implemented or envisaged under the National Airspace System Plan suggest both a need and an opportunity to explore the potential for applying artificial intelligence (AI) technologies in the future ATC system.

Artificial intelligence is the name given to a broad field of computer techniques that have the general goal of developing "intelligent" processes which enable computers to perform tasks that usually require human skills, such as understanding language, pattern recognition, learning, problem solving, and so on. The field of artificial intelligence deals both with developing general methods for solving problems and with applications of these methods to specific domains of interest. Although recent interest has tended to focus on expert systems (computer programs that attempt to replicate the performance of human experts by means of rule-based reasoning), in part because of the availability of commercial software products, there is a wide range of other AI techniques and applications that may be relevant to ATC problems, including computer vision and speech recognition.

However, merely because certain computer techniques can be applied to ATC automation does not necessarily mean they should be. In the light of the complexity of the ATC system and the heavy costs of failures, in terms of human lives at risk and wasted resources, an assessment of the potential for introducing such techniques must answer two broad questions:

1) How can it be done?
2) What are the costs and benefits of doing it?

The first question must address not only how to make the techniques themselves work at the desired level of reliability and performance, but also how they can be fitted into the rest of the ATC system. The second question addresses the "value added" that can be obtained by using the techniques, compared to solving the problems in other ways.

The large number of potential AI applications in the ATC system that have been identified in research to date may be grouped into six categories:

- o Intelligent assistance
- o Strategic planning
- o Improved sensing and communication
- o Tactical control automation
- o Failure recovery management
- o System planning and training.

Intelligent assistance includes improved presentation of information, alerts for potential decisions and automatic execution of routine functions. Strategic planning techniques utilize knowledge representation and search methods to anticipate future conditions and regulate traffic flow to reduce aircraft conflicts and delay. Improved sensing and communications includes voice synthesis and recognition and computer vision. Tactical control automation applications utilize expert systems and heuristic planning techniques for conflict resolution, runway and airspace configuration management and dynamically adjusting the control rules. Failure recovery management includes both system monitoring and contingency planning techniques, as well as provision of real-time support to system managers attempting to redeploy resources. Applications in system planning and training include improved simulation tools and use of expert systems to assist in system configuration planning. The range of possible AI applications is summarized in Table 1.

In order to assess the usefulness of AI techniques in ATC, it is necessary to define the control environment within which these techniques might be applied. To illustrate the wide range of possible ATC environments, research at the University of California, Berkeley, has identified seven sample control strategies (1).

1) See and avoid, in which each aircraft is responsible for identifying and avoiding other aircraft through visual contact;
2) Collision avoidance, in which on-board systems monitor the position of nearby aircraft electronically and provide flight crew guidance for evasive action;
3) U.S. Today, in which ground based

Table 1. Potential Applications for Artificial Intelligence in Air Traffic Control.

Area	Application
1. Intelligent Assistance	o Improved Presentations of Information o Alerts for Potential Decisions o Menus of Alternative Actions with Recommendations o Automatic Execution of Routine Functions
2. Strategic Planning	o Extended and Coordinated Probes o Deconflicted 4D Flight Plan Generation o Improved Interface with Tactical Control o Fuel Analysis as Part of Control Decisions o Demand Responsive Scheduling o Aircraft Specific Delay Allocation o Airport Capacity Forecasts
3. Improved Sensing and Communication	o Voice Synthesis and Recognition o Automatic Clearance Transfer o Computer Vision
4. Tactical Control Automation	o Collision Avoidance Direction o Runway and Airspace Configuration Management o Automated Decision Making o Flexible Control Rules
5. Failure Recovery Management	o System Monitoring and Crisis Anticipation o Contingency Planning o Failure Recovery Support and System Configuration Selection o System Restoration o Major Disruption Response
6. System Planning and Training	o System Configuration Planning o Improved Simulation Techniques o Pseudo-pilot Automation

controllers monitor aircraft with radar, supported by partially automated data processing, and issue clearances by radio;

4) AERA Stage 1, in which the current system is supplemented by improved communications and controller support functions;
5) AERA Stage 2, in which the computer would detect and resolve aircraft conflict, automatically generating the appropriate clearances;
6) Deterministic, in which advanced aircraft flight management systems would permit aircraft to follow approved deconflicted four-dimensional flight paths, with ATC intervention only to handle unplanned deviations;
7) Integrated, in which deconflicted four-dimensional flight plans are adjusted on a real-time basis to respond to changing conditions.

Although conventional approaches are capable of making the first four strategies function, it appears that AI techniques may enable higher performance to be achieved. In contrast, it appears that the last three strategies may require application of AI techniques to enable their implementation.

Evaluation Methodology

In view of the large number of potential applications of AI techniques and the high cost of developing and testing prototype software, there is a critical need to develop improved methods for performing preliminary evaluations of proposed ATC system enhancements. Most conventional ATC simulation software has the disadvantage of being designed to replicate the performance of the existing system and being very costly to modify.

An evaluation methodology has been proposed for assessing the potential application of particular AI techniques, based on a computer model that can be easily configured to simulate the functioning of any specified ATC system and record the necessary data to assess the performance of the system (2). The proposed model operates by simulating the behavior of generally defined entities, termed actors, that represent components of the ATC system, such as controllers, aircraft, and computers. Each actor behaves according to specified behavioral algorithms that select from a set of permissible actions in order to meet defined objectives. The actors exist within an environment which has spatially and temporally definable properities, such as wind or precipitation, which affect the outcome of any given action by an actor. In addition to simulating the operation of the system, the model also records the data necessary to assess the system performance. Record keeping functions monitor the flow of requests, instructions, and information and record them in a data base for subsequent analysis.

Model runs are performed by specifying the characteristics and objectives of each actor, as well as the rules that govern the behavior of the simulation. The physical and other conditions of the environment must also be specified. High (strategic) level control of the simulation is achieved by specifying a detailed set of objectives for certain classes of actors, as represented, for example, by aircraft flight plans, but the moment to moment conduct of events is entirely in the hands of the behavioral and performance algorithms.

Because of the potentially catastrophic consequences of a failure of the ATC system, evaluation of particular techniques should address how the system will handle and recover from failures. Conventional failure analysis has severe limitations for use in the type of evaluation proposed, and alternative approaches need to be developed.

In order to evaluate any proposed system, a set of measures of effectiveness must be defined that reflect the objectives of the air traffic control system. These measures must address issues of

- o safety
- o efficiency
- o economy
- o equity.

Safety measures include collision risk, proximity measures (number of near mid-air collisions and separation violations), and measures of pilot and controller workload. Efficiency measures describe how well the available airspace is utilized for the movement of aircraft, and can be expressed in terms of the number of aircraft-miles flown per hour per unit volume of airspace. Economy measures reflect the resources required to operate the system and include both user costs, such as fuel consumption and travel time, as well as ATC system equipment and operating costs, together with the schedule disruption impacts of delays imposed on the system. Equity considerations address how the costs and benefits of the system are distributed among the various classes of user, taking account of both the type of user (air carrier, general aviation, and military) and the size of aircraft.

Conclusions

The current state of the art of artificial intelligence techniques appears to support a wide range of possible applications to air traffic control under different control strategies. It appears that techniques developed for heuristic search and the creation of expert systems offer the most promise for near-term application. Areas such as speech interpretation and computer vision may offer potential applications further into the future.

Alternative control strategies can be identified that offer a wide range of both performance and implementation cost, suggesting that different strategies would be appropriate under different circumstances. The development path for future ATC systems should therefore address what mix of strategies is most appropriate under the expected circumstances. Artificial intelligence techniques appear to have potential application in all types of control strategy, including those with less automation than envisaged under the National Airspace System Plan. In addition to applications providing support to controllers for real-time control of air traffic, such as intelligent displays and monitoring/planning functions, there appear to be useful applications for expert systems in areas that include failure recovery management, traffic flow control, training, and airspace configuration planning.

It should be recognized that to achieve the full benefits of AI techniques, it may be necessary to change significantly either procedural rules or the way ATC services are provided. In order to assess the cost and benefits of such techniques and changes, there is a need for significantly more sophisticated evaluation tools than exist at present, with particular attention being paid to analyzing complex failure modes involving equipment, software and human operators, and developing clearly defined and accepted measures of system performance. Critical issues remaining to be addressed include

- o the appropriate role for the human controller in a more automated control system;
- o software testing and certification procedures;
- o formal representation of how controllers and other personnel actually do their existing jobs;
- o specification of requirements for developing the capabilities to implement AI techniques in ATC system software;
- o resolution of trade-offs between conflicting objectives of the ATC system.

In the light of the massive investment being made in the ATC system modernization, it would appear highly appropriate to devote considerable resources as a matter of some urgency to a long-range research program directed at the problems to be faced in the future evolution of the ATC system.

It should be recognized that the skills necessary to perform research of this type are in short supply, given the technical complexity of the ATC system and the intensely competitive market for those with experience developing AI applications. If FAA and its contractors are to be able to draw on a diverse and well-founded body of knowledge and scientific personnel with the skills to support long-term development of the ATC system, it is important that current basic research efforts are expanded and sustained. In particular, adequate funding should be directed at universities in order to ensure a stable supply of Ph.D. students with the necessary background and skills. Although not requiring large amounts of money in comparison to other research and development efforts, these programs must be sustained at realistic levels over the long-term in order to be effective.

References

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