

RESEARCH NEEDS FOR AIRPORT AND  
TERMINAL-AREA OPERATIONS OF THE FUTURE

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The continuing upward trend in air traffic levels, combined with the reorganization of the airline network on a hub and spoke basis since deregulation, has led to increasing congestion at major airports. Many of the largest hub airports in the United States are experiencing demand levels in excess of their airside capacity at peak periods, especially during bad weather. As air traffic levels grow, the frequency of occurrence of delays is likely to increase. Although the airlines are attempting to spread some of the load by establishing additional connecting hubs at less congested airports, this is only a partial solution. Not only are the potential cost and frequency advantages of hub and spoke operation reduced, but eventually rising traffic levels will congest even the secondary hubs. It is clear from an examination of current traffic trends and the technical aspects of increasing airport and terminal airspace capacity, that major difficulties lie ahead in meeting the traffic demand at many major airports (OTA, 1984).

In the long term, it may be possible to provide additional airport capacity at the largest metropolitan areas by constructing new airports. However, the problems associated with locating a suitable site, and achieving agreement between all the parties affected, do not offer much hope for significant progress in this direction within the next decade, except perhaps in the Denver region. In any event, many of the large metropolitan areas already have several airports, and interaction between their approach and departure paths is creating an airspace constraint that would be exacerbated by any additional airports. There is therefore a pressing need to find ways to increase the capacity of the existing airports and terminal airspace. In the short term, some increase in capacity can be achieved for particular airports by solving airport-specific problems with existing technology and procedures through enhanced equipment or construction, or through procedural modifications. Possible projects have been identified at some of the business airports by an Air Transport Association study (ATA, 1985) and are the subject of an on-going FAA-sponsored program of capacity enhancement task forces. Beyond these gains however, additional capacity will have to come from new technology or procedures. Even where new airports are possible, airline hub operations favor one large airport for a region rather than several smaller ones, suggesting that the new airport might replace existing ones rather than supplement them. Techniques for increasing the capacity of existing airports could also be applied to the design of new airports.

Recognizing these problems, the U.S. Federal Aviation Administration (FAA) has embarked on an ambitious program of technology development as part of the National Airspace System Plan (NASP). The two central themes of this program are the replacement of existing, largely obsolete, equipment with state-of-the-art technology in the areas of air traffic control, communications and weather monitoring, and the introduction of increased levels of automation, permitting the national airspace system to handle

increased future traffic levels without significantly expanding the labor force involved (FAA, 1984). However, with the exception of a few elements of the plan, discussed below, the current research and development program does not primarily address the critical constraint in the system, namely the capacity of existing airports. This is not to say that this aspect is not receiving attention. Indeed, the FAA has recently established an Airport Capacity Program Office and published an airport capacity enhancement plan (FAA, 1986). But while the measures proposed under the NASP will establish a context within which airport capacity improvements can be addressed, there is a need to develop technologies and procedures that go beyond those proposed as part of the NASP. This need was recognized by the Industry Task Force on Airport Capacity Improvement and Delay Reduction (AOCI, 1982). In addition to proposing a number of possible capacity enhancement measures that have been incorporated in the FAA capacity enhancement plan, the task force also stressed the need for an ongoing research program that would involve a broad industry participation, possibly on the model of the National Cooperative Highway Research Program.

The future is, as has often been noted, hard to predict. Both system requirements and technological opportunities are difficult to determine very far in advance. Surprises are likely, both pleasant and unpleasant. It is therefore important to explore as wide a range of alternative solutions to anticipated problems as possible. Not only will this increase the chances that the best solution possible will in fact be adopted, but if circumstances change unexpectedly, a broad selection of responses will be available to permit mid-course corrections. Given the complexity of the national (and international) airspace system, this presents something of a dilemma. It is understandable that, faced with a need to get something working in a reasonable time, decisionmakers will want to concentrate their resources on what appears at the present time to be the best way to proceed. However, history has taught us time and again the importance of keeping options open, and exploring alternative paths to the obvious.

The development of any sophisticated technology requires a strong basis of knowledge and theory. This is clearly understood by the Department of Defense, in their distinction between basic research on the one hand and applied research and engineering and development on the other. Air traffic system research in contrast, is characterized by a preoccupation with engineering and development, the building of ever more sophisticated black boxes, unguided by any theoretical basis of how the system ought to evolve. In contrast to the hundreds of millions of dollars being spent on hardware procurement and software development, the amount of money currently being spent on long-range basic research is almost insignificant. Unless this situation is rectified, we are likely to find ourselves at the turn of the century in exactly the same position that we were five years ago, with obsolete equipment, insufficient capacity, and no real idea on how to implement the perceived functional requirements for the next generation, let alone any operational experience with the concepts.

At the same time, the air traffic system is facing a wave of new technological possibilities, from satellite position finding through artificial intelligence to infrared vision systems. The successful integration of these technologies into a system as interconnected and complex as the air traffic system will pose a major challenge.

## ISSUES IN AIRPORT AND TERMINAL AREA OPERATIONS

The array of issues that must be faced in planning for future airport and terminal area operations can be divided into four categories: capacity, safety, impacts, and cost.

### Capacity

In the present system, airport capacity is generally determined by the runway system capacity. In some cases, the presence of adjacent airports may create capacity limitations in the surrounding airspace, as noted above. Aircraft gate capacity and other landside constraints may also limit airport capacity, although these problems are more easily solved than runway capacity limitations. While the construction of additional terminal buildings and ground access facilities may be expensive (the JFK 2000 improvement program at New York Kennedy Airport is currently estimated to cost between \$1.5 and 2.0 billion -- and this does not include any additional gate capacity), ground facility costs are still a small part of the operating costs of an airline, and if the facilities are really needed, the necessary financing arrangements can usually be worked out. Additional runway capacity is a more difficult problem because of the enormous land area required to meet current separation requirements for independent instrument operations and the site constraints at most existing airports.

The runway capacity problem arises because of the peaking of arriving and departing flights, arising from airline operational requirements. The connecting hub concept has led to arrival and departure peaks at different times, and considerable peaking over periods of less than an hour. Under existing air traffic rules, considerable capacity is lost when the ratio of arriving to departing flights becomes unbalanced. The development of large connecting hubs has also stimulated the growth of feeder services from smaller communities by commuter airlines, using smaller aircraft. These airlines not only try to coordinate their schedules with the flights of the larger carriers, but in many cases enter into code-sharing agreements, making their flights part of the connecting flight complex. The presence of smaller, slower aircraft in the arrival stream further reduces runway capacity.

At many larger airports (such as San Francisco International), the existing runway configuration is such that while fairly high flow rates can be sustained in good weather, when aircraft can maintain visual separation, the runway capacity reduces significantly under instrument flight rule (IFR) conditions.

The key to increasing airport capacity is therefore to develop ways to sustain a high rate of aircraft operations on existing runway systems under IFR conditions. This will require ways to reduce the effective separation between aircraft on approach, to get landing aircraft off the runway more quickly, and to reduce the interval between departing aircraft. If this can be achieved, situations may arise in which congestion in the terminal airspace begins to limit capacity. Ways must therefore be found to either reduce separation standards or to utilize additional flight paths.

Continued growth of air traffic will also require additional terminal facilities. Traffic growth will lead to both more aircraft movements and more

passengers, although the growth rates may not be the same. Past trends have indicated that the average aircraft size is increasing, leading to higher passenger growth rates, creating a need for expanded terminal facilities. However, recent aircraft procurements have generally been for smaller aircraft, suggesting that this trend may not continue. Because of its importance for the balance of gate capacity and other terminal facilities, this deserves careful study. The handling of large amounts of connecting baggage at the hub airports is a particular problem, while those airports with large volumes of originating and terminating traffic are often facing vehicle parking and circulation problems.

### Safety

Although airport capacity is likely to be the principal concern at large airports, safety is also an important issue, for two reasons. First, it is clear that increased capacity cannot be achieved without making some procedural changes. Care must be taken to ensure that safety is not compromised in order to gain capacity advantages. At the same time, rising traffic levels are going to lead to increased congestion if capacity is not improved, producing situations in which safety is likely to be degraded. Improved technology will be required even to maintain current safety levels. Second, although the current safety record is remarkable, few would suggest that it cannot be improved. As the record of recent near misses and, tragically, mid-air collisions demonstrates, there are major weaknesses in the present system.

The existing safety rules and procedures were developed in a different technological environment, and have evolved incrementally in response to perceived weaknesses, often as a response to a particular accident. There is little evidence that they are the most appropriate basis for the present environment, let alone some future environment. Many of the rules clearly apply inconsistent criteria (the use of a fixed separation requirement irrespective of aircraft closing speed and orientation is but one example), while the methodology for deciding whether more, or less, stringent requirements are justified is fuzzy at best. This becomes particularly important when decisions are being taken on whether to spend resources on measures to increase capacity, given the existing rules, or rather to spend those resources developing the technology that might allow the rules to be changed.

Since capacity is the inverse of headway, for a given facility, it follows that if capacity is to be increased, the headway must be reduced. As long as aircraft speeds are largely determined by operational considerations, this means that ways must be found to safely reduce separation. In the case of runway systems, capacity can be enhanced by reducing longitudinal separation on approach and departure, or by reducing lateral separation between runways, thereby permitting additional approach and departure paths to be utilized.

A particularly difficult safety problem arises from the mix of general aviation and air carrier aircraft on the airport and in the terminal airspace. By their nature, general aviation (GA) aircraft are typically much smaller than air carrier aircraft, and less well equipped. Often their pilots are also less experienced, and in some cases very inexperienced. While segregating the two flows makes sense from the standpoint of both safety and capacity, the problem of how to make sure that the GA aircraft do not inadvertently stray into the

wrong part of the airspace remains unsolved, although the technology to do so exists. The fact that it has been implemented illustrates the underlying difficulty with determining the cost effectiveness of alternative safety measures, and developing appropriate user charging mechanisms that reflect the costs the user is imposing on the system.

A third safety concern arises with the detection of severe weather and weather-related conditions and the control of aircraft to avoid undue hazard. This is an area that is currently receiving considerable attention, with particular regard to wind shear. Runway surface friction is another area that could probably benefit from increased attention, especially the real-time prediction of changing conditions. In both cases, difficult decisions must be made on how far to continue runway operations into marginal conditions. How these decisions should be made, by whom, and on what basis, would seem to be an important area for research.

The current research and development on traffic alert and collision avoidance systems (TCAS) suggests that thought needs to be given to how such systems should be integrated into the air traffic control environment. One possibility is that such systems might not only provide last-minute evasion guidance, in the event that the ATC system has failed to ensure adequate separation, but that they might also provide an electronic equivalent of visual contact (electronic flight rules), permitting aircraft to operate in close proximity under IFR conditions.

### Impacts

In addition to the technical problems of providing increased capacity at the major airports, consideration must also be given to the impacts that the additional traffic will create. It is clear that unless these impacts can be satisfactorily mitigated, local opposition is likely to impede or prevent increasing the airport capacity, even if the technical problems can be overcome.

The principal concern is aircraft noise. Steady reduction in the source noise levels have been achieved over the past decade or so, culminating in the current standards. This improvement has been helped by a slower growth (or even a decline) in aircraft movements compared to passenger traffic, due to the use of large aircraft. It can be expected that the resulting reduction in airport noise levels will soon flatten out, as most of the fleet achieves Federal Aviation Regulations Part 36 Stage 3 standards and growth in aircraft size (if any) fails to keep up with rising passenger volumes, and subsequent increases in aircraft operations will result in higher noise levels. The transition from an era of reducing noise levels to increasing noise levels may require a reassessment of historical relationships between noise levels and annoyance. Consideration should also be given to the effect on disturbance of the variation of air traffic intensity over periods of less than an hour. The established method for assessing noise impacts assumes that the impact of a given number of operations is the same, irrespective of how they are distributed within broadly defined periods of the day, and that any increase in traffic levels causes an increase (albeit logarithmically) in annoyance. It is perhaps time to re-examine these assumptions. The need to route air traffic away from noise sensitive areas in the airport environs will place constraints on the terminal air traffic procedures that can be followed.

At some of the larger airports there is also a concern over the impact on surrounding communities of ground traffic generated by the airport. In addition, congestion on the local highway system impedes those trying to reach or leave the airport. These problems will only get worse if airspace capacity constraints are relaxed. While it is beyond the scope of this paper to address ways in which these problems can be tackled, it is clearly important to ensure that improvements in airside capacity are balanced where necessary by corresponding measures on the landside.

### Cost

The need for increased airfield and airspace capacity arises from the heavy costs of aircraft delay. However, consideration also needs to be given to measures that will enable the airlines to reduce the operating costs even of those aircraft not subject to delay. Advances in flight management systems have enabled aircraft to determine and fly flight profiles that minimize fuel burn. However, ways need to be found to accommodate these profiles in terminal airspace procedures (Ratcliffe, 1985).

In addition to fuel burn, measures that increase the flight time will also increase other aircraft operating costs. Existing air traffic flow control procedures attempt to minimize airborne delay, but as a result some capacity is wasted and total delays are higher than necessary. The determination of the appropriate mix of airborne and ground delay will be a continuing problem. Sequencing strategies that maximize runway capacity are also likely to increase flight times, due to the path stretching or speed control involved.

It can reasonably be expected that incremental measures to increase capacity at major airports will become progressively more expensive. The point will be reached at which the cost of increasing the capacity of a given airport is not justified by the benefits resulting from the increment of capacity. At present there is no way to determine this point, yet being able to address this issue is critical to the rational allocation of resources.

### TECHNOLOGY

The technological environment within which future airport and terminal airspace operations will be conducted can be expected to provide a number of opportunities that are not currently utilized. Several new technologies are being developed as part of the NASP or other programs, and others are likely to become available in the near future.

The installation of microwave landing systems (MLS) will greatly increase the options for routing aircraft in the terminal airspace, and utilizing multiple flight paths to and from each runway. Combined with improvements in navigation capability obtainable from inertial navigation systems (INS) and computerized flight management systems giving a four-dimensional navigation capability, considerable improvement can be expected in the ability to direct aircraft along arbitrary paths and adjust arrival times to suit the traffic needs. The introduction of satellite navigation is expected to improve the navigation accuracy by providing a check on INS positions, and may include a position monitoring capability that could surpass existing radar technology.

The development of doppler radar will significantly improve the weather information available, and may permit the detection of wake vortex hazards. The introduction of Mode Select (Mode S) radar technology, with the ability to transmit data to aircraft as well as receive considerably more information from them than is available with existing radars, will greatly improve the communication capabilities and make control actions possible that would be too complex to be handled by existing voice communication.

The steady advances in computer science will also benefit more advanced control systems. The use of higher level languages will facilitate the creation and maintenance of the complex software that will be required in the future. Distributed and parallel processing will both increase the redundancy in the system and increase computational rates. Advances in hardware reliability, combined with fault tolerant designs and software engineering techniques, will not only increase the system reliability, but may permit new approaches to automation of critical functions.

In the longer term, other technologies will be developed that may have application to airport and terminal area operations. The field of artificial intelligence appears to offer many possibilities to enhance existing computer techniques (Gosling & Hockaday, 1984). Developments of sensor technology may provide new ways to supplement conventional radar and visual methods. Current work on the use of infrared wavelengths to supplement flight crew vision at night and in poor visibility appears to be showing considerable promise.

However, while the development of these technologies presents a major challenge in itself, their integration into an already complex system is perhaps even more difficult. The design of systems that can adapt to new technologies, and evolve to take advantage of new opportunities as they become available, will require careful thought.

#### RUNWAY CAPACITY IMPROVEMENT

Measures to increase runway capacity must address ways to reduce the time interval between aircraft crossing the runway threshold, or to permit more runways to operate simultaneously within the same area. Reduction of separation between aircraft using the same runway can be achieved either by reducing the minimum separation or the variance in the separation.

Minimum separation standards in trail depend on the ability of the surveillance system to detect loss of separation and hazards posed by aircraft wake vortices. Reduction of these standards therefore depends on improved surveillance techniques and ways to detect and avoid wake vortices. Lateral separation standards are likewise affected by the ability to detect deviation from the assigned flight path. Because of the smaller distances involved, controller and pilot reaction time becomes an important consideration. One way to reduce the variance in headways across the threshold is to segregate the traffic by either speed class or severity of wake vortex interaction. Exactly how best to achieve this in a given situation will require careful research.

Reductions in headway will need to be balanced by changes in runway occupancy. Techniques need to be developed to reduce the runway occupancy times for landing and departing aircraft. The present prohibition on simultaneous use of the same runway should be examined. Situations clearly

exist in which appropriate procedures could permit aircraft to safely share a runway. At many airports, intersecting runways offer the potential for increasing capacity, if ways can be found to safely permit operations on both runways at once.

#### Requirements for Improved Operations

In order to be able to operate the airport and terminal airspace system at higher levels of traffic intensity than the current system permits, it will be necessary to improve both the information available to the ATC system and the communications between the control system and the aircraft. In addition to the location of each aircraft within the terminal airspace or airfield system, the control system should have information on the flight crew intentions and the aircraft performance. The intentions are not only necessary to confirm compliance with control instructions in view of the limited time to detect deviations from intended flight path, but also form the basis of the negotiation between the flight crew and the ATC system to arrive at the most acceptable flight profile. With the increased use of flight management systems, enabling aircraft to fly nonstandard flight paths, and the need to take full advantage of aircraft capabilities to enhance capacity, knowledge of the performance characteristics of each aircraft will become critical.

With more complex procedures, tailored to each aircraft, it will be necessary to communicate much more extensive instructions than at present. Data links between the aircraft and the ATC system, such as planned with Mode S radar, will become essential. Research is needed into the future requirements for such links, in terms of message protocols and bandwidth. Another potential communication medium is the airfield lighting system. The use of variable lighting patterns to assist in the guidance of aircraft deserves further exploration. The technology is largely in place and requires no additional equipment on the aircraft.

#### Alternatives to Increase Runway Capacity

While some capacity gains may be achievable through the use of established design measures, significant increases in capacity may require the development of alternative measures not currently considered (Gosling et al., 1981). Airfield design measures might include new designs for high speed exits, permitting aircraft to leave the runway earlier, and the development of high speed entrance taxiways. In order to achieve higher runway use rates, it may be necessary to develop the capability to dynamically reallocate the functions of particular areas of pavement, so that aircraft moving at high speed are segregated from slower moving aircraft and ground vehicles. The ability to provide aircraft with deceleration and exit guidance while on the runway will not only assist in minimizing occupancy time, but will enhance safety by providing flight crews with visual confirmation of their exit path.

Procedural changes worth exploring include the use of multiple runway occupancy, such as permitting an aircraft to land as long as the preceding departure is past the arriving aircraft's exit, and the use of multiple approach and departure paths to a single runway. Since the interarrival times at the runway threshold must be tightly controlled in order to achieve maximum capacity, and these times interact with runway occupancy times of the preceding landing and departing aircraft, it is important that the control of aircraft on

approach is integrated with the control of aircraft on the runway, to produce a coordinated landing and departure sequence.

Where airports can be operated with more than one runway configuration, the selection of the appropriate configuration to maximize the airport capacity under given conditions deserves attention. The runway configuration management system in use at Chicago O'Hare Airport could provide a model for other airports. However, this problem could probably benefit from further study.

#### TERMINAL AIRSPACE

Although the runway is usually the critical component in the system, a number of problems must be addressed in planning the terminal airspace operations.

Current work has established the use of 4-D navigation to sequence arrival flights at the threshold (Tobias et al., 1985). The determination of appropriate flight profiles to accommodate airspace constraints and aircraft performance limitations, while maintaining required separations, is likely to require further research. The impact of variation in aircraft fleet mix on 4-D sequencing must also be considered.

Operations within the terminal airspace will also have to be coordinated with the en-route centers. Development of the appropriate procedures will require research. Flows from several different air routes will have to be merged in the terminal airspace. Some amounts of airborne delay may have to be incorporated into aircraft flight paths, and decisions taken on which aircraft to delay and by how much. Where aircraft are attempting to fly fuel efficient flight profiles, the negotiation of descent profiles will have to involve both the center and the terminal control.

Changing the pattern of runways in use at an airport, in response to changes in wind direction or other causes, can result in significant disruption to the flow of aircraft in the terminal airspace. In the case of runway configuration management, the gains in capacity by the change might be offset by the flow disruption. Developing better techniques to manage these flow transitions is an area that appears to deserve further study.

Finally, the terminal airspace control tasks are currently performed largely without the use of automation. The NASP envisages the development of a number of automated features as part of the AERA software, targeted primarily at en-route control problems (Goldmuntz et al., 1981). Consideration needs to be given to what automation can best assist the terminal airspace controllers.

#### TERMINAL GATES

Although the provision of adequate terminal gate capacity does not present quite the same technical problems as increasing runway capacity or managing the terminal airspace, there are a number of problems that will need attention, and that could benefit from research. At many airports, existing terminal buildings are extremely constrained, and provision of the large amount of space necessary to construct new gates is difficult. Techniques for configuring ramp areas so as to utilize available space in the most effective way would be a useful contribution. At many airports the decision will have to be taken at

some point to abandon the old terminal configuration and completely rebuild, perhaps on a new site. Techniques for deciding the optimum time to make this transition would be useful.

A number of issues arise with day to day station operations that deserve attention, both as they influence the design of terminal buildings and as research issues for improving airport operations. A major concern at the large connecting hubs is the volume of transfer baggage that must be moved in a relatively short time. The ease with which this can be done is clearly influenced by the gate configuration for each airline, and the allocation of flights to gates. Interline transfer baggage is less of a problem, except at large international gateway airports, where baggage must be rechecked and transferred to domestic carriers after clearing customs. The way in which airlines schedule flights not only affects the peaking of traffic at the runway, but also the ground personnel requirements. Schedules that ensure efficient personnel utilization may or may not help reduce runway congestion. This is an area that deserves further study. When aircraft are delayed, this may disrupt the entire connection bank. Flights may have to be rescheduled and aircraft reassigned to flights, in order to get as many aircraft out on time as possible. The later the flight is scheduled in the arrival bank, the more critical the problem. Consideration should be given to measures to expedite the handling of such critical aircraft, as well as optimum ways to reschedule after severe delays.

The provision of sufficient gate capacity should also take into account terminal building functional requirements such as passenger walking distance accessibility of passenger services and concessions, and ground transportation facilities.

## CONCLUSIONS

It appears that runway capacity at the major hub airports is likely to be the critical constraint on the future development of the air transport system. While existing techniques have limited potential for significantly increasing runway capacity, new technologies are becoming available that offer possible solutions. However, in order to develop the necessary procedures and to integrate these new technologies into the airport and terminal airspace operations, a sustained research effort will be needed. This effort will have to be funded at a realistic level, consistent with the scale of the problem being addressed, and will have to address underlying system relationships, as well as the development of end products. The research should be long range in orientation, and care should be taken to ensure that it does not become unduly restricted by preconceived ideas or short term programmatic goals.

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FAA/NASA R&D FOR FUTURE AIRPORT  
AND TERMINAL-AREA OPERATIONS

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INTRODUCTION

I would like to talk today to just one of the elements of our R&D program in the FAA's Advanced Concepts Division of which I am a part. This is a topic we call terminal area ATC automation in the Agency's R,E&D Plan.

Mr. Cirino mentioned at the outset that the NAS plan is the document to which they turn to find out what the FAA is doing. What I am about to talk about is not a part of the NAS plan but is described in the FAA R,E&D Plan which picks up where the NAS plan leaves off. To pick up on Dr. Gosling's last point, there is a need for sustained activity in both research and development of concepts to improve capacity and efficiency of operations of our nation's terminal areas. I would like to go back to an earlier point he made in his