

LINKING EXPERTISE AND
NATURALISTIC DECISION MAKING

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Distributed Cooperative Problem Solving in the Air Traffic Management System

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In the design of complex systems, there is often a tension between a desire to achieve solutions that are globally optimal and the limitations imposed by the cognitive complexity of determining such optimal solutions (Billings, 1997). These limitations can arise for one of two reasons:

1. The individual operators who are trying to make the system function could not deal with the cognitive complexity of the task if they were to fully consider all of the relevant goals and data in arriving at an optimal solution.
2. The designers of technological tools, who intended to make it possible to overcome the cognitive limitations of human operators, are themselves unable to fully model the true complexity of the system.

Because of these two types of limitations, most real system designs rely on simplifications that allow the system to perform well, without trying to achieve optimal solutions. One common approach is to decompose the task of managing the overall system into subtasks, and then assign these subtasks to separate

individuals. The hope is that there is sufficient independence among these subtasks, so that when each subtask alone is performed well, the combined effects will produce acceptable (rather than optimal) levels of performance for the system as a whole. Furthermore, because few systems are actually decomposable into fully independent subtasks, it is also hoped that these individuals will interact with one another as needed when the solutions to their various subtasks in fact interact in significant ways.

These considerations about the design of complex systems are discussed in the context of the Air Traffic Management (ATM) system (Hopkin, 1995; Wickens et al., 1997). Four points are highlighted in these considerations:

1. The traditional design of the ATM system has been highly distributed. Tasks are assigned to different individuals in order to limit the amount of information and knowledge that each individual is expected to access and process directly, thus limiting the cognitive complexity of the task for that individual.
2. This traditional decomposition generally produces acceptable performance in terms of safety and efficiency. However, it occasionally results in safety hazards because the decision maker does not have direct access to all of the important data and knowledge and fails to interact with the person who has access to the data or knowledge. It also routinely results in less than optimal performance in terms of efficiency within the ATM system.
3. Efforts to improve efficiency in order to achieve closer to optimal system performance have focused on changing either the frequency and nature of the interactions among different people, or on changing the locus of control. For this latter solution to be effective, however, such changes in the locus of control (which result in significant changes in the overall task decomposition) need to be accompanied by appropriate changes in direct access to the relevant data and knowledge, or by new patterns of interaction between the decision maker and the people who have the relevant data and knowledge.
4. The ATM system has changed in significant ways over the past few years. By studying this evolution, we gain insights into how different control paradigms influence individual and group performance, especially with regard to the degree of interaction among different individuals when the distribution of knowledge and data does not match the distribution of control. In addition, we begin to identify some of the more detailed design features that influence decision making performance.

AN EXAMPLE OF TASK DECOMPOSITION IN AIR TRAFFIC MANAGEMENT

As a specific example of task decomposition, consider the following setting within the air traffic system. In order to reduce cognitive complexity, the overall task of selecting safe routes of flight and of operating these flights is currently decomposed such that each of the participants (pilots, controllers, dispatchers, and traffic managers) has only partial information. In particular, within the current air traffic management system, tactical decisions are made by flight crews and controllers without always having the information necessary to develop the same big picture about weather system developments available to dispatchers and traffic managers. As an example, in cases involving significant reroutes, the flight crew needs to bring the dispatcher back into the loop to ensure that the big picture has been adequately considered. Although this distribution of information and responsibilities generally affords an efficient operation, it is susceptible to occasional errors due to false assumptions about "what the other guy has already considered" or due to incorrect assessments of whether a particular change in route is "significant."

Details of the Scenario

As an illustration of the impact of this task decomposition, consider an actual incident involving a Boeing 727-200 flying from Dallas/Ft. Worth to Miami. As part of his job, the dispatcher responsible for this aircraft was required to provide the pilot in command with information regarding any hazardous enroute weather. In this case, the dispatcher noted a line of thunderstorms that he felt potentially jeopardized the safety of the flight and issued a reroute to the aircraft, with the captain's concurrence. During this process, the captain was briefed on the situation. That reroute was coordinated with Air Traffic Control (ATC) and approved, but as the flight progressed along its refiled route of flight, the receiving center rejected the reroute and put the airplane back on its originally filed route of flight. The sector controller in that center rejected it because that new route was already congested due to flights from Europe and the East Coast, and because he had no access to data that would have informed him about the weather problems in southern Florida. As a result, the aircraft became trapped south of the line of weather.

More specifically, as the aircraft was going across the Florida panhandle, there was a line of thunderstorms from the Tampa Bay area southeastward down to the Miami/Ft. Lauderdale area. At that point, the dispatcher contacted the captain, briefed him on the enroute weather conditions, and recommended a reroute

taking the aircraft direct to Ormond Beach and then down the east coast of Florida into the Miami airport from the northeast, ahead of the weather. The captain concurred with the reroute and contacted the appropriate Jacksonville Center frequency to coordinate the reroute. The reroute was approved. The aircraft made a turn to the east and was proceeding directly to Ormond Beach on the Florida east coast. At the point where there was a hand-off made from one controlling center sector to the next center, the receiving center sector advised the captain that, due to traffic along the east coast of Florida, they would not be able to accommodate the reroute and that the aircraft would have to return to the originally filed route of flight. The aircraft made a fairly abrupt turn back to the southwest, got offshore along the west coast of Florida and proceeded down toward the Ft. Myers area. Furthermore, the aircraft was slowed to 180 knots due to traffic, increasing fuel burn.

At that time, the line of thunderstorms was sinking to the southeast, moving down toward Miami/Ft. Lauderdale/Sarasota/Ft. Myers. As the aircraft arrived in that vicinity and was preparing to turn to the east for the final to Miami to land to the east, the weather came across the airport and shut down the operation. As a result, the aircraft entered airborne holding and was given "expect further times from ATC" that continued into the future. Thus, the crew was faced with an indefinite situation as to when they would be released to proceed into Miami.

It was not until this point that the captain contacted the aircraft's dispatcher and advised the dispatcher that the reroute the captain and the dispatcher had agreed upon had been refused by an ATC sector, that the aircraft had ended up back on its original filed route of flight, and that they had encountered airborne holding. The dispatcher's attention had been diverted to another situation and he had not noted the ATC-initiated reroute. Thus, at that point the aircraft was holding with thunderstorms between its position and the intended destination.

What complicated this scenario was that Sarasota, Ft. Myers, Ft. Lauderdale, and West Palm Beach, which were all of the other usable alternate airports for this aircraft, were either unusable due to thunderstorms or were now north of the weather as well. The aircraft was basically trapped south of its intended destination and south of its usable alternates. (This aircraft was not authorized to use the Key West airport.) Consequently, the crew was faced with a situation of being very low on fuel with limited options in terms of available diversion airports. The aircraft finally broke through the line of thunderstorms as the weather passed south of Miami and was able to land at Miami. However, they picked up significant turbulence going through the line of weather, producing a very uncomfortable ride for the crew and the passengers as the aircraft passed through severe turbulence.

It is also important to understand that the dispatcher working this particular flight on this day had about 30 other flights that he was responsible for at that time and felt as though this situation had been resolved and had turned his attention to other situations that required his attention.

Important Features Illustrated by the Scenario

This scenario provides an example of one of the ways in which the air traffic management system has been decomposed into subtasks to reduce the cognitive complexity for individuals. This particular scenario also illustrates one potential weakness of such a decomposition: the reliance on individuals to decide appropriately when there is a need for interaction (i.e., when the decomposition is inadequate).

One response to such an incident would be to attempt to improve judgments about when to interact by improved training or more clearly defined procedures. A second would be to maintain the existing task decomposition, but to give everyone better access to critical elements of the bigger picture (such as weather), so that they could better judge when there is a need to interact with the other system operators. Another would be to develop technological support tools such as an "intelligent" alerting system that would inform the dispatcher when a flight has begun to deviate "significantly" from its original route. A fourth would be to try to integrate decision making, abandoning or partially abandoning the task decomposition strategy. All of these approaches have strengths and weaknesses and merit serious consideration for this specific scenario. The remainder of this chapter, however, focuses on the fourth approach and does so in another ATM context concerned with preflight planning and traffic flow management.

DESIGN OF THE AIR TRAFFIC MANAGEMENT SYSTEM

Historically, traffic flow management (TFM) has primarily been a function under the control of the Federal Aviation Agency (FAA), with traffic managers at various facilities making decisions about what routes could be flown by the flights scheduled by the airlines (Odoni, 1987). In recent years, however, there has been an emphasis on giving the airlines greater flexibility, based on the assumption that the airlines have better information about the costs of alternative flight plans and should, therefore, be in a position to make better decisions about the economics of alternative flight plans. In essence, this shift changes the task decomposition as, under such changes, airline dispatchers must consider a much larger set of factors if they are to in fact improve performance. Issues surrounding such a shift are discussed in terms of alternative system architectures for accomplishing it.

Alternative System Architectures

Alternative architectures for the ATM system that change the decomposition of tasks for flight planning can be grouped into three categories (Smith et al., 1997):

1. Management by directive, in which FAA traffic managers simply inform an airline regarding the route that can be flown by a particular flight.
2. Management by permission, in which there is a default flight plan assigned by the FAA, which can be revised if the airline operations center requests an alternative and receives permission from FAA traffic management staff.
3. Management by exception, in which the airline operations center can simply file the flight plan that it desires for a given flight (Sheridan, 1987, 1992). This flight plan is automatically approved, and the route of flight is changed only if a problem is detected while it is enroute.

Over the past several years, the ATM system has been evolving from a system in which management by directive was the predominant form of interaction to a hybrid system including examples of all three forms of interactions.

Control by Permission

The first major change arose in 1992, with a shift in management by directive to management by permission. Specifically, FAA Advisory Circular 90-91 (FAA, 1992) established a formal procedure allowing the airlines to request nonpreferred routes (routes for flights that differed from the FAA assigned preferred routes). Under this procedure, an airline could send a message via teletype to the FAA's Air Traffic Control Systems Command Center (ATCSCC) requesting an alternative route for a particular flight. A specialist at ATCSCC would then evaluate this request, checking with traffic managers at the involved enroute regional air traffic centers and, based on their input, would approve or disapprove the request.

This shift to management by permission gave the airlines a means for improving efficiency, because they had better information for determining the most economical flight plans for their aircraft. It still left the locus of control with the FAA traffic managers, however, as they had to individually approve all requested alternative routes. These approvals were made based on considerations of safety and overall efficiency in traffic flows. Thus, this shift left the basic task decomposition the same, but provided a procedure for increasing the frequency of interactions among traffic managers and dispatchers.

This new paradigm was viewed very positively by both the airlines and the FAA. One airline, for example, reported that in one year, it submitted 15,279 requests for nonpreferred routes and that 75% of these requests were approved. These approvals resulted in an estimated savings of 13,396,510 pounds of fuel. Studies by Smith, et al. (1997) identified a number of factors that appeared to contribute to this success.

Factors Contributing to Success. The first factor concerned matching the locus of control with access to relevant information. The criticism of prior procedures was that, under the management by directive paradigm, FAA traffic managers were making decisions that did not take into consideration the airlines' business concerns. Thus, the claim was that, for any given flight, there could be a number of equally acceptable flight plans from the perspective of safety and overall system efficiency and in such cases the FAA was making the choice without the benefit of any input from the airline about its economic considerations. Under this new paradigm based on management by permission, the ultimate decision was still left up to FAA traffic managers, who had information and experience regarding potential traffic bottlenecks, but it allowed the airlines to indicate their preferences based on economic concerns; safety was ensured while economics were improved.

As with any system architecture, however, supporting arguments based on high-level considerations do not, by themselves, ensure that the architecture will be successful. The details of its implementation are equally important. Three major factors appeared to contribute to the success of this program:

1. Implementation of communication channels that led to the development of a shared understanding of goals, problems, constraints and solutions.
2. The form of the distribution of responsibilities to a number of different individuals.
3. Incorporation of feedback and process control loops.

Regarding the relevance of these hypotheses to naturalistic decision making, the point is twofold. First, an architecture involving control by permission has the potential to ensure that certain important interactions occur without requiring changes in the basic task decomposition or the locus of data and knowledge. Thus, the patterns of behavior during decision making are significantly influenced by a relatively straightforward architectural change. Second, however, is that several other factors need to be considered to make the resulting interactions as efficient and effective as possible.

Thus, in terms of the earlier discussion regarding task decomposition, this procedure maintained the basic decomposition that had previously been used, in the sense that both the FAA traffic managers and airline dispatchers still had to analyze alternative routes from their own perspectives. The routine interactions, however, gave both groups a broader understanding of the factors considered by the other group, resulting in more effective and efficient interactions when they were likely to be productive (i.e., when the task decomposition was inadequate, and there was a need for interactions between both groups in order to determine the best solution).

Limitations of Control by Permission. The primary weakness of this paradigm was that it was manpower intensive (requiring extra staffing to support the additional interactions) and was thought by the airlines to, at times, be excessively conservative in terms of the approval of requests for alternative routes. As a result, the system evolved further in 1995 to give the airlines additional flexibility using a different "architecture."

Control by Exception

Although the use of the "control by permission" architecture was viewed as a significant improvement, its perceived limitations were sufficient to result in a followup program based on "control by exception." This new program, known as the expanded National Route Program (FAA, 1995), allowed the airlines, subject to certain constraints, to simply file the routes that they preferred for particular flights. FAA traffic managers would then monitor conditions, watching for situations (such as severe weather) where the program had to be canceled temporarily for particular portions of the country. Tactical changes by FAA air traffic controllers (as well as by airline pilots and dispatchers with the concurrence of the responsible air traffic controllers) could also be initiated after the flight was enroute. Unlike the earlier shift to control by permission, this architectural change significantly altered the historical task decomposition, requiring airline dispatchers, if they wanted to be fully effective, to now consider factors (such as the prediction of air traffic bottlenecks) that in the past had been handled largely by FAA traffic managers.

To evaluate the impact of this architectural change, two studies were conducted dealing with the impact of the expanded National Route Program (NRP) on fuel consumption. The motivation for this study came from two sources. First, dispatchers at a number of airlines as well as traffic managers at enroute air traffic control centers provided numerous examples of how flights filed under the NRP were sometimes given significant amendments and suggested that some of these changes occurred on a regular basis. In at least some cases, the changes were clearly initiated by the ATC system to deal with traffic congestion. Along these lines, dispatchers made comments such as:

Under the expanded NRP, it's like shooting ducks in the dark.

The problem with the expanded NRP is that there's no feedback. Nobody's getting smarter. Someone has to be responsible for identifying and communicating constraints and bottlenecks.

It used to be the weather that was the biggest source of uncertainty. Now it's the air traffic system.

In short, the dispatchers appeared to be indicating that the shift in their tasks gave them more flexibility but did not give them the information and tools necessary to integrate considerations of air traffic (one of the major factors that used to be handled primarily by the FAA traffic managers) into their decision making.

As a specific example, one dispatcher indicated that NRP flights from Washington National to Cincinnati frequently have a problem because of the strategy used by ATC to deal with crossing traffic:

It happens to us all the time. We file the flights at altitudes of 35,000 or 39,000 feet and they're held at 23,000, 25,000 and 27,000 feet. They don't tell us ahead of time that it's going to happen.

A second example of how traffic bottlenecks can affect NRP flights was provided by a traffic manager:

Quite often ... 8-10 extra aircraft are on this northern route to DFW [from Southern California to Dallas flying north of White Sands into the northwest cornerpost at the Dallas-Fort Worth airport] during the noon arrival rush [noon local time]. This causes a sector saturation problem in ZFW Sectors 93 and 47 [two Dallas-Fort Worth (ZFW) air traffic control sectors]. To relieve this volume problem, the ZFW TMU [Traffic Management Unit] moves 5 aircraft back to the south route [south of White Sands] via CME.TQA.AQN.DFW [a sequence of navigational fixes into the southwest cornerpost of the Dallas-Fort Worth airport]. This longer route of flight, plus the fact that DFW is in a south flow (meaning these flights will spend more time flying below 10,000 feet), will reduce fuel savings or negate them altogether for this bank of flights.

Thus, anecdotal evidence suggested that traffic bottlenecks were arising that influenced the efficiency of NRP flights and raised questions about the effectiveness of this new decomposition of tasks. To gain further insights into this concern, two followup studies were conducted. These are described next.

Study 1: Analysis of Predicted Versus Actual Fuel Consumption

To look for evidence of such inefficiencies, we collected data from a major airline on all of their flights filed over a 5-month period. These data were used to compare predicted fuel consumption on NRP routes with both predicted fuel consumption on FAA preferred routes and with actual fuel consumption. In the following discussion, a *flight* is defined to be a particular combination of an origin, destination, Ptime (scheduled departure time), and equipment type. Thus, a given flight could have a new instance filed each day. Predicted and actual fuel consumptions were from wheels-up to wheels-down.

Predicted fuel consumptions were first analyzed, comparing performances on FAA preferred routes with the filed NRP routes. This airline filed 21,334 flight instances under the NRP during this time period. The average predicted fuel savings per day during this time period ranged from 2.3% to 6.0%. The total predicted savings was 17,723,329 pounds of fuel.

Comparison of Predicted Versus Actual Fuel Consumption. Given the anecdotal evidence outlined earlier, however, it seems possible that these predictions overestimate actual fuel savings for some flights, because the computer's predictions do not take into account the new reroutings that might occur as a result of filing an NRP route and then encountering a traffic bottleneck while enroute. Consequently, we also compared predicted with actual fuel consumption for these flights.

To ensure adequate statistical power, only flights with at least 20 instances were considered. There were 267 such flights. A statistical analysis indicated that 94, or 35%, of these 267 flights routinely burned more fuel than predicted ($p < .05$). Of these 94 flights, 21% routinely burned more extra fuel than was supposed to be saved by flying the NRP route instead of the FAA preferred route. As an example, the flight from Dallas-Fort Worth to San Diego scheduled to depart at 1645 Universal Coordinated Time on average burned 1,013 pounds of fuel more than predicted for the FAA preferred route. That flight, which was supposed to save 759 pounds of fuel compared to the FAA preferred route (a predicted 4% savings), actually burned 254 pounds more than the prediction for the FAA preferred route (a 1.3% loss).

Thus, these data indicate that there was some sort of a problem associated with 35% of the flights filed by this airline under the NRP during this time period. One possibility would be an underlying inaccuracy in the prediction model for one or more of these flights, over and above any new problems introduced by use of the expanded NRP. If, however, we assume that the prediction model provides unbiased estimates for the FAA preferred route (and assume no new inefficiencies are introduced for the FAA preferred routes by the use of the expanded NRP), then these data indicate that the actual benefits in terms of fuel consumption from the use of the NRP are less than predicted.

Study 2: A Detailed Observational Study of Los Angeles-Dallas-Forth Worth Flights

These data also indicated that the city pair that most often had flights with regular problems was Los Angeles to Dallas-Forth Worth (LAX-DFW). Seventeen of those flights routinely burned more fuel than predicted. Therefore, we decided to study this route in detail in order to collect more detailed data on the nature of the problems with NRP flights for this city pair and to better quantify the influence of these problems.

Methods. Four students from the Aviation Department at Ohio University collected data from June 22, 1996 to August 23, 1996 on the performances of flights from LAX-DFW. Flights with five different scheduled departure times (Ptimes) were studied (1400, 1415, 1445, 1515, and 1810 Universal Coordinated Time). The students collected data on predicted and actual fuel consumptions and observed each flight instance on an aircraft situation display that showed filed and actual routes in order to record any flight amendments.

Results. The resulting observations quickly made it clear that the underlying problem was the rerouting described earlier. Very briefly, what happens is this:

1. A flight instance is filed under the expanded NRP along a route north of White Sands (special use airspace) to the northwest cornerpost at DFW.
2. While that flight is enroute, the ATM system decides that there is likely to be a sector saturation problem in the Turkey or Falls high sectors when the flight reaches that point as it approaches the northwest cornerpost into DFW.
3. To deal with that problem, the flight or flights with the most southerly routes that are flying to the northwest cornerpost are rerouted south of White Sands to the FAA preferred route so that they will approach DFW via the southwest cornerpost.

Table 22.1 indicates the frequency with which the cornerpost swap occurred for the different flights that we observed. (Keep in mind that this swap usually occurs before White Sands, not as the flights are approaching the airport.) The results indicate that the flights that arrive at DFW for the noon rush (flights that are arriving into DFW around noon local time and that have scheduled departure times or Ptimes of 1400 and 1415 Universal Coordinated Time) are particularly affected. During that time period, 33% to 39% of the flights fell into that category and were rerouted south of White Sands to the FAA preferred route.

Table 22.2 indicates the impact of this rerouting on overall savings for the NRP flights filed at particular Ptimes for those instances where an NRP flight was actually rerouted south of White Sands. All of these flights, on average, burned more fuel than was predicted if they had been filed on the FAA preferred route. On average, for example, it cost an additional 1,502 pounds of fuel each time the flight at 1400 Universal Coordinated Time was rerouted to the southwest cornerpost. A statistical test comparing actual with predicted fuels consumptions for these flights was significant ($p < .05$) for the Ptimes of 1400, 1445, and 1810.

TABLE 22.1
Percentage of Flights Flying the FAA Preferred Route (Pref Route)
and NRP Routes with or without Cornerpost Swaps

Prime	Equipment Number		Pref Route	Route Flown	
	Type	Observed		NRP-No Swap	NRP-Swap
1400	DC10	41	44%	17%	39%
1415	B767	42	48%	19%	33%
1445	MD80	36	50%	44%	6%
1515	MD80	41	51%	39%	10%
1810	DC10	29	38%	52%	10%

Note. Prime is Universal Coordinated Time.

TABLE 22.2
Expected versus Actual Fuel Savings for Flights that were Rerouted from the
Northwest Cornerpost to the Southwest Cornerpost

Prime	Equipment Number		Observed	Expected Change	Actual Change
	Type	Type			
1400	DC10	16	-3.5%	+0.4%	
1415	B767	14	-4.5%	+0.3%	
1445	MD80	2	-3.4%	+1.9%	
1515	MD80	4	-2.3%	+0.1%	
1810	DC10	3	-3.0%	+2.7%	

Note. Only those flights that were rerouted in this manner are included in this table. Prime is Universal Coordinated Time. Savings are the percentage reduction or increase relative to the predicted fuel consumption for the FAA preferred route that day.

OVERALL CONCLUSIONS

As described earlier, the ATM system has gone through two major evolutions in terms of the paradigm for controlling preflight planning. Initially, the shift was to a control by permission paradigm, where FAA traffic managers maintained control of the actual decision to approve requests from the airlines to deviate from the FAA preferred route. This procedure was then further modified to a control by exception paradigm, in which the airlines were allowed to file their desired flight plans without permission from FAA traffic managers but these plans were then altered tactically by air traffic controllers (as well as pilots and dispatchers) only as needed

while the flight was enroute. As documented in this study, both of these alternatives had a sizable influence on the patterns of decision making and performance.

The control by permission paradigm is particularly interesting because of two factors:

1. It left the basic task decomposition the same, except for providing an impetus to increase interactions between airline dispatchers and FAA traffic managers in order to consider airline requests for individual flights to fly something other than the default (FAA preferred) routes. One implication of this is that there was no need to change the distribution of data and knowledge, because the party with control (the FAA traffic manager) already had the data and knowledge necessary to decide whether a given request for a different route was acceptable from an air traffic perspective, whereas the party requesting permission (the airline dispatcher) already had the data and knowledge to identify route changes that were preferable from an airline business perspective. Thus, without having to shift the locus of data and knowledge, significant changes in decision making were induced through the introduction of a new pattern of interactions.
2. A caution regarding this paradigm, however, was that even though the shift to control by permission was viewed as a significant improvement, it was ultimately replaced with another paradigm. The motivation for this appeared to be a belief that there remained a sort of anchoring or inertial effect when the locus of control was left the same (with the FAA traffic managers). Essentially, this belief was that, for one of several possible reasons (habit, workload, comfort, level of understanding, etc.), traffic managers tended to be more conservative than necessary and that, because they had the final say, airline requested routes were sometimes denied unnecessarily.

In contrast, implementation of the control by exception paradigm shifted the locus of control from traffic managers to airline dispatchers and clearly served to overcome some of this anchoring or bias toward the traditional FAA preferred routes that appeared to continue under the control by permission paradigm. However, use of the control by exception paradigm lead to additional considerations:

1. Even though the dispatchers now had more control to determine the routes to be filed, they were not provided with direct access to the data and knowledge necessary to evaluate alternative routes in terms of the effect of potential air traffic bottlenecks.
2. Because there was no longer a mechanism requiring routine interactions with traffic managers to identify and deal with such problems, the patterns of communication originally induced by the control by permission paradigm were now greatly reduced.

Thus, as a result of these two factors, dispatchers frequently were filing routes that did not achieve the desired improvement in efficiency.

Overall Implications

The case studies reviewed in this chapter serve to illustrate several points:

1. One classic strategy for reducing cognitive complexity in the ATM system has been to decompose the system into subtasks and to assign these tasks to different individuals. Then, in those circumstances where the assumption of independence among these subtasks is inadequate, it is necessary for the responsible individuals to interact with each other.
2. A drawback of such a decomposition strategy is that the responsible individuals may not recognize the need for such interaction. This can result in problems from either a safety or efficiency standpoint, as illustrated by the example of the flight from Dallas to Miami.
3. Another drawback is that, because the assumption of independence made during the task decomposition is at best an approximation and because the "as required" interactions of individuals to deal with inadequacies in this task decomposition typically only partially compensate for these approximations, although overall system performance may be good, it is not likely to achieve its theoretical optimum.
4. Because of these two drawbacks, a variety of alternative architectures or task decompositions are now being explored within the ATM system. Two such architectures, control by permission and control by exception, are illustrated in the context of preflight planning. The first architecture, control by permission, attempts to improve performance by maintaining the traditional task decomposition, but by improving the interactions between traffic managers and dispatchers to cope with the limitations of the decomposition. The second architecture, control by exception, represents a major change in task decompositions.
5. Studies of the use of the control by exception architecture provide cautions about the need to consider fully the impact of alternative task decompositions on information requirements and on the cognitive complexity of the newly defined tasks. These studies caution that, without such considerations, the expected move toward a more optimum level of performance may in fact not be fully achieved.

In short, these studies on the evolution of the ATM system help demonstrate how relatively high-level decisions regarding task decomposition and the locus of control can impact patterns of interaction and decision making in very profound ways.

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