Max-Planck-Institut
für Gesellschaftsforschung
Köln

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The Development of Large Technical Systems

Campus Verlag · Frankfurt am Main
Westview Press · Boulder, Colorado

blished in 1988 in the United States by WESTVIEW PRESS
derick A. Praeger, Publisher
00 Central Avenue
ulder, Colorado 80301

3N 3-593-34032-1 Campus Verlag
3N 0-8133-0839-9 Westview Press
CCard Number 88-27708

rary of Congress Cataloging-in-Publication Data

e Development of large technical systems / edited by Renate Mayntz
l Thomas Hughes.
. cm. – (Publications of the Max Planck Institute for
cial Research, Cologne, West Germany)
SBN 0-8133-0839-9
. Technology-United States-History. 2. Technology-France-
tory. 3. Technology-Germany-History. I. Mayntz, Renate.
Hughes, Thomas. III. Series.
1.D49 1988
)–dc19

P-Titelaufnahme der Deutschen Bibliothek

development of large technical systems / [Max-Planck-
. für Gesellschaftsforschung, Köln]. Renate Mayntz;
omas P. Hughes (ed.). – Frankfurt am Main : Campus Verlag;
ılder, Colorado : Westview Press, 1988
SBN 3-593-34032-1 (Campus) brosch.
SBN 0-8133-0839-9 (Westview Press) brosch.
: Mayntz, Renate [Hrsg.]; Max-Planck-Institut für
Gesellschaftsforschung <Köln>

CONTENTS

CHAPTER 8

THE UNITED STATES AIR TRAFFIC SYSTEM: INCREASING RELIABILITY IN THE MIDST OF RAPID GROWTH[1]

Todd R. La Porte

1 Introduction

United States air traffic system (USATS) providing both air navigation and traffic separation became a nationwide governmental service in 1936 after two decades of expanding private and public activity. Within fifty years, this system has grown into an extraordinary matrix of 600 airports and 300,000 miles of airways in continuous flux and motion as millions of people and mountains of freight (and air mail) are shepherded throughout the U.S.. It has been a remarkable development of a very large-scale, publicly owned technical system with quite different properties than the other systems discussed in this book. It is at once, more far-flung and complex, and less integrated and dependent upon technologies as a means of coordination. It has a different relationship to the national state. After a brief review of the dimensions of the USATS, we turn to these properties, suggest their importance for more general understanding of large-scale technical systems, and go into more detail in describing the extraordinary development of the USATS.

The initial stimulus was transporting mail by air. Both early airmail and airways services were managed by the U.S. Post Office Department until 1925, when private contractors took over the mail services. Air mail flights had expanded from the first regional (daylight) links in 1918 between New York and Washington, D.C., to reach across the continent with the development of night-flying navigation aids.[2] Rotating beacon lights set up every 10 miles guided low-flying pilots over 2,000 miles of lighted airways between New York; Dayton, Ohio; Chicago; Cheyenne, Wyoming; to San Francisco (with a spur to Los Angeles). Coast-to-coast runs took 34 hrs. 20 min. westward, and 29 hrs. 15

min. eastward in clear weather, with airplanes travelling at an average air speed of 100 mph. In the first months of service in 1918, 66,555 lbs. (about 33 tons) of mail were flown at an average speed of 72.6 miles per hour. By 1925, there were 96 planes in service. Regular passenger travel also was begun in 1925 in the eastern United States and by 1930 the five major airlines had carried about 400,000 passengers.[3] By 1927, this growing airways system was handed over to the Department of Commerce.

Full use of airplane capabilities awaited the technical developments necessary to deal with blinding weather, the ubiquitous enemy of pilots. By 1929, the accumulated inventions of the artificial horizon, directional (heading) gyro, and improved altimeter in the cockpit and ground based radio navigation ranges combined to provide the instruments necessary to maintain aircraft altitude orientation and navigation information while "flying blind" in dense clouds. Insuring the capability for "all-weather" flying and navigation through increasingly accurate instrumentation and an expanding network of ground based navigation and communication capabilities continues to be a priority in the Air Traffic Control (ATC) system.

Early institutional developments set much of the basic pattern that still persists.[4] Government subsidies of air mail contracts in the late 1920s provided the infant industry a stable market and prompted techniques that became the basis for airline operations. They also laid the foundation for the present Federal role in providing navigable air routes and other air traffic services. With considerable encouragement from the aviation industry, the Federal government reluctantly accepted responsibility for licensing pilots, inspecting aircraft and supervising the use of airfields and navigation safety.

Due in large part to the controversy surrounding the case of General Billy Mitchell and the use of air power for military purposes and the work of the President's Aircraft Board (1925), the military was separated from civil aviation with the establishment of the Aeronautics Branch, (to become the Bureau of Air Commerce in 1934) within the Department of Commerce.[5] In 1940, experimenting with various regulatory and administrative arrangements, President Roosevelt re-organized the Civil Aeronautics Authority. Economic regulatory functions were placed in a new Civil Aeronautics Board. Navigation and airways management functions remained under the Civil Aeronautics Administration.

By 1940, an embryonic operational air traffic management system was nearly in place and its essential, persisting dynamics established. Several communications and navigation aid innovations had been deployed in the mid-1930s. Twelve airway traffic control centers were spread round the country and airport and airway traffic procedures were standardized.

Finally, an important - political - element in air traffic system development emerged in response to the hazards of air flight. The hazards were made very clear in 1935 when Senator Bronson Cutting was killed in a highly publicized crash. Both the obvious benefit - and threat - to individual leaders became vividly evident. This event focused Congressional attention on the Air Traffic Control System and greatly accelerated air navigation modernization programs. One could describe the repeated pattern of Congressional alarm and complacency as a stimulus/response.

The present system is far-flung, the activities within it intense: thousands of aircraft depart and land at peak periods in the mornings and afternoons in the daily ebb and flow of traffic. Annual traffic in 1980 was over *47 million* hours of commercial and private aircraft flight time, *380 million* passenger enplanements, and *200 billion* revenue passenger miles.[6] Two tiers of airways separate the high flying jets from slower propeller driven craft. High altitude airways are used by a mix of civilian and military airplanes travelling at over half the speed of sound (about 6-7 miles a minute). High flying aircraft are guided through their slower, lower and more numerous brethren to airports with runways over a mile and a half long. Any aircraft above 18,000 ft. must be logged-in, visible on an air control radar screen, and in direct radio communication with an air traffic control center.

The air traffic system is based as much on the cooperation of large cadres of pilots, air controllers, and airways facilities providers as on the array of sophisticated electronic, communications and computer technologies they operate. Its overall performance is remarkable: in 1980, U.S. air traffic controllers handled an aircraft across an airspace *73 million times* with no mid-air collisions. (See Table 1: Elements of USATS and Changes in Scale.)

The system's growth has been phenomenal; its record of safety, astonishing. It affords safe passage at any hour, in almost any weather - usually to any airman who is qualified to seek it. It is a system that spans the globe, and reaches to heights where the curve of the earth is visible. What has been the path of its development; the princi-

Table 1: Elements of Air Traffic System and Changes of Scale: 1940-1985

	1940	1980	[1986]
Airports:			
(paved, lighted)	776	5,830	6,720
Aircraft:			
Prop	--	238,160	246,540
Jet	--	5,869	8,174
Air travel (in 1000 hours):			
Domestic Air Carriers	710	6,250	7,360
General Aviation	3,200	41,000	34,063
(Revenue Passenger Miles in Millions)	1,050	200,000	270,100
Air traffic control:			
Airway miles (1,000s)	32k	296k	325k
Nav. aids (all types)	340	2,090	2,261
Landing aids (all types)	--	988	1,166
Facilities (terminal/route)	11	527	525
FAA employees (1,000s)	5k	55k	47k
Aircraft Handled per yr (in 1,000s)	(1945)		
Air Carriers	2,610	23,600	26,373
Air Taxi	--	7,230	11,794
Gen. Aviation	410	36,720	30,523
Military	2,610	5,990	6,328
Total	5,630	73,540	75,020
Safety Record:			
Air Carriers (Dom. Ops.)			
Accid. per 100K hrs	4.2	0.22	0.22
Fatal Accidents	3	0	4
Fatalities	45	0	197
Fatal accid. per 100K hrs	0.42	0	0.05
General Aviation			
Accid. per 100K hrs	108.4	9.2	8.6
Fatal Accidents	232	618	490
Fatalities	359	1,239	937
Fatal accid. per 100K hrs	7.2	1.7	1.53

ples that have informed it? Are there lessons to be learned from its evolution that alert us to the deeper dynamics of large technical systems?

2 Conceptual perspectives

In this chapter, the United States' huge air transportation system is viewed as a complex socio-technical system of moderately linked organizations shaped by the country's political culture. The system's rapid growth has resulted from a mix of public and private interests facilitating financial, operational and technological advances. The outcome is a complex, quasi-formal mix of private interests and firms and several government agencies. It is a large, highly integrated socio-technical system with essentially no competitors.

A full discussion of the entire U.S. air transportation system is well beyond the scope of what is possible here. It would include attention to the technical development of a growing variety of airplanes, airport construction (heavily subsidized by the Federal government), and the role of the U.S. military in the development of the communication and coordination infrastructure. It would attend to the politics and growth of popular non-commercial flying (so-called general aviation), as well as government regulation of aircraft structures and pilot performance and safety.[7]

Each of these components is itself complex and large-scale. Each is linked to important segments of American society: networks of technical elites, operational managers, industrial and governmental organizations and legislative interests. Together, these actors and organizations comprise a public/private sector of critical importance to the economy, national security and social life of the nation.

Our attention centers on "United States Air Traffic System" (USATS). It is a web of technologies and institutional relationships linking the components of the larger U.S. air transportation system through continuous coordination of aircraft. The system's primary institutional embodiment is the Federal Aviation Administration (the FAA) and its predecessor agencies.[8] Secondary notice is taken of the air carriers and other "users" of the system.

The USATS, unlike EUROCONTROL its younger and much smaller brother in western Europe, is predominantly funded by resources from the general tax fund.[9] Conceptions of economic development do not adequately explain USATS development. Instead, I draw, in part, from developmental concepts as heuristic metaphor, and, in part, from the literature of organizational theory. Our purpose: to understand the development of an organization that manages a growing volume and complex mix of traffic with increasing scope, safety and reliability.

The time frame of this review is limited, beginning with the early days of the system in the 1940s and ending in 1980, just before its third major institutional crisis - the tumultuous strike of the Professional Air Traffic Controllers Organization (PATCO).[10] This strike, its aftermath in operational travail, and the recent problems of the FAA (brought on by a combination of the deregulation of air transport and a controller cadre working continually at or near full capacity) are fascinating in their own right. Understanding this crisis, however, requires a good bit more than the story discussed below.

Parts of this story have been treated in institutional histories of the Federal Aviation Administration (FAA) and its predecessor agencies,[11] in descriptions of the technical systems planned by engineering groups to carry expected loads,[12] and in evaluations of FAA operations.[13] All of this literature speaks to those who already know a good deal about the technical and operational aspects of national air traffic systems. None provide a perspective which can directly assist us in teasing out insights into the development of the air traffic system as a social system. A conceptual frame is needed which brings the technical languages of machines, structures and operations closer to the languages of social science and social history.[14]

An integrating frame

A major step toward integrating technical and social science perspectives can be taken by conceiving of technical systems as social organization. In this view, the technical design and operational imperatives become guides to operator and managerial behavior.[15] From a social science (or public policy) view, unless a technology becomes widely spread (or is likely to become so) it is a trivial activity. Widespread distribution or deployment of a technology necessarily requires some form of large-scale social organization. It may be decentralized

as in the manufacture and distribution of personal computers. It may be physically and organizationally widespread and highly integrated like the distribution of electrical energy through large regional, national or even multi-national grids.

In this view, the techno-organization animates or gives social expression to technical possibilities. This perspective challenges us to examine the properties of technical designs and engineering systems in terms of their organizational requirements and imperatives. It leads us to explore the relationship between the designers' views of operational necessities and the implications of implemented designs for the behavior of operators who man the system.

Conceiving of technical systems in this way enables us to use organization theory to understand the social dynamics of techno-organizational systems, and the patterns of adaptation they exhibit in different situations or environments.[16] A techno-organizational system, then, is shaped, internally, by the social requirements and social properties of technical operations inherent in its engineering designs and, externally, by cross-cutting pressures from its "host society."

When we conceive of the USATS in this way and compare it to the other LTSs under discussion in this volume (telephone, railroads, electrical power), important similarities and differences are evident. These are outlined schematically in Table 2. The similarities are reasonably obvious and we merely list them. The differences point to several important dimensions that would be useful for more general comparisons of LTSs.

Functionally, the USATS is a complex "sub-system" of the larger "whole system" of the U.S. air transportation industry. It is a lesser included, crucial element, in air transport operations. It is also much less fully integrated with its system neighbors than the elements of other systems discussed in this book. Put another way, the "hold" over USATS by other sub-components is a good deal less tight than that evident among the components in European or U.S. rail, electrical power, or telephone systems. It is less tightly coupled, physically, technically, and administratively to its system symbionts. USATS has experienced many of the same dynamics in its development from a small regional to a national network, as our European comparison systems, although changes have occurred more quickly in the U.S.. The logic of national benefit and integrated technical scope have been more immediately compelling. At the same time, the aviation technologies of flight and coordination are less integrated with each other than we see in our comparison systems.

Table 2: Similarities and Differences Between Air Traffic Systems and Other Large-Scale Technical Systems

1. Similarities (parallel components and connectors)		
Central Input Facilities (Initiating activity)		
Airports		Rail heads and roundhouses Power generators Phone exchanges
Network Connectors and Control		
Air Traffic Control		Rail beds and traffic control Transmission networks and Switching centers Phone networks and Exchange/control systems
Network Users		
Users' aircraft (Commercial, General Aviation, Military)		Rail cars Electricity Telephone messages, Data transmission
2. Differences (ATS vs. Other LTSs)		
System level: Sub-system	vs.	Whole systems
Rate of National Development: Relatively very rapid	vs.	Sustained regional development
Degree of Technical Integration: Relatively disjointed	vs.	Compact and tightly coupled
Degree of Personnel Integration: Full operator involvement	vs.	Operator as machine monitor

Airplanes and pilots can operate with more autonomy than trains, telephone services and electrical power systems. The connective networks are much less dominated by physical objects - rails, wires and power grids.

Finally, an air traffic (sub)system is largely a mental rather than a physical construct. It has no visible, concrete supporting connectors. The system must be "seen in the head," a mental construct recognized by thousands of people, (controllers, pilots, facilities managers) in order for "it" to be operative. U.S. Air Traffic Control (ATC), the operator/controller of the USATS, is the arbiter of the mental maps and procedural agreements guiding the behavior of its members. These are quite detailed, with many critical aspects, and must be known and followed by many, many users in order for the system to work highly effectively and reliably. This aspect is much less evident for telephones, electrical circuits, or railroad systems.

For the comparative objectives of this volume, it is important to keep these characteristics in mind as we describe some of the salient aspects of USATS development.

3 The development of USATS: External and internal guiding dynamics

The USATS has had an almost unbroken path of vigorous expansion. Such a pattern requires, at least, a high degree of agreement on system purposes and functions. Throughout its history, the USATS has been the object of an extraordinarily high degree of consensus about its mission. All of the major actors within and outside of the system have agreed that:

- Flying is intrinsically valued and air travel produces a major social benefit.
- All those who wish (and can afford) to fly should have the technical and operational means to do so.
- Due to increased demand for flight, increased technical capacities for aircraft, airports and coordination of aircraft aloft are required; It is the responsibility of the Federal Government to assist this development.

There has been an underlying political agreement that access to air travel via either private means or commercial carriers is very nearly a public right.[17] (This has only recently been questioned.)

The result of this consensus has been a readiness, if not always an ability, to respond favorably to proposals for increased resources for development. Indeed, during the time of our interest, the U.S. Congress had never reduced the amount of money requested by the FAA in support of their air traffic control function.[18] Favorable treatment depended on the degree to which needs could be established and programs justified on the basis of meeting operational criteria. These criteria set the framework for the logic of development, and shaped the character and intensity of energies propelling organizational growth.

External demands from the host society have been constant, if potentially contradictory. The public (and especially its Congressional leaders) demands a system which:

- Is always safe;
- Carries anyone, anywhere, anytime (and is always safe);
- Enables private carriers to make a reasonable profit (while always being safe);
- Requires only modest coordination expenses of carriers, and the flying public. (Secondarily, keep costs for governmental administration moderate in terms of the level of safety and ease of traffic movement provided.)

From the earliest days of air travel in the U.S., there has been a strong emphasis on reducing the risk of operating an inherently hazardous technology. The economic success of air travel depends, in part, on the public's perception that using the service "can be habit-forming," i.e., one can do it time and again and survive. It is an activity of special utility to busy elites. Some of these elites are U.S. legislators whose political success is predicated on being able both to attend to the nation's business in Washington *and* maintain contacts with home constituencies often many hundreds (sometimes thousands) of miles from the capitol. Many of these legislators take an active interest in the quality of air traffic management, especially as it pertains to the movements in and out of one of the two airports the FAA had managed directly - National Airport across the Potomac River from Capitol Hill. (The other FAA airport - Dulles International Airport - is also in the Washington area.) One of the peculiar properties of the

U.S. air traffic system is the degree to which its performance is visible to those who have a direct influence on its funding and regulation.

The twin pressures from the travelling public and elites for extraordinarily reliable and safe performance resulted in a system - one of several large technical systems in the U.S. - that has attempted to achieve failure-free operations. That is, the goal of failure-free performance is a central objective of everyone in the system. This drive to achieve very high levels of operational reliability and the demonstrated effectiveness in nearly reaching these goals year after year qualifies the system as a "high reliability" organization.[19] It is a quality that has had an overwhelming impact on the character and shape of the system's evolution.

Technical systems, then, are initially shaped by the operating requirements and social properties of technical operations that are inherent in its technical design. In the operation of the air traffic system, these imperatives were (and remain):

- *The Technical/Operational imperatives* to provide accurate, unequivocal information about location and intention of every aircraft; procedures which eliminate or drastically reduce the likelihood of disoriented aircraft or unexpected convergence of aircraft aloft, and assure timely guidance information to aircraft operators so that no aircraft "loses separation" from another or has a near collision or, most especially, a mid-air collision. The operative goal is to avoid "loss of separation," i.e., to allow two aircraft to come closer than 5 miles apart (and 1,000 ft. in vertical separation.) This is an absolute criterion for controller performance. If a controller suffers a moderate loss of separation between two aircraft s/he is working *three times during their whole career,* they are discharged.

- *The Technical/Managerial imperatives* to expand an integrated network throughout the nation and strive for optimum internal activity, interaction, and density of flow. The result was/is efforts to "pack the system," specifically, to press for headway between aircraft just above legal separation limits - now 5 miles at altitude, and 3 miles near airports under visual flight rules (VFR).

This combination of "imperatives" leads to a fundamental and abiding tension between safety and reliability on the one hand, and efficiency, on the other. In operational terms, tensions are between those who directly benefit from perceptions of safe systems - commercial pilots, air traffic controllers, Congress (and passengers) - and those who must pay for it - air carriers, general aviation pilots, and the administering agency, its political/budgetary overseers. Users press for the resources and regulations necessary for totally safe commercial flying conditions; payees worry that the technical and regulatory safety and capacity requirements are more costly and constraining than necessary to keep air traffic moving economically and safely.[20] This has frequently pitted the following pairs against each other.

Invest in the system	*vs.*	*Avoid overinvestment*
Airline Pilots Associations		Airline management, and General Aviation Groups
Flying Public		Taxpayers Groups
Air Controllers Associations		Agency Management
Congress (and later, the National Transportation Safety Board)		Executive Office, esp. the Office of Management and Budget

This is a rich stew of advocates and watchdogs. It is fruitful ground for conflict over means and has the potential for exploitation. Much of the development story of U.S. Air Traffic System reflects such dynamics.

4 The development of USATS: Growth and consolidation

The USATS' maturation has been characterized by strong technical advocacy, institutional turbulence, extraordinary growth and astonishing reliability. The central developmental dynamics swirl around the need to manage a growing volume of complex air traffic while anticipating and implementing the technical transformations necessary to keep safely ahead of demand for air traffic services. Operational requirements consist of maintaining a cadre of dedicated air controllers and airway facilities employees who give social animation to the technical systems

of communications, electronics and procedures. Technical planning and development requirements call for advanced engineering, solutions to demanding (and interesting) technical problems and the deployment of costly new systems likely to change the working conditions of the operator cadre (and alter their relationships with pilots).

Early FAA leadership was in full accord with both Congressional and industrial leaders: increase the use of air transport (rail transport was the implicit comparison).[21] There was a vigorous program of airport construction and improvement, and, in the pre-war late 1930s, a sense of urgency and then action to promote the growth of aviation infrastructure in preparation for hostilities. Early technical developments of air-to-ground communication, low frequency radio ranges and standardization of procedures for flying by instrument flying rules (IFR) had improved the capacity to identify and locate precisely the flight path of an aircraft. Controllers were trained to use coordination procedures and "flight strips", manually enter a paper strip for each aircraft aloft, then track the aircraft across airways, routing it in place in the sequence of other aircraft before and after it. These capacities and procedures improved service and allowed effective coordination among aircraft separated by a minimum of 10 minutes or 10 miles headway separation. The system - in the midst of its first major technological phase - was established and "in equilibrium" just prior to WW II.

The war brought substantial increases in traffic, technical developments and institutional challenges that set the stage for the FAA's first crisis. The character of the first crisis typifies subsequent problems and developmental dynamics. FAA and military responses to national defense requirements resulted in rapid expansion of communication service networks within the U.S., the deployment of FAA personnel to operate airport air traffic control towers to facilitate defense activities, and the establishment of provisional rules of air navigation. Military needs overwhelmed all others and the FAA functioned in large part as a civilian adjunct to military aviation and defense requirements.

During the war, military aviation developed new air navigation and air traffic technologies complementary to those of the civil aviation system. Military systems advanced beyond those employed for civil aviation, especially with the development of radar and its capability of "seeing" aircraft many miles from an airfield. Military commanders became de facto managers over many in the civilian controller cadre.

In 1946, immediately after the war, there was a rash of activity attempting to reorient the management of U.S. air traffic system for peacetime conditions. As the system had grown, it had become dispersed and its management structure ambiguous. It was time to re-assert civil control of air traffic management.

The Department of Commerce was authorized to take over the operation of military air navigation facilities overseas. Scattered administrative and training units were consolidated in Oklahoma City, where all the FAA schools were to be centered. Joint research and development policies were established to assure continued technical development and the application of military technologies to civil air uses. Common civil-military instrument flight rules (IFR) were officially issued. The President established the Air Coordinating Committee by Executive Order with the responsibility for coordinating national aviation policy. The International Civil Aviation Organization (ICAO), the authoritative international standard-setting body, assembled representatives of 60 foreign states for a demonstration of U.S. air navigation and traffic control equipment and techniques at the FAA's Evaluation Center in Indianapolis, Indiana. This move was influential in ICAO's later decision to recommend acceptance of the U.S. systems and techniques as international standards.

These post-war activities reflected a deep and persistent tendency for leaders of air traffic systems to coalesce administratively as well as a tendency to eliminate institutional ambiguities which might be the source of operational uncertainties. They concentrated training operations, agreed on common standards, used institutional mechanisms to coordinate policy. Above all, they attempted to limit the likelihood of uncoordinated competition.

There had been earlier attempts to move in this direction, but pre-war civil aviation had been struggling for initial viability. Before WW II, airways were not crowded; the problems of safety were not yet closely related to the real likelihood of mid-air collisions. However, the rapid growth of aviation activities, the blossoming of military facilities and activities during the war years, and the general reluctance to raise post-war types of administrative matters until the war was over resulted in a general sense that the system could become inchoate and disorganized as demobilization got underway.

For some technical "systems," e.g., the automobile or aircraft production, a "disorganized" sector means freedom to compete, possibly

to prosper. Monopoly or finely grained coordination, the intent of the 1946 developments, is not preferred by those who stand to gain from competition. In the case of USATS, we see another tendency: the drive to reduce sources of ambiguity or conflict that might be the root of operational surprise. It is a tendency likely to be shared by all technical systems that have a relatively high level of perceived hazard.[22]

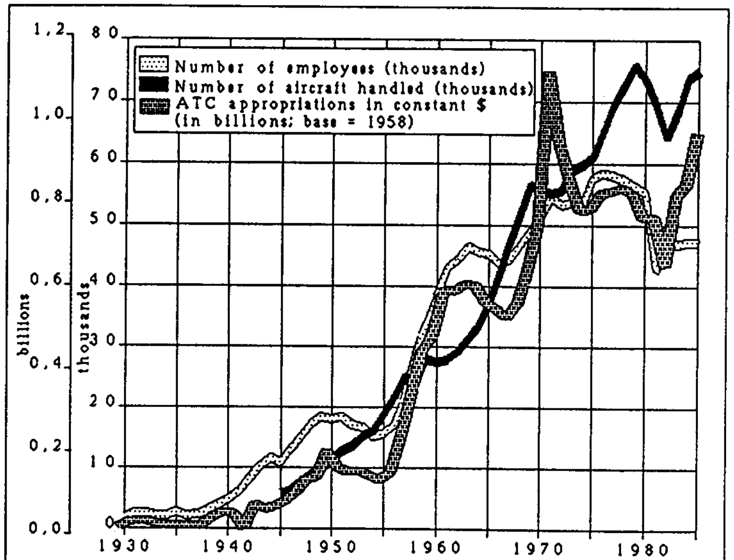
Technical developments also serve to reduce operational surprise. In addition to institutional coalescence, 1946 was the year in which perhaps the single most important technical advance in air traffic control was introduced - the radar equipped control tower for civilian flying. This technology was first installed at Indianapolis Airport. (It was a modification and up-grade of radar developed by the armed forces.)

This development signalled the end of the first major technical phase of U.S. air traffic system development. The predominant coordination technique had been a manual/voice reporting system of "flight strips and shrimp boats" (small cutouts moved about a navigation map tracking the location of an aircraft as reported by the pilot). The manual/voice system would be supplanted either by a combination of radar, improved high-frequency navigation aids (VOR) and instrument landing systems (ILS) to improve pilot control during landings in foul weather or by "ground controlled approach" (GCA) in which the aircraft was "talked in" by operators scanning the plane's location and glide slope on specially designed radar. Radar would greatly improve the capacity of ground personnel to identify and assist aircraft aloft. As importantly for the development of the airways system, the *omni-directional* VOR capability exploded the number of courses available for navigation constrained in the past by the ubiquitous *four* course radio ranges.

In a sense, the original system had nearly filled up. With the generous margins for error necessary in the manual/voice reporting-based system, peak time air traffic near the most used airports was approaching full capacity. Increased system capacity was required. Radar, the new instrumentation and added radio and telephone communications between control centers provided it. This enabled controllers to increase substantially the number of planes that could be worked safely.

New technologies made the controller task less problematic when handling individual aircraft but more complex when dealing with up to 12 to 15 aircraft simultaneously. It also raised the question of how to deal with the situation if the newer, more sophisticated, more vulnerable technology failed. Would the controllers be blinded? How could they re-establish their picture of where everyone was? As radar was introduced, the original system was not replaced. Rather this non-electronic, "cannot break" system is still manned and exercised, operating in parallel with newer systems, "on call" as a continuously available backup.

Figure 1: General Scale of the U.S. ATC System



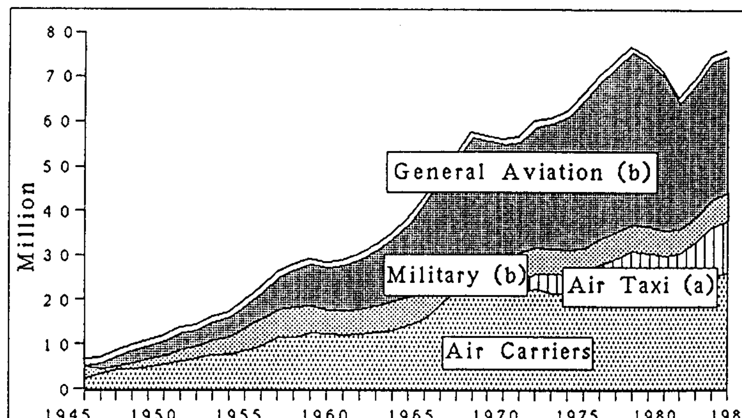
Source: U.S. Department of Transportation; U.S. Dept. of Commerce

Radar gave controllers an independent source of information on the location and disposition of aircraft. The first relatively primitive, sweep radar was augmented by a series of technical changes that systematically reduced the controller's dependence on aircraft captains for flight information. It thereby increased air traffic safety and reduced pilot autonomy.

As radar was deployed to airports and the air route traffic control centers (ARTCC) that monitored the airways between airports, the whole system could handle more aircraft simultaneously. The radar surveillance system was complete: the skies rapidly became more crowded.

One view of FAA's overall developmental pattern is shown in Figure 1. This charts the annual number of employees, and financial resources (adjusted for inflation) available to the agency. A third curve - the growth in actual use of air traffic control services - is laid over the other two. The three curves could be expected to follow parallel paths: however, they are disjunct for three periods and point to times of strain and change. Each of these periods is discussed below. (Figure 2 shows the gross activity load placed on the air traffic control system by different branches of aviation.)

Figure 2: Gross Activity Load on Air Traffic Control System: Combined Aircraft Operations of FAA Towers and IFR Aircraft Handled at Enroute Control Centers.



a) Air Taxi operations is not reported separately from 1930 through 1971, but is included in General Aviation.
b) Only "Itinerant" aircraft operations category noted. No "local" aircraft included.

Source: U.S. Department of Transportation, Federal Aviation Administration. Handbook of Aviation, 1930-1986 Editions.

The Korean War produced the first period of strain. Air activities increased over 100 percent from 1950 to 1956, while the FAA's budget and manpower levels declined significantly. The FAA was again part of a war effort and controllers, most of whom had been in WW II, buckled down and kept the system together. It was a time in which technical changes and increased traffic flows would significantly complicate air traffic management tasks. In 1951, the number of air passenger miles first exceeded rail-sleeping car passenger miles, (10.7 to 10.2 million). In 1953, airplane speeds could average over 200 miles per hour. In 1956, the first large jet liners carrying over 100 people were certified. In effect, the stakes involved in commercial aviation had doubled: twice as many people could travel twice as fast and twice as high as in the early days. This was tragically demonstrated high in the western skies in June, 1956.

Two commercial airliners flying in the clear, deviated from their normal route to show their passengers glimpses of the Grand Canyon. They collided, killing 128 people. A Congressional investigation resulted and a series of restrictive measures were imposed to control the movement of aircraft at high altitudes. A continental airspace control service was instituted by the FAA requiring all aircraft in IFR conditions (in clouds) above 24,000 feet to be under positive ATC control. (Submission to this service was optional in clear air.) In 1958, a series of three more tragic airline accidents in the New York/New Jersey area triggered a Presidential investigation and resulted in recommendations for positive air traffic control on the main airways across the U.S. For all aircraft flying between 17,000 and 35,000 feet (this included all jet traffic), IFR rules conducted under prior clearance would apply. Visual Flight Rules (VFR) were rejected in these airways regardless of weather. These changes combined to increase the number of aircraft required to use ATC services and lowered the altitude above which aircraft control was required. The result was a sharp increase in controller work loads, and stimulated a need for more controllers.

At the same time, a battle was brewing between civil and military aviation circles. Research and development on more powerful navigation aids was going apace by both the FAA and the armed forces. In the early 1950s, FAA had begun to deploy a much improved Very High Frequency radio beacon (VOR) that greatly improved the accuracy of determining and following specific directional headings and allowed for a considerably more complex airways system. It also had a distance

measuring estimating (DME) capability which gave an indication of the aircraft's distance in miles from the radio beacon. Military development groups were developing a different system, the Tactical Air Communication and Navigation system (TACAN), with similar features, but employed different principles and was more robust for the varied types of operating environments they expected, especially aircraft carrier operations.

In 1947, Congress had directed that future technical developments should strive for a single integrated system. The military insisted that its TACAN be the preferred system on national defense grounds. Plans were to install it at military air bases, and on-board naval aircraft carriers; it was the proposed new navigation aid for the next generation of military aircraft. The FAA was adamant, insisting on its VOR/DME system. Many commercial aircraft were equipped to receive its signals; it was already in operation. Views were fixed and for eight years (1948-56) progress on determining the single system stalled. Two major commissions had been charged with resolving the controversy: two had failed. Finally, at the highest level a compromise was struck: VORTAC was agreed upon. The military would use TACAN, civil pilots would get their directional guidance from VOR but rely on TACAN for the distance measuring component. Efficiency flagged in the face of technical aggressiveness and stubborn operational argument. In effect, redundancy was enhanced despite the best efforts of Congress and the White House.

Problems with the civil-military relations were not limited to technical rivalry. The Air Force and Navy still carried out a number of air traffic control functions. On the grounds of maintaining capacity for use in wartime, they wished to keep them. Some way of coordinating and rationalizing the use of facilities and integrating military and civil air traffic functions was needed so they would be compatible with national defense needs.

To work out what was proving a very difficult process, President Eisenhower felt he needed a man skilled in both aviation and the military. His aviation adviser, Air Force General Elwood Quesada, appeared the ideal person. But Congress had provided in the Federal Aviation Act that no career military man, including those retired, could hold the office of Administrator. The General, wealthy enough to retire early from the Air Force, was persuaded to forego retirement benefits and to accept a special Congressional measure allowing him then to become the first Administrator for the new Federal Aviation

Agency. (When he stepped down, Congress restored his military benefits.) Quesada had the job of consolidating civil aviation services and conducting Project Friendship, i.e., to negotiate what military facilities, practices and operations would be transferred to the FAA. This was completed in two years with the transfer of over 2,000 military air traffic control facilities in over 300 global locations to the FAA. The lineaments of the present system were in place.

By the early 1960s, the jet age was maturing. A number of jet aircraft had been certified that carried well over 100 persons. Jet speeds were increasing. Air passenger transport had forged well ahead of both the railways (for long haul domestic travel) and ships (for the Atlantic crossing). In addition to much higher aircraft speeds and flying altitudes, further technical and system enhancements were made.

In 1958 and 1959, the FAA had instituted Continental Control Areas (above 24,000 ft.) and several Positive Control Routes (between flight levels of 17,000 and 35,000 ft.) in which aircraft were mandated to be under Instrument Flight Rules (IFR), have operative radar and radio communications, and place themselves under ATC direction. By 1961, this system was replaced by a national system providing routing direction and radar advisories along three tiers of airways: lower level from 1,200 to 14,500 ft., intermediate airways from 14,500 to 24,000 ft. and high altitude jet ways above 24,000 ft. At about the same time, computers were beginning to be used for aircraft accounting tasks.

This three tiered airways system enabled the FAA to continue serving a rapidly growing aviation industry within a traffic system which had become increasingly dense and tightly coupled. It also further complicated air traffic control operations, and required a parallel division of labor within ATC centers. Total FAA employment had increased to about 30,000. The air traffic system had become a full fledged bureaucracy of sizable proportion.

The FAA established Associate Administrators for Administration, Programs and Development. The airspace system programs included the Air Traffic Service, Flight Standards Service, Systems Maintenance Service and Airports Service providing guidance to seven U.S. FAA regions. Then, partly in response to the increased coordination needs, the FAA reversed a 15 year policy and gave the Washington office direct supervision over programs in the field. This immediately preceded several years of increasing operational and administrative complexity when air

route traffic control centers (ARTCC) were being up-graded technically and, as a consequence of better radar and communication capabilities, were consolidated into fewer, more widely ranging ARTCCs.

The mid-1960s brought the second, now operational, period of strain. Between 1963 and 1967, there was some 65 percent overall growth in the amount of ATC traffic. Resources, however, did not follow the same pattern. The FAA's resources and manning levels *dipped* some 10 percent. The U.S. had become embroiled in Vietnam and war costs were soaring. President Johnson was attempting policies of both "guns and butter" and many Federal agencies faced increasing demands for services with stable budgets. While personnel resource levels hit a plateau, work loads increased steadily, due about equally to growth in both commercial and general aviation users.

At the same time, technical, procedural and administrative changes were "rationalizing the system." By 1964, three tiered airways gave way to the present two, and DME (distance measuring equipment) was mandated for all civil aircraft flying above 24,000 ft. Solid-state, real-time computers were introduced throughout the system. As a result, ATC operations were modestly simplified. Advanced radar systems increased the accuracy of aircraft position images. Computer-generated displays of aircraft identification and position enabled controllers to increase the number of aircraft they could handle simultaneously from 12-15 to 20-25. By 1965, the Continental (positive) Control Areas were expanded to cover the whole U.S. These technical and procedural improvements increased individual controller effectiveness.

Communications and administration were also improved. By 1968, the FAA had put in place a nationwide telephone and telex system connecting the central office with the most active airports, ATC regional offices and area managers. Daily conference telephone calls became a standard feature of management coordination. In addition, the FAA and Air Force increased their coordination and eliminated overlaps. ATC played a larger role in defense interception work and Continental Defense Command activities. Key FAA programs were centralized under the Administrator, while several critical functions that varied from region to region, such as the designation of controlled air space in terminal areas, were de-centralized.

Demand, however, grew faster than the system's capacity to handle the volume with ease. The ATC system geared up to handle increased demand. It extended the amount of controlled airspace and improved more airports to enable them to receive ATC coordinated aircraft. Yet budgets and manpower allocations remained relatively constant. The few modest increases were used for capital and computer purchasing programs. The system became more densely packed, the margins for error declined, and working conditions worsened.

This situation drove controllers to consider organizing to secure relief from increasingly demanding, fatiguing and harrowing work conditions. FAA management was unsympathetic. The controller cadres were expected to perform in the face of adversity. They were then and still are part of a "can-do" organization. In many respects, they had a number of the characteristics of a quasi-military management culture. And they endured these conditions for some five years after the onset of the "stable state." In 1968, after considerable internal debate, the Professional Air Traffic Controllers Organization (PATCO) was formed with a membership of 5,000 in the first year. (It was to grow to over 15,000 by 1980.)

In a direct sense, the union that was to attain such notoriety in the early 1980s was yet another fractious product of the Vietnam War. It arose in a context of an increasing number of personnel related issues. The system became more vulnerable to personnel recruiting and retention problems. It also revealed the deep tension between controllers and management that continues to this day. This abiding tension is rooted in differences in judgment regarding what it takes to keep air traffic moving economically and safely. It results in recurrent labor troubles, as well as controversies about the character of technical solutions for future ATC problems.

Shortly after the formation of PATCO, the ATC system experienced its first instance of extreme airport congestion when the New York area airports had a day in which almost 2,000 aircraft were significantly delayed in taking off or landing. For the first time, the FAA was put into a position of having to restrict the use of certain airports. This was the initial break in the FAA's long standing public policy of serving any pilot who sought assistance at the time he/she requested it. The agency was edging into a position of having to ration its service - a process it still has a difficult time carrying out.

During the 1960s, the goals of service to all in a climate of extraordinary safety led to a series of incremental improvements in new technical systems, changes in procedures and air use restrictions, and operating rules that brought considerably more air space under

direct FAA control, e.g., through lowering of Positive Control Area altitudes from 24,000 to 18,000 feet, and raised the spector of perhaps having to assign priorities to different classes of aviation. This, in turn, raised the question of the optimum relation between serving commercial, highly professional air crews and companies contrasted with the much more numerous, generally less well trained and equipped, though increasingly well organized association of general aviators.

There was and is the general recognition that safety problems arose primarily from pilots who were less skilled and/or were not under direct control of the ATC aloft. This was the source of the unidentified, surprise aircraft suddenly appearing on the radar scope or inadvertently entering restricted airspace and tangling with a commercial carrier. These were almost inevitably General Aviation pilots, i.e., private and business employed pilots flying unscheduled, irregular flights. (See Table 3 for the comparative safety records of commercial vs. general aviation.)

There has been a steady trend - continuing to the present - toward expanding the positive airspace under mandatory ATC control and increasing the instrument flying skills and navigation equipment requirements, e.g., multiple radios and radar transponders, in order to obtain ATC services. In the interest of overall efficiency and safety, users of the system have been required to increase their skill levels, technical and equipment capabilities and procedural and operational complexity. These changes have squeezed out the General Aviation aviator who has neither the time nor the money to keep highly skilled and to purchase and maintain costly on-board electronic equipment necessary to qualify for ATC service.

The benefits, stakes and costs of reliable, effective air transport were steadily growing. Thus far, however, sharp trade-offs in service had not been necessary. Vigorous activity was continually required to stay ahead of the demands of increased traffic. Higher skills, more information and tighter coordination processes were also necessary to handle increased system complexity and density. Computer-based data links and inflight following and up-dating of aircraft progress, were improved. And more finely integrated landing and navigation systems were introduced.

In the late 1960s and early 1970s, the FAA paid greater attention to the improvement of ATC controller training and retention. The agency expanded its national ATC training facility. Measures were taken to

Table 3: Accident Trends: U.S. Air Carriers (Domestic Operations) and General Aviation, 1930-1985

	U. S. Air Carriers			General Aviation	
	Accidents per 100,000 hrs. fln.		Fatalities/ 100 million	Accidents per 100,000 hrs. fln.	
Year	Total	Fatal	pass. miles	Total	Fatal
1930	29.43	3.01	28.2	---	---
1940	4.22	0.422	3.0	108.4	7.2
1950	1.90	0.195	1.1	46.6	5.1
1960	1.78	0.286	0.9	36.5	3.3
1970	0.539	0.017	(0)	18.1	2.5
1980	0.22	0.00	0.001	9.9	1.7
1981	0.38	0.06	0.001	9.5	1.78
1982	0.23	0.05	0.001	10.1	1.84
1983	0.32	0.06	0.001	9.9	1.78
1984	0.19	0.01	0.001	9.6	1.73
1985	0.22	0.05	0.001	8.6	1.53

Sources: U.S. Dept. of Transportation, Federal Aviation Administration, FAA Statistical Handbook of Aviation, 1930-1986 Editions.

nprove controller work situations. These changes came at a time when ATCO first tested its strength by initiating a three day, small scale, elatively ineffective work stoppage or "sick-out" in June, 1969. The ick-out" was followed by the organization's first formally called strike 1 mid-1970. Some 3,000 (of some 16,000) controllers, mostly at the ey ARTCCs, walked out for nearly three weeks. Airline schedules were everely disrupted. The issue, as in the earlier "sick-out," had to do ith working conditions, pay and benefits. Having made its point, PATCO alled off the stoppage during the court ordered show-cause hearing.

Another technical/systems development advance, Central Flow Control CFC), was quietly introduced at FAA headquarters in 1970. CFC has een critical to the increased coordination of the sprawling ATC system.

This facility took over some of the responsibilities of controlling the flow of traffic from the 21 ARTCC centers throughout the U.S. Linked by telephone and teletypewriters, the facility was able to determine the overall capabilities of the system on a daily basis and issue instructions for restricted air traffic flows into areas that fell below expected capacity. (CFC became immensely important in the FAA's response to

Table 4: Hours Flown by General Aviation and Scheduled Domestic Air Carriers, and Passenger Miles Flown by Scheduled Domestic Air Carriers, 1930-1985

	Hours Flown (1,000s)		Revenue Passenger Miles (1,000,000s)
Year	General Aviation	Scheduled Air Carriers*	Scheduled Air Carriers
1930	--	299	85
1940	3,200	710	1,052
1950	9,650	2,055	8,007
1960	13,121	3,530	30,567
1970	26,030	5,770	104,156
1980	41,016	6,247	200,829
1981	40,704	6,080	198,715
1982	36,457	5,962	210,149
1983	35,249	6,175	226,909
1984	36,119	6,971	243,692
1985	34,063	7,364	270,061

* Prior to 1971, Hours Flown was calculated by dividing the number of revenue miles by average speed per year.
Sources: U.S. Department of Transportation, Federal Aviation Administration, FAA Statistical Handbook of Aviation, 1930-1986 Editions; U.S. Department of Commerce, Bureau of the Census, Historical Statistics of the United States, Colonial Times to 1970; U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1978 and 1987 Editions.

the near national emergency precipitated by the firing of 11,400 PATCO controllers in 1981.)

The third period of strain occurred in the latter half of the 1970s. General Aviation levels exploded. While commercial carriers were more or less constant in their hours of flight time (see Table 4), jumbo jets were introduced. The passenger carrying capacity for commercial flights almost doubled, up to 200-250 per flight and flying speeds rose dramatically. Once again, the stakes involved with safe flight escalated.

The system approached another period of expected saturation. Brisk planning went on in anticipation of changes in the 1980s. A National Airspace Plan was devised which was intended to provide the radar and computer technologies to "tighten the system" even more, packing more aircraft into the airspace, with more finely coordinated traffic control in metropolitan areas hosting an increasing number of airports with enhanced landing capacities.

Air traffic levels continued to increase dramatically. During the same period, FAA financial resources declined in constant dollars. Personnel levels declined as well. The stage was being set for a conflict between controllers and management. This time a robust union was in place.

5 Conclusions. Properties of networked technical systems

From this review of USATS development, what can be learned about the developments of large-scale technical systems? Does this story point to similarities among the systems discussed in the book? I think it does. They are the properties of *networked* LTSs. These are the systems whose benefits depend on the qualities of networks of dispersed facilities and connectors that are relatively tightly coupled. These properties appear to intensify over time - as a function of the scale and complexity of the system.

Networked large technical systems are:

- Tightly coupled technically, with complex "imperative" organization and management prompted by operating requirements designed into the system, i.e., unless operations are conducted in x,y ways, there are no benefits, maybe great harm can be imagined. (This is a kind of soft technical determinism: either do it my way or it won't work and do good things for you.)
- Prone to the operational temptations of network systems, i.e., drive to achieve maximum coverage of infrastructure, and maximum internal activity or traffic within the network.
- Non-substitutable services to the public, i.e. there are few competing networks delivering the same service. (The more effective the existing systems, the more likely its monopoly.)
- The objects of public anxiety about the possible widespread loss of capacity and interrupted service. (The more effective it is, the more likely the anxiety.)
- The source of alarm about the consequences of failures to users and outsiders of serious operating failures, e.g., mid-air collisions, nuclear power station disruptions, etc., and subsequent public expressions of fear and demands for assurances of reliable operations.

Notes

1 Work for this chapter was supported in part by the National Science Foundation Grant No. SES-8708046, and the Institutes of Governmental Studies and Transportation Studies, University of California, Berkeley. My thanks to Nick Komons, Historian, Federal Aviation Administration, for his careful review and Paula Consolini for able assistance in data collection and review. Remaining errors are, of course, my responsibility.

2 Night mail flights were initiated in 1921 after this was proved feasible by following bonfires provided by volunteer farmers. See W. Leary, Jr., Airmail Pioneers. Washington/D.C.: Smithsonian Press, 1973.

3 C.V. Glines, "ATC's First Half Century", Air Line Pilot (June 1986), pp. 18-23.

4 Cf. A. Stinchcombe, "Social Structure and Organizations" in J. March (ed.), Handbook of Organizations. Chicago: Rand McNally, 1965, pp. 142-193.

5 For much of the historical detail we draw on the very useful chronology of technical and institutional developments in the U.S. Air Traffic Systems. A.E. Briddon et al., FAA Historical Fact Book, A Chronology, 1926-1971. Department of Transportation, Federal Aviation Administration. Washington/D.C.: Government Printing Office, 1974.

6 The statistics used herein are found in U.S. Department of Transportation, Federal Aviation Administration, Statistical Handbook of Aviation, Statistical Yearbooks. Washington/D.C.: Government Printing Office, 1981, 1986 editions.

7 See D.E. Charlwood, Take-off to Touchdown: The Story of Air Traffic Control. Sidney: Angus and Robertson, 1967; G. Gilbert, Air Traffic Control: The Uncrowded Sky. Washington/D.C.: Smithsonian Institute Press, 1973.

8 Note: The Federal Aviation Administration (and its predecessor agencies) have carried on three functions since the mid-1930's. Air traffic coordination and extending and maintaining a national system of airways has been its primary function, occupying some 75 to 80 percent of its annual budgets throughout the years. The FAA also has promotional and regulatory functions. The agency encourages communities to develop more effective and higher capacity airports to facilitate commercial air transportation services. It is quite visible politically, the vehicle for the dispersement of millions of dollars each year for airport construction and improvements in states across the country. The FAA has an important regulatory function, as well: assuring the public that the aircraft operating within the U.S. possess a high degree of airworthiness and that the pilots flying them are highly skilled and fit. To provide such assurances, the FAA has had vigorous programs in pilot certification involving, in 1980, some 800,000 currently qualified pilots; and it conducts technically demanding certification of aircraft prior to their introduction into regular use. An important aspect of these latter activities is the investigation of aircraft accidents in support of the National Transportation Safety Board, ferreting out causes as a basis for improving procedures and/or making remedial changes in aircraft design and configuration.

9 We set aside for the time being, a) the tale of the engineering developments of navigation, communication and aircraft tracking technologies that are the electronic nerves of air traffic identification and coordination, and b) the process and conditions that resulted in the assurance of continuous growth in air travel. There is also a small charge added to each airline ticket and deposited in the Airports and Air Ways Trust Fund. Until recently, this fund has been used mainly for the improvement of existing and the development of new airports.

I assume that aircraft operate very reliably and are flown by very skilled pilots. In effect, we hold constant the predictability of the machines and their operators - the prime objects of coordination by those who man the air traffic system.

10 The fourth crisis is upon us: a clear sense that the system is nearing its capacity to deal with existing traffic in a safe and expeditious manner. This is due to the effects of deregulation and a continued growth in general aviation (non-commercial carrier) flying.

11 See N.A. Komons, Bonfires to Beacons: Federal Civil Aviation Policy under the Air Commerce Act, 1926-1938. U.S. Department of Transportation, Federal Aviation Administration. Washington/D.C.: Government Printing Office, 1978. J.R. Wilson, Turbulence Aloft: The Civil Aeronautics Administration Amid Wars and Rumors of Wars, 1937-1953. U.S. Department of Transportation, Federal Aviation Administration. Washington/D.C.: Government Printing Office, 1979. S.I. Rochester, Take-Off at Mid-Century: Federal Civil Aviation Policy in the Eisenhower Years, 1953-1961. U.S. Department of Transportation, Federal Aviation Administration. Washington/D.C.: Government Printing Office, 1976; R. Burkhardt. The Federal Aviation Administration. New York: Praeger, 1967. (Primarily the administrative and legislative politics until 1965.) R.J. Kent, Jr., Safe, Separated and Soaring: A History of Federal Civil Aviation Policy, 1961-1972. Washington/D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1980. E. Preston, Troubled Passage: The Federal Aviation Administration During the Nixon-Ford Term, 1973-1977. Washington/D.C.: U.S. Department of Transportation, Federal Aviation Administration, 1987.

12 For example, FAA Facilities and Equipment Programs for Safety: Hearings before the Aviation Sub-committee of the House Public Works and Transportation Committee, Washington/D.C., January 1978, and Plans and Developments for Air Traffic Systems: Presentations at Symposium of Guidance and Control Panel, Cambridge/Mass., May, 1975.

13 For example, Issues and Management Problems in Developing an Improved Air Traffic Control System, Report to Congress. Washington/D.C.:General Accounting Office, 1976.

14 T.R. La Porte, "Beyond Machine and Structure: A Basis for the Political Criticism of Technology", Soundings (Fall 1974).

15 See T.R. La Porte, "Technology as Social Organization: Challenges for Policy Analysis," Working Paper, 84-1. Studies in Public Organization, Institute of Governmental Studies, University of California, Berkeley, January 1984, for an elaboration of this conception and the data requirements it stimulates.

16 This approach parallels C. Perrow's recent work. See Normal Accidents. New York: Basic Books, 1986, esp. Chap. 3. It differs in stressing the variations in the social properties of the technologies. Perrow orders the technologies he examines in terms of their physical properties, e.g., their internal equipment complexity and the degree to which they are mechanically tightly or loosely coupled. Cf. L. Winner, Autonomous Technology. Cambridge/Mass.: MIT Press, 1974.

17 "Any citizen ... [has] a public right of freedom of transit through navigable airspace." Sec. 104, Federal Aviation Act of 1958. In organization theoretic terms, this is a situation in which there is high agreement on goals, and the problem is to gain agreement on means, a much less difficult matter than if specifying organizational goals were also a matter of contest. See J.D. Thompson, Organizations In Action. New York.: McGraw-Hill, 1967, among a number of others, for the decision-making and structural implication of this situation.

18 The FAA has experienced periods of scarce resources (see Figure 1), but these have been visited on the agency from the Executive Office of President. Whatever the agency could get through that office for Air Traffic Control, Congress appropriated. While there have been budget disputes in Congress, and the FAA has not gotten all it sought, these disputes have not concerned the support of the air traffic control function. Rather, they have been about the degree to which funds set aside for "airway and airport development" would be used not only to provide funds to states and communities to build and improve airports but to carry the increasingly heavy costs of operating the system. Until 1980, almost none of these funds, collected as a small tax on each airline passenger ticket, had been allocated for ATC operating costs. These funds are politically precious resources to be dispensed by Congressmen to favored local constituencies.

19 See T.R. La Porte, "High Reliability Organizations: The Dimensions of the Research Challenge." Working Papers on Public Organizations, Institute of Governmental Studies, University of California, Berkeley, March 1987; T.R. La Porte, "High Reliability Organization Project Overview," Institute of Governmental Studies, University of California, Berkeley, July 1987, for an overview of a major project investigating the characteristics of three such large techno-organizational systems.

20 In the public and media mind, the FAA's function as manager of the air traffic system is often confused with its responsibilities for assuring the airworthiness of airplanes themselves. On occasion, airline problems with the physical integrity

of airframe and engines and the FAA's visibility in regulating the manufacture and maintenance of aircraft is blurred in the media. The regulatory role is much less directive than the managerial one and occupies only about twenty percent (20%) of the agency's resources and personnel. See Note 7 above.

21 The Federal Aviation Administration, hereinafter understood to include the FAA and its predecessor agencies, especially, the Civil Aviation Administration (CAA).

22 Indeed, a case can be made that all organizations attempt as much to reduce or contain sources of uncertainty in their internal and external environments as they seek to maximize economic or operational values. See for example, J.D. Thompson 1967, op. cit., and J. Galbraith, Organizational Design. Reading/Mass.: Addison-Wesley, 1977.

CHAPTER 9
THE FRENCH ELECTRICAL POWER SYSTEM: AN INTER-COUNTRY COMPARISON

Maurice Lévy-Leboyer

1 Electrical power in France - a deviant case?[1]

On the basis of available statistics the French record in the field of electrical power does not seem to match that of other major industrial nations. Production according to official sources did not amount to more than 0.4 billion Kwh at the turn of the century and 1.8 billion Kwh in 1915-19. This is less than 4% of the 30 billion Kwh produced over the same period by Germany, the U.K. and the U.S., taken together. Of course, statistics were quite defective in those early years. They were improved only in 1923 when the French census included for the first time all productive facilities, instead of a sample restricted to the larger electrical plants as in earlier periods. Nevertheless, the gap was a real and persistent one, as indicated by the fact that French output of electrical power only improved (by 5-year averages) from 7.5 to 20 billion Kwh in the interwar years, while that of the three major countries went up from 90 to 230 billion Kwh, leaving the ratio unchanged at 8.4%. In a way it might not seem fair to compare economies so different in terms of population size. But on a per capita basis, output remained at 325 Kwh in 1920-24 and 480 Kwh in 1935-39, i.e. in both cases at only 53% of the three major countries. And the ratios are similar when total energy consumption or domestic consumption (i.e. the use of electric appliances, including light, by households) is used as an indicator.

Obviously one might point out that France was not endowed with natural resources: coal was lacking and distance made power transportation from the Alps or other mountains a costly undertaking at that stage of technological development. However, when one takes into account the engineering tradition of the country, its financial resources,