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Toward Managing the National Airspace System As a Common Pool Resource

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Abstract

As air traffic increases, so will competition for resources in the National Airspace System (NAS). This will result in more congestion-related delays unless something is done to increase capacity or alter the demand. Currently the Federal Aviation Administration (FAA) operates the National Airspace System on a "first come, first serve" basis. When the system lacks capacity to serve everyone immediately, a *de facto* allocation scheme has evolved. Further government control and/or privatization have been proposed as offering potential improvements. However, there is a viable alternative.

Managing the NAS as a common pool resource (CPR) can offer a more attractive solution to the current *de facto* allocation, and a more immediately workable solution than an integrated private market. CPR solutions have successfully been applied to many environmental problems where "free rider incentives" congest or deplete resources.

This paper analyzes the using an accepted CPR framework. As predicted by CPR literature, a group process, known as Collaborative Decision Making, has formed to in an effort to reduce delay and congestion. However this effort many not be sustainable because it is missing several key design elements that characterize long enduring CPR organizations.

Keywords: Capacity Allocation, Common Pool Resource, Collaborative Decision Making

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1 Introduction

As the world's population grows, so does competition for the earth's manmade and natural resources. This puts pressure on renewable resources that were once considered vast and plentiful. The National Airspace System (NAS) is no exception. Increases in air traffic levels have created congestion at airports and more competition for airspace, resulting in longer and more frequent flight delays.

Congestion, degradation, and depletion are all symptoms of overuse. If there are no limits on use, renewable resources, such as forests, streams, fish, wildlife or grazing land, can be harvested past the point of sustainable regeneration. Similarly, manmade transportation resources such as highways, central business districts, airports and seaports become congested. Without limits, individuals over-consume common resources because they do not bear the full costs of their actions. Taken to its logical conclusion, overuse can lead to the destruction or degradation of resources users depend for their economic well-being.

This harmful incentive is often referred to as the "tragedy of the commons," a phrase made famous by Garrett Hardin in a 1968 article of the same name. Hardin used the term "tragedy" because rational action by individuals collectively produces an irrational result. To remedy the situation, Hardin proposed limiting access to the common resource in question via government control or privatization.

However, a seminal work by Elinor Ostrom (1990) recognized that, in fact, there is a third way of handling the problem, which falls in between the extremes of government regulation or taxation, and complete privatization. She found numerous empirical examples where communities have organized to sustain what she called "common pool resources."

Ostrom's work has spawned an entire field of theoretical and empirical research focusing on common pool resources (CPR). This field recognizes there are ways to alter individual behavior by changing the incentives individuals' face, short of either instituting markets or using governmental intervention. For those familiar with the prisoners dilemma paradigm, Ostrom demonstrated empirically that a cooperative strategy is more likely to emerge if the game is repeated and participants are allowed to communicate, thus overcoming the incentive to defect.[1] Researchers have identified institutional arrangements that can be devised to alter the payoffs for different behavior. These arrangements attempt to align individual consumption levels with a sustainable level of resource consumption.

Unfortunately, there is no one-size-fits-all approach to successfully changing the payoff structure. Each arrangement must be specifically tailored to match the characteristics of the

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[1] For a detailed explanation of game theory consult http://en.wikipedia.org/wiki/Prisoner's_dilemma.

resource and its users. Over the last 17 years, some generally accepted design principles of successful arrangements have emerged. The ultimate goal of this paper is to present concepts that will lead to better capacity allocation before traffic and congestion in the NAS grow to unmanageable levels.

Section 2 outlines current demand management techniques. Section 3 gives a brief background on the infrastructure that supports the NAS and those who use it. Section 4 explains how the NAS operates by outlining the difficulties associated with efficiently aligning capacity and demand. Section 5 also discusses some of the causes and remedies that have been found for congestion and delay in the NAS. Section 6 presents a framework for goods and services, focusing on public, private and common pool goods. Section 7 brings together the two domains, by examining how the NAS and its users form the basis of a common pool resource. Capacity management in the NAS will be discussed as it relates to current thinking in common pool resource management techniques. A gap analysis will be performed to identify promising new techniques that have been proven over time with other types of common pool resources in Sections 8 and 9.

2 Traditional Demand Management

Economists have long viewed the problem of overuse as an instance of market failure due to the externalities produced. An externality is a cost or benefit which is not borne by the actual consumer of the resource. In transportation networks, congestion is considered an externality. Once a threshold has been reached, each additional user imposes delay and inconvenience on the other users of the system.

The solutions economists tend to propose are those which attempt to "internalize" the external cost. In other words, if users of the resource are forced to pay the full value of the costs they impose on other members of the community, then consumption of the resource will be closer to the socially optimal level. Traditionally, economists have offered two solutions that internalize the costs.

One solution is to impose a tax or fee on consumption of the "under-priced" resource. This solution is often referred to as a "Pigouvian" tax, in honor of the French economist Pigou (1932). The amount of the tax or fee should be equal to the marginal social cost of consuming the resource. In transportation, variable tolls have been imposed on congested highways with considerable success. In this setting, the challenge is to set the fees or taxes at the appropriate level.

A second solution is to assign property rights to the resource in question, which users would then be forced to pay the owner to obtain use rights at some negotiated price. This solution, advanced by Coase (1960), is attractive because it involves minimal government intervention, short of defining and enforcing the property rights. However, in practice, it only works well if there is a small number of users involved. For example, tradable departure and arrival slots at a congested commercial airport works acceptably well in practice, but would be completely intractable if applied to a freeway. Nevertheless, one could assume that privatizing a highway and allowing the private-sector owner to charge whatever they want could be considered a Coasian solution. However in a market based solution granting property rights to one individual or group (instead of another) has very real distributional consequences. To see this in practice, one only has to consider that landing slots at New York LaGuardia Airport[2]—most of which were grandfathered to the carriers which were operating there at the time—are now so valuable that they are used as collateral for multi-million dollar bank loans.

A full discussion of the relative strengths and weaknesses of taxes and fees, versus the assigning of property rights, is beyond the scope of this paper. However, it is sufficient to say that – depending upon the situation – either solution to the tragedy of the commons is

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[2] Non-airline ownership was allowed under the High Density Rule that expired in January of 2007.

imperfect, and necessarily involves some amount of government intervention. This is to say nothing of the solution which is usually imposed in practice – across the board government regulation. Perhaps regulation is politically popular because it is the easiest to explain, but economists particularly dislike this approach because it treats all users of the resource as if they valued it the same way.

To date almost all demand based congestion research has focused on examining and experimenting with private property rights. The concepts put forth in this paper do not dispute the general merits this solution. It is the author's view, that if markets are to emerge based on private property or use rights, it will be a slow and incremental process that could take many years to fully develop.

Workable solutions will be needed long before this process has matured. The framework presented in this paper explores common pool resource management in the hopes of finding a third solution that can be implemented in the near-term. CPR concepts are especially attractive because they are not at odds with longer-term market-based solutions. In fact, they offer a logical evolutionary path toward private property. Thus, CPR-related mechanisms can also be viewed as an interim and complimentary solution.

The framework presented in this paper offers an alternative that has been successfully applied to manage other non-market public domain systems. Some CPR solutions have endured for centuries, however for every success there are also many failures. While a CPR based solution is no panacea for the tough problems facing the system today, it does provide the foundation for a workable alternative way forward.

3 The National Airspace System

Early aviation was characterized by a saying that is still sometimes heard today, "big sky, little plane." As aviation began to capture the imagination of the American public, advancements in aircraft and technology rapidly followed. By the second half of the 20th century, air traffic, as well as aircraft speed had both increased, making the simple procedure of "see and avoid" inadequate in busy metropolitan areas. In response, modern air traffic control and procedures evolved to ensure separation of aircraft in the en route, terminal and airport environments.

Today the NAS is made up of an interconnected web of stakeholders and resources. A brief description is necessary to facilitate the analysis.[3]

- *Federal Aviation Administration (FAA).* The FAA operates under the United States Department of Transportation. It is the primary government agency overseeing the NAS. Its duties can be divided into two main functions. The first is regulatory, and includes certification for pilots, aircraft, and airlines. The second is operational and safety related, and includes the day-to-day Air Traffic Control (ATC) and ongoing maintenance of the NAS. Since the NAS is so large, ATC activities have been organized on smaller, more manageable levels based on the type of operation and airspace involved. The following list explains more about the different roles and responsibilities within ATC.
    - *Air Traffic Control Tower (ATCT).* Typically referred to as towers, these facilities primarily determine runway usage, in terms of takeoffs and landings. In addition, these controllers provide separation for aircraft in the immediate vicinity of the airport and for aircraft and ground vehicles on runways and taxiways.
    - *Terminal Radar Approach Control (TRACON).* These facilities are also known by the term approach control, because their main function is to provide separation for aircraft in busy terminal airspace. These facilities are often consolidated for large metropolitan areas with multiple airports.
    - *Air Route Traffic Control Center (ARTCC).* There are 21 ARTCCs, also known as en route centers. These centers are responsible for providing separation in all airspace that is not assigned to towers or TRACONs. En route centers group their airspace into areas, which are then subdivided into sectors.

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[3] For a more detailed description of the NAS please see FAA Office of System Capacity, 2001.

- *Air Traffic Control System Command Center (ATCSCC).* Also known as central flow, the ATCSCC works with Traffic Management Units located at other ATC facilities to coordinate traffic flows so that separation can be maintained in individual sectors.

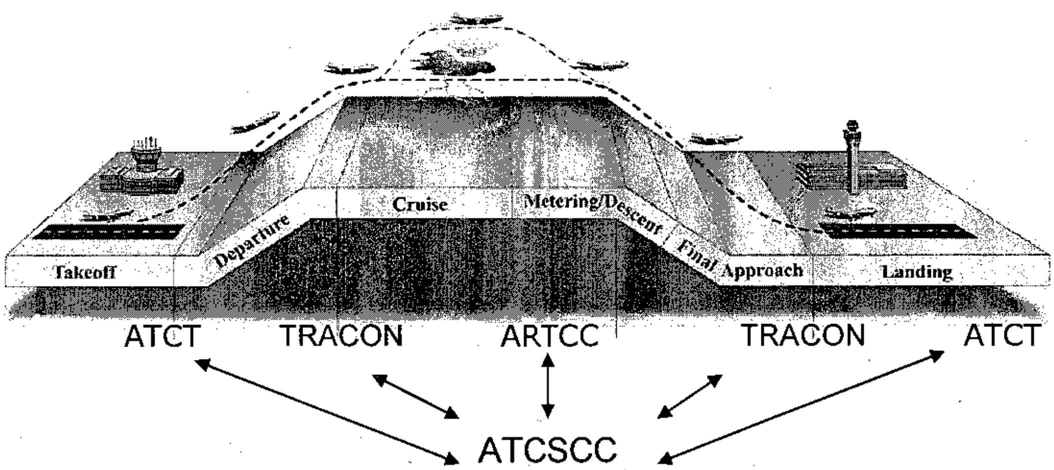

Figure 3-1. Air Traffic Control Facility Jurisdictions

- *Air Traffic Control Specialists (ATCS) or Certified Professional Controller (CPC).* An ATCS is typically certified to control traffic at a particular position or group of positions. For instance, at an en route center, a CPC is only qualified to work at the positions in one geographic area. This controller specialization makes it difficult to boost capacity via staffing, and can easily constrain capacity if there are staffing shortages.
- *Airspace.* Structure and procedures have been developed to facilitate the orderly and safe movement of air traffic. Domestic airspace has been broken into two major categories, controlled and uncontrolled. The FAA provides separation services only in controlled airspace. Not all flights must be under positive control. Approximately a quarter of all flights still operate using "see and avoid" procedures at lower

altitudes.[4] However, the majority of commercial jet traffic is under positive control, cruising between 18,000 to 60,000 feet above mean sea level.

- *Airports and Airport Authorities.* As of February 2007, there are 5,217 public use airports, and 15,295 private airports in the U.S. Airports are often managed in two parts, the airside, and the landside. The airside includes the runways, ATC tower and staff. Most public airports are generally owned and run by local governments or regional authorities. Some airports have leased particular facilities such as terminals, gates and ramps to the airlines for exclusive use. In many cases, the airlines have helped finance improvements to these facilities.

In addition to the major facilities types listed, the FAA also maintains navigational aids and flight service stations (FSS).[5]

- *System Users.* System users tend to be classified into three broad categories based on their purpose for using the NAS. Users are often referred to based upon which part of the FAA regulations they operate under (see Code of Federal Regulations Part 14). A rough estimate of the number of daily flights by each group is also provided.[6]
  - *Commercial* (35,000 daily flights). Traditional passenger service, charter service, freight, cargo, sightseeing, business and corporate use of the NAS. Most passenger flights are required to fly using ATC services. These users tend to use the system more intensively, but they are prohibited by antitrust concerns from coordinating their use.
  - *General Aviation* (45,000 daily flights). Non-commercial, recreational or subsistence use of the NAS. These flights are not required to use air traffic control services, but many still do.
  - *Military/VIP* (4,000 daily flights). Military use of the NAS includes both aircraft and airspace. A large amount of special use airspace (SUA) has been set aside for use by the military. The FAA can request temporary use of some designated airspace; however, it is not always released. VIP (e.g., Air Force 1) and military aircraft also use civilian airspace. The FAA has increased its coordination with

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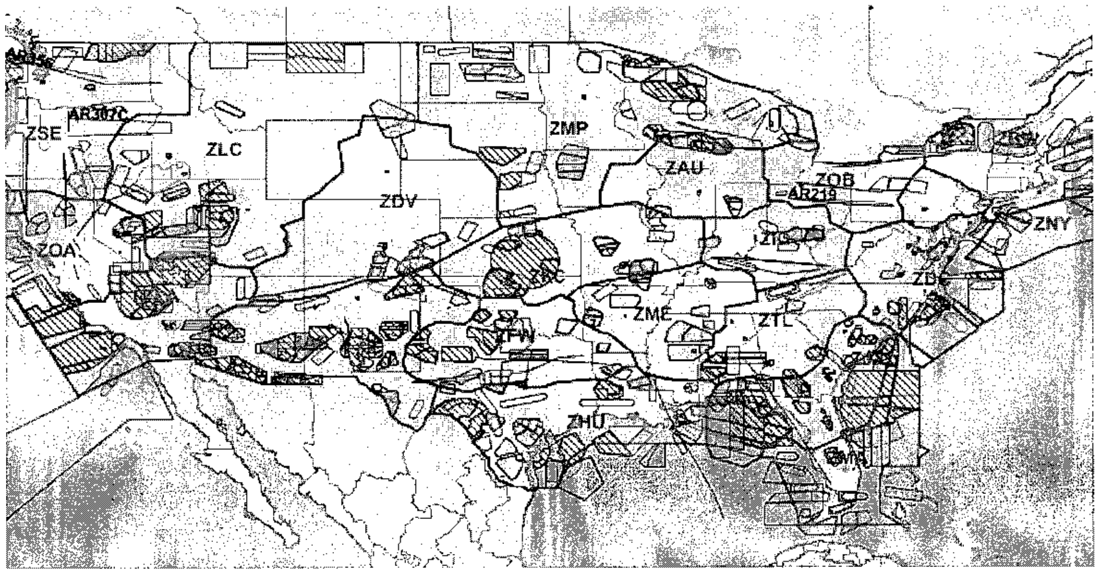
4 Data based on fiscal year 2006 Operations Network (OPSNET) data. The OPSNET is the official FAA source of historical NAS air traffic Delays and Operations. Local flights were assumed to be visual flight rules (VFR).

5 The ongoing operation of these flight service stations has recently been contracted out to Lockheed Martin Corporation.

6 FY06 OPSNET for 495 airports was used to derive a daily average number of flights by user category.

the military related to the use of military airspace when system capacity is constrained.



Source: sua.faa.gov/sua/Welcome.do

Figure 3-2. Map of Special Use Airspace and 20 En Route Centers

(Active Airspace on 2/8/2006 15:35 GMT has Red Lines)

4 NAS Operations and Capacity

The NAS is a complex and dynamic system. Its ability to support aviation related activities is dependent on multiple variables, many of which can change from day-to-day and even hour-by-hour. The dynamic elements affecting capacity fall into two main categories, those that can be influenced by humans, and those beyond our realm of control. Elements we do control include ATC staffing levels, equipment levels used by pilots and ATC personnel, airport design, as well as policies and procedures. Weather related events, such as wind, thunderstorms and fog, as well as unexpected safety related events such as go-arounds, fuel shortages, and equipment failures are the main factors influencing capacity beyond our control. Of course, some static infrastructure elements do exist, such as the number of airports, and air traffic facilitates, but even these slowly change over time.

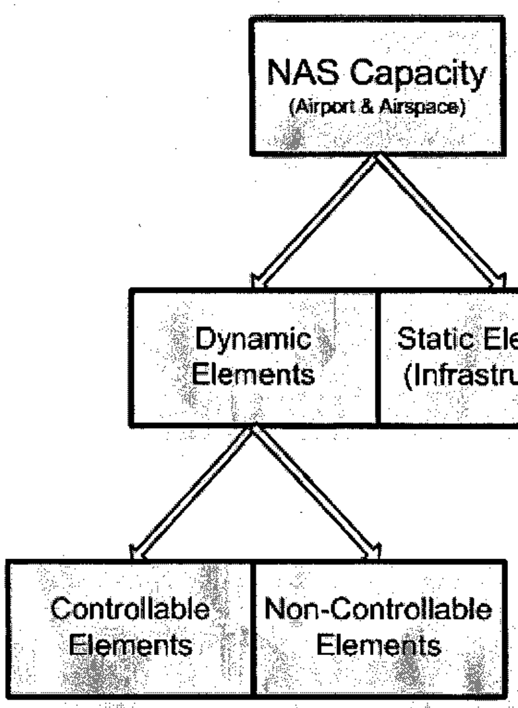


Figure 4-1. NAS Capacity

Given the dynamic nature of the system, the first challenge is to determine how much capacity is available at any given instant in time. While this may sound easy, it is actually very challenging. Capacity is almost never fixed for NAS resources. There are many interrelated variables that affect capacity, which makes it impossible to determine the precise impact for all NAS resources. The static infrastructure elements of the NAS do place an upper bound on capacity, but even this upper bound changes if procedures are modified. Instead, general guidelines have been developed, such as arrival rates for airports and monitor alert parameters for airspace. However even these general guidelines are reevaluated as more precise information becomes available such as weather conditions, aircraft fleet mix, etc.

It should be noted that operational efficiency does not imply the complete absence of congestion and delay. In fact, some field personnel suggest constant demand pressure (in the form of delay or queues) is necessary to fully utilize all available capacity. Once airborne, planes cannot wait until it is their turn to land, which means capacity can go unused if an aircraft is not immediately available to access it.[7]

The FAA must constantly balance the competing goals of efficient use and safe operations. For instance, increasing separation between aircraft means fewer aircraft in the system, but much more flexibility if conditions become unsafe. Policies and procedures in aviation are designed to emphasize redundancy and safety. If an airport is operating at its maximum capacity for given conditions, there is very little room for schedule recovery if an unexpected events occur to reduce capacity (such as equipment failure). In other words, a very small disruption can have a tremendous impact in the NAS if it is already operating at peak capacity. While some events can be absorbed because capacity is not a hard and fast number, often these events ripple through the system as delays.

[7] ATC can hold aircraft, but it requires a great deal of airspace and fuel burn, and should only occur if other options have been exhausted. Even when aircraft hold nearby, capacity can go unused if an aircraft is not properly positioned in the holding pattern to take advantage of the spot.

5 Congestion Management in the NAS

NAS resources have always been allocated on a "first come, first served" basis. However in practice, a *de facto* system of allocation has evolved over that last 25 years to address increased demand and congestion. The challenge moving forward is to institutionalize an efficient and equitable system of capacity allocation.

A complex set of traffic flow policies and initiatives has evolved to manage en route and terminal congestion, to maintain separation, and avoid excessive delays. These measures and their respective strategies tend to fall into three separate time horizons, long-term, short-term (day-of operations), and tactical. It is no coincidence that these time frames are aligned with the amount of control and information available concerning NAS capacity.

Long-term capacity management occurs in response to a structural imbalance between capacity and demand. Even if dynamic capacity is at its operational peak, the underlying infrastructure can only handle a finite number of operations. This situation occurs most often at busy metropolitan airports. In response, the FAA has taken action to limit the amount of hourly operations at these airports. Examples include slot allocations and operating rules at New York LaGuardia and Chicago O'Hare airports. When possible, the FAA has tried to remedy the structural imbalance by increasing capacity via airspace redesign, new technologies and procedures, and new runways.

In general, commercial users tend to plan their use of the system based on good weather capacity. When weather or other unexpected events reduce available capacity on the day of operations, it creates an imbalance between capacity and demand. Day-of operations strategies attempt to align demand once all of the dynamic elements have been taken into consideration. Traffic Flow Management (TFM) initiatives are used to allocate capacity and/or spread out demand. These initiatives are implemented and revised throughout the day as new capacity and demand information becomes available. TMIs often result in aircraft being delayed on the ground prior to takeoff. Some events occur that cannot be forecast in advance and must be dealt with in a tactical manner. Tactical traffic flow maneuvers include airborne holding and vectoring.

The Air Traffic Control Command Center (ATCSCC) was created to assess the state of capacity in the NAS on a day-to-day basis. The ATCSCC coordinates with local level facilities to optimize the use of available capacity by tailoring operational strategies to local and national conditions. Responding quickly and effectively to ever changing conditions requires a great deal of coordination and data because the NAS is large and complex. Over the years a collaborative process of information data exchange between the FAA and users has emerged to help increase situational awareness and improve the decision making process.

This group and the processes they employ are known simply as Collaborative Decision Making, or CDM. The initial organizing principle was to share flight status data. This effort has proved fruitful and has expanded to include the development of other capacity/traffic management initiatives and solutions. This group and their activities will be discussed in depth in Section 9.

6 Common Pool Goods

Goods and services can be categorized across two dimensions. 1) How the use by one individual, affect the use or supply for another, referred to as "rivalry" in Figure 6-1, and 2) the extent to which it is possible to control access to the good or service, referred to below as "excludability."

The first dimension, rivalry, relates to the effect one person's consumption has on others. Some goods are not affected by use once they have been produced. These goods are non-rival since everyone can enjoy them at once, like radio broadcasts. The second dimension relates to ease of access or excludability. It is hard to exclude others from using some goods, like lighthouses. Goods that are both non-rival and non-excludable, such as National Defense, are public goods.

Private goods demonstrate the exact opposite qualities. It is possible to limit their use to specific individuals, and their consumption affects overall availability of supply. Examples of private goods include cars, houses and merchandise.

	Rival	Non-Rival
Excludable	**Private Goods** -Automobiles -Boats	**Club Goods** -Electrical Power -Fire protection
Not Excludable	**Common Pool Goods** -Congested roads, airways, airports, waterways	**Public Goods** -Lighthouse -Uncongested roads, airways, airports, waterways

Figure 6-1. Categorization of Goods

This same classification paradigm can also be used as a general guideline for determining how to provide and allocate goods and services. Most Western economies recognize this distinction. Their economies are blended, relying primarily on markets to provide private goods, and the government to provide many pubic goods.

Market economies often look to the government to supply public goods if there is a "free rider" problem. Free riding occurs when individuals enjoy the benefit from a good or service because it is non-rival, but are not willing to pay for its production or use. However, this is not a hard and fast rule. For instance public radio such as NPR has found a way to combine listener contributions with advertising to fund its operations and overcome some degree of the "free rider" incentives that exist.

Initially common pool goods and club goods were considered special classes of private goods associated with market failures. Eventually the private/public paradigm expanded to recognize the unique properties of these two types of goods.

Common pool goods are rival, but not excludable. Thus, they suffer from a similar "free rider" incentive problem as with public goods.[8] The key distinction between public and common goods is that supply *is* affected by consumption of a common resource. With no way to limit consumption, common pool resources can easily be depleted or destroyed.

This tragedy occurs because rational behavior leads users to consume more than the socially optimal amount of a common resource, because individual costs are lower than the social cost. Consumption of common resources creates negative externalities because individuals impose costs on others that are not reflected in their own decision making process. It should be noted, that even at the socially optimal level of consumption, some level of degradation or congestion can occur.

Unfortunately, overuse is often accompanied by underinvestment in the good's maintenance and upkeep. Ironically, this situation also leads to inefficient or overinvestment in harvesting mechanisms because users try to capture as much of the economic value of the resource before others are able to.

Many goods initially thought of as public goods, are now considered common pool goods. This primarily occurs with environmental resources, once use has exceeded a threshold. When the threshold has been reached, an additional user, or increased use by current users, affects the resource's long-term viability.

There are several reasons common pool goods are distinct from private goods. Typically, it is because it is difficult, expensive, or undesirable to divide these goods into individual

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[8] In the economic literature, "free riding" is associated with un-willingness to pay for the production of a good that can be enjoyed by all. In the CPR literature, the term is more often associated with individual lack of restraint, to the detriment of the larger user group (i.e. free riding on their goodwill, as opposed to displaying cooperative reciprocity). The main difference between the two is that once a common pool good exists, it is subject to over use, not under-production. One reason common pool resource solutions are not widespread is because they typically pose a two tiered organizational dilemma. First the CPR and/or the governing rules must be produced. This is a collective action dilemma that exhibits public good characteristic because there is a strong incentive to free ride (resulting in under-production). Once a CPR exists, the next challenge is to restrain use to a sustainable level.

increments. For example, it would be socially inefficient for multiple irrigation canals to be constructed to irrigate the same region. Instead, some canal systems are managed by a collective that allocates water to each of the users based on use rights. In other situations, if a common pool resource is very large, the cost of dividing it and monitoring use can outweigh the individual benefits gained from exclusive use.

Some goods remain a common pool resource even though they could be privatized. This tends to occur when resources are mobile or storage is difficult. The behavior is explained by the fact that individuals can share or diversify risks over a greater community. For instance, new technologies have enabled some goods to transition from common pool to private good. Barbed wire has made it cost effective to transition pastures into private goods. However, this technology has not completely eliminated common grazing land. When rainfall and soil conditions vary considerably, it makes some grazing lands better one year but worse the next. By maintaining common grazing lands, this uncertainty and risk can be spread among many individuals.

The NAS exhibits the same behavior as many environmental resources. For instance, the NAS, like water and wildlife populations, exhibits natural variations and cycles. This variation makes it difficult to determine the appropriate level of sustainable consumption. Like the oceans, the atmosphere, and biodiversity, the NAS is a complex and dynamic system. Often small changes can set in motion a chain of events, which are difficult to quantify and model. These events affect both the users and the resource in unexpected ways.[9]

Unfortunately, there is no well accepted governance mechanism for allocating these goods. In fact, allocation of common pool and club tends to be very controversial, precisely because they do not naturally lend themselves to a particular form of governance. For example, club goods tend to be most efficiently provided by a single source. The natural monopoly that many club goods providers enjoy makes it difficult to determine the appropriate level of resource to be produced and the right price to charge. In other words, there is no market mechanism to easily indicate how much capacity should be made available and where capacity investments should occur.

Researchers initially found solutions for allocating, managing or regulating common pool goods by studying irrigation systems, grazing land, ground water basins, and fishing grounds, which all fell neatly into the common pool good category. As the research field has

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[9] A good example of cascading effects is seen in cases of deforestation. Harvesting forests reduces the amount of carbon dioxide that will be removed from the atmosphere and turned into oxygen. It will also lead to soil erosion, contaminated runoff water, and cause loss of wildlife habitat. The full extent of the negative externality of this action is very hard to quantify.

expanded, it has attempted to tackle more complex goods that exhibit a mix of characteristics. There are many goods that demonstrate common pool good traits, such as medical services, digital media and the internet. In these instances, governance and allocation solutions have struggled to evolve. As noted in the introduction, there is no clear-cut solution for managing these types of resources. In fact, solving common pool problems requires solutions that are highly tailored to the needs of the users and the resource itself. Yet the incentive to find a proper solution is strong, because these solutions preserve the resource and attempt to use it in an efficient and equitable manner.

It is sometimes difficult to separate out the characteristics of a good from how it is governed and allocated. For instance, radio programming uses a common pool resource (radio spectrum), to produce a public good (radio programming), usually run by a private business (radio station). The NAS is very similar in this respect since it demonstrates a mixture of characteristics and governance models. In the next two sections, the NAS itself will be examined to determine the degree to which it exhibits common pool resource characteristics. The allocation and governance of the NAS will be discussed in the section that follows.

7 Categorizing the NAS[10]

Most common pool resources can be segmented into two components, *stocks* and *flows*. The *stock* is the common pool itself, such as a water reservoir or forest, from which *flows* are drawn. The *flow* is the element of the resource that is appropriated for individual or commercial use, such as the water from a reservoir, or timber from a forest. In this case, the NAS infrastructure is the *stock*, and the flights using the NAS are the *flow*.

7.1 Providing the Stock

The NAS is a man-made resource. It is also a resource that must be constantly maintained and staffed for it to be usable. The provision and maintenance of the NAS infrastructure is characteristic of a club good. Due to economies of scale and network considerations, it is optimal to have one, non-overlapping, common infrastructure platform, but it is fairly easy to collect money for use of the infrastructure provided (i.e. aviation fuel taxes).

No consensus approach for providing ATC services has emerged. This is consistent with many other club goods that struggle to find an appropriate governance mechanism. Thus, some countries have privatized this function, and other places, like the US, have left this function to the government. In either case, user fees and taxes tend to pay for the bulk of the costs associated with running and maintaining the airspace systems in modernized economies.

While the NAS infrastructure itself may be supplied as a club good, its actual use is consistent with common pool goods. The existing NAS infrastructure is the *stock*. It is the resource that users compete over. As noted earlier, the availability or capacity of the stock is not static. For instance severe weather regularly shuts down major airports and airways for hours at a time. In these situations, even if more capacity could be built, it would not solve the resulting congestion.

7.2 Timing the Flows

The *flow* the NAS infrastructure produces is a flight.[11] In other words, a flight is the unit of output that is extracted from the NAS. Most CPRs systems focus on limiting the *flows* of a renewable resource in order to sustain the *stock*. However the NAS is unique as a common pool resource on two important dimensions. Unlike the *stocks* of most natural resources, the provision of NAS services cannot be depleted or destroyed over time. It is an instantly

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[10] To the author's knowledge no substantive work has focused on the entire NAS as a common pool resource. Sened & Riker (1996) examined the effectiveness of industry self-regulation, which he likened to common property management of arrival slots at high density airports.

[11] It is rather ironic that the aviation community often refers to busy air traffic routes as flows.

renewable resource, similar to a communication frequency spectrum. This implies that the entire *stock* can be appropriated at any given time as long as there is no simultaneous competition for resource use (loss of separation).

While the NAS *stock* is not depleted over time, it also cannot be stored across time. The ability to store the *stock* of a resource, such as water, allows resource users to create predictable *flows*. Arrival capacity at an airport is a constantly changing condition, and cannot be "saved up" for use in periods when demand is high. The inability to deplete the capacity of the NAS over time, and the inability to store the capacity of the NAS, interact to create a strong incentive for users to appropriate as much of the *flows* as they deem profitable, without regard to how they will effect the system.

The NAS does not have enough capacity to support everyone using the system at the same time. The ability of humans to coordinate *flows* and avoid competition for the same NAS resource at the same time is very limited. Thus, for the NAS, it is always a question of timing, coordinating and allocating *flows*. This results in a situation where the *stock* and *flows* of the NAS become almost indistinguishable because the goal is to have them move in sync (e.g. if there is less capacity, the *flow* should be reduced).

NAS *flows* exhibit many of the traits that are characteristic of a common pool resource.

- *Over-Harvesting*: In recent years, there has been a trend toward using more planes that carry less people between the same two cities. This creates additional congestion at some of the busier hub airports.
- *Free Riding*: There are flights that "free ride," while others voluntarily constrain their use of the system. These flights perform the equivalent of cutting in line to use a congested airport, delaying the flights behind them.
- *Indivisible*: NAS resources are of little use on their own accord. NAS users require a bundle of well-coordinated services. For most users, an arrival slot is of no use unless there is a gate available at the airport; airspace is of no use, unless it provides access to an airport, and an arrival fix is of no use without the clearance to land, etc.
- *Resource Uncertainty*: There is considerable risk and uncertainty about the supply of the resource. Sharp and unexpected drops in NAS capacity cause congestion and cascading delays. Constant monitoring and assessment is needed to determine the appropriate level of resource use.

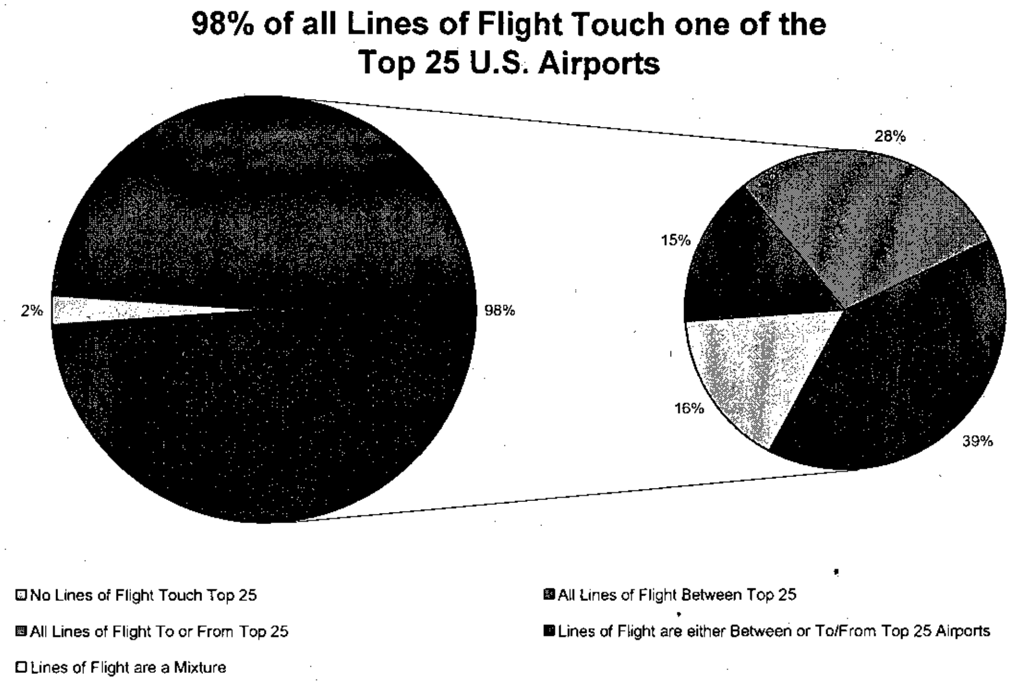
Another way to think about the *stock* and *flow* of the NAS is to equate the *stock* to capacity, and the *flow* to demand. This is consistent with the way the industry itself thinks about operations; balancing supply and demand.

7.3 A Network in Transition

In transportation systems each additional network node incrementally increases the value of the whole system. This "network effect" complicates the *stock* and *flow* dynamics of a typical CPR. In a more traditional CPR, the value of a *flow* does not change with the size of a *stock* the way it can in the NAS. In the NAS, all elements have some value because they contribute to the size and ability to use the network as a mode of transportation, but not all NAS resources are equal in value. Institutions governing CPRs have rules in place to discourage the behavior that results from this variation in economic valuation. For example, there are procedures in place to guard against up-gauging in fishing (removing smaller and/or less valuable fish species from a catch quota). This is not an easy problem to address in the NAS because resource valuation is tied to the uniqueness of location and time.

Today the majority of NAS resources are still congestion free. Roughly 20 percent of NAS flights use resources that are congested. Congestion only occurs regularly at a relatively small, yet extremely important group of resources, primarily airports and airspace in and around the busy Northeastern corridors.

Of course other resources can easily become congested because the NAS is made up of a dense and complex network of flights. Major passenger airlines route the same plane through multiple airports in a day, propagating delay across less congested resources. On average the same plane flies to 5 different locations in one day, and 98 percent of these planes will land at least once at one of the top 25 airports during the day (see Figure 7-1). Thus, small incidents can easily ripple through the system causing problems in areas that are normally congestion free.



Source: Airline Service Quality Performance (ASQP) (Airports in the top 25 - ATL ORD DFW LAX LAS PHX DEN IAH IAD PHL MSP DTW CLT CVG SLC EWR BOS LGA MEM MIA JFK MCO SFO SEA FLL)

Figure 7-1. Intensity of the Air Transportation Network

7.4 Managing the NAS: First Come, First Served Equates to Open Access

There is no "one-size-fits-all" solution to managing a CPR in a sustainable way. In a traditional setting, the *stock* itself is a common pool resource, and the *flow* is what can be appropriated by an individual (this is also true for the NAS). Once appropriated, the *flow* becomes private property (like timber from a forest, water from an irrigation canal). Therefore most CPR management systems and institutions focus on who appropriates *flows* by governing how much they take and how often.

Four basic property rights systems for administering the use of common pool resources have been identified over the years. The first two systems are the same traditional methods initially proposed by Hardin in 1968, individual property and government property/regulation. Open access and group property are the other two systems that have been associated with CPR management. Group property is similar to individual property, however buying and selling tends to be more restrictive.

Open access regimes are characterized by the absence of enforced property rights. Some open access resources are common because there is no easy way to limit access (i.e. groundwater basins, migrating wildlife). Others are common because there is no desire to limit access (i.e. Internet). Open access essentially means there are no limits placed on individual consumption, and thus "tragedy" can occur if no other steps are taken to manage the resource.

7.4.1 Flows are Open Access

In theory, the government could limit access to the NAS (excludability), but it chooses to manage it based on a philosophy of "first-come-first served." This situation is akin to what is known as "open access" in the CPR literature and explains why so much "tragedy" occurs as users compete for limited resources.[12]

This is not to say the NAS is completely open for use by anyone in the general public. Both pilots and aircraft are required to be certified. These certification requirements can vary widely depending on the purpose of the flight. For instance, there is a big difference in the certification requirements between a sport pilot and a commercial passenger pilot. However, anyone who meets these criteria can access the NAS, just about anytime and place they chose.[13]

7.4.2 The Stock is Regulated by the Government

While the *flows* (i.e., conducting a flight) in the NAS can be considered "open access," the *stock*, NAS services and infrastructure, are primarily managed and provided by the FAA and airport authorities. The FAA administers the rules, regulations and associated procedures, and also provides the ATC services and NAS infrastructure which enable the *flows* to safely occur.

7.5 Private Property Elements in the NAS[14]

Some elements of the *stock*, such as arrival slots at busy airports during the day, exhibit characteristics that are consistent with private goods (rival and excludable). In these cases, private property and use rights have been advocated. At New York LaGuardia Airport, the FAA is currently in the process of creating a more formalized structure to facilitate this process. However, the lack of a formal backing by the FAA has not stopped the airlines from engaging in activity that is more consistent with use of private property.

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[12] Some boundaries limiting use exist, such as airport noise restrictions as well as restrictions related to use of military resources.

[13] There are many rules and regulations pilots must follow while using the NAS. These regulations should not be confused with access to the system itself.

[14] For a detailed treatment of this issue see Welman, 2005.

Some elements of the NAS are already privately owned, primarily airports and landing strips.[15] It should be noted that these private resources hold little value on their own accord. They must be combined with other elements of the NAS to produce something of value (a flight). Most transportation networks experience increasing returns to a point. The NAS is no exception, the more airports and airspace available to users, the more valuable the network becomes to those who wish to use it.

There are both political/legal and technical hurdles to privatization. While it is not explicitly stated in the FAA's mission, it can be argued that the agency maintains and operates the NAS for use by the public as part of our national heritage. Conceptually this is similar to the "prescription" doctrine for public roads or the public trust doctrine related to navigable waters.[16] Theses doctrines and other related public property doctrines assert that government does not have the right to turn over public resources to private parties. For a historical description of public property origins, focusing on transportation networks such as waterways and roads see Rose, 1994. Particularly relevant to common pool resources, she states:

"... ... commercial travel was a central factor behind the presumption that certain property-notably roadways and waterways-were to be open to the public. When used for commerce, these properties had qualities akin to infinite returns to scale, because commerce becomes ever more valuable as it expands to larger numbers of persons. Thus here, the commons was not tragic at all but comedic, in the classical sense of a story with a happy outcome- the more people engaged, the better off we all become."

The second major hurdle is technical. The technology does not exist to facilitate a large-scale integrated market based allocation. Private property may be able to emerge on a static level, but it will be a technical challenge to allocate rights consistent with dynamic day-of operations. These "day-of" decisions account for the bulk of capacity allocation activities.[17] The transaction and information costs associated with maintaining a market this dynamic and sophisticated are also extremely high.

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15 In this case, private does not include government or quasi-government entities.

16 This doctrine, derived from English Common Law is typically applied to environmental resources and navigable waters. This doctrine is based on the concept of *jus publicum*—a right of public ownership.

17 For the relatively few cases where demand is chronically over capacity, allocative decisions have been made, but so far they have not been based on willingness to pay.

8 Collective Action

In response to increased congestion, primary stakeholders (the major airlines) organized, under the auspices of the FAA, to mitigate the ongoing impact of congestion. As mentioned earlier, this group is named after the process they employ when constructing operational strategies for a day, Collaborative Decision Making.

When, why and how groups organize to avoid "tragedy" with respect to a CPR is an important contribution of the field. A great deal of effort and analysis has focused on identifying factors that lead to self-organization. Over the years a general consensus of variables has developed.

Instead of discussing each of the consensus factors related to self-organization in depth as they apply to the NAS, they are presented here in a table. The factors influencing the tractability or feasibility of self–organization from the consensus theory and subsequent explanation (columns 1 and 2) are directly excerpted from Ostrom's "Reformulating the Commons," which appeared in *Protecting the Commons*. The applicability to the NAS is discussed in the third column along with a notional evaluation (a ▲ means favorable circumstances, a ▼ unfavorable, and a ◀ neutral.).

Table 8-1. Factors That Influence Self-Organization

Self-Organization Consensus Theory	Explanation	NAS Implications
Attributes of the Resource		
Feasible Improvement	Resource conditions are not at a point of deterioration such that it is useless to organize or so underutilized that little advantage results from organizing.	▲ NAS is subtractable across users but not time, so improvement is almost always possible.
Indicators	Reliable and valid indicators of the condition of the resource system are frequently available at a relatively low cost.	▲ The FAA collects and supplies average delay and capacity related information such as runway configuration. A large percentage of use patterns and intent can be found in the published future airline schedules. Because of the sheer volume of data produced, the trick is to process it and turn it into information decision-makers can act on.
Predictability	The *flow* of resource units is relatively predictable.	◀ Airlines typically create schedules based on good weather capacity. These schedules give the FAA an estimate of how many planes to expect at a given place and time. However day-of operations are extremely fluid, with uncertainty coming from both the *stock* and the *flow*.

Spatial Extent	The resource system is sufficiently small, given the transportation and communication technology in use, that users can develop accurate knowledge of external boundaries and internal microenvironments.	◄ While the NAS has a size and scope unrivaled by most resources, technology has made it possible to monitor use. Unfortunately, decision makers are not able to absorb all the data produced by this technology. Data context is very important in aviation because the same variables interact to produce many different outcomes.
Attributes of the Users		
Salience	Users are dependent on the resource system for a major portion of their livelihood or other important activity.	▲ Airlines do not make money if their planes are on the ground. Non-commercial flights are not dependent, but are also more flexible, and typically use congested resources sparingly.
Common Understanding	Users have a shared image of how the resource system operates and how their actions affect each other and the resource system.	◄ The NAS is a very complex environment, so it is difficult for users to know their true impact on the system. (CDM tools have greatly improved common situational awareness.)
Low Discount Rate	Users use a sufficiently low discount rate in relation to future benefits to be achieved from the resource.	▼ Intense resource use today does not affect future benefits. However, for commercial users, it can eventually lead to problems if passengers experience too much delay.
Trust and Reciprocity	Users trust one another to keep promises and relate to one another with reciprocity.	◄ Initially the operational folks at the major carriers worked together to create CDM. While competitors in theory, they all had a stake in improving the system. Oddly enough, when the airlines first began to organize, they did not trust the FAA itself. With experience, this relationship has improved. To reduce this impact, FAA and user roles and responsibilities have been outlined.
Autonomy	Users are able to determine access and harvesting rules without external authorities countermanding them.	◄ Antitrust regulations prohibit this type of activity for commercial aviation, thus the FAA must act as an intermediary. However, day-of operations are discussed and information is shared across users. Antitrust concerns have been mitigated to some degree with user group operational representatives (similar to a lobbyist representing an industry of competitors).
Prior Organizational Experience and Local Leadership	Users have learned at least minimal skills of organization and leadership through participation in other local associations or learning about ways that neighboring groups have organized.	▲ Airlines either have these skills onboard or can hire people with this type of experience.

Key:
▲ = **Favorable**
◄ = **Neutral**
▼ = **Unfavorable**

Each common pool resource system is unique, so the factors favoring self-organization interact differently depending on the resource. The table above only shows the NAS and its users meeting 4 of the 10 criteria in a strongly positive way, and 5 of 10 in more neutral way, with one criteria being unfavorable.

Despite meeting the criteria rather weakly, CDM still emerged. In part, this is because an additional explanatory factor exists. When individuals, or in this case, companies, come together to take positive action on their behalf in a public forum, it is known as collective action. Mancur Olson (1965) explored the situations and incentives that lead to collective action. His theories are often applied to the political realm; however, they also can be applied to this situation. He predicted that small groups with a lot at stake would organize to produce a benefit on their behalf even though this benefit will also be enjoyed by others (free riders).[18]

In the case of CDM, a small, relatively homogenous and powerful user group, the airlines, took action that would ultimately create operational benefits. While these actions will benefit others using the NAS (either directly or indirectly) in the form of reduced congestion and delay, the direct benefits will be concentrated among the organizers. This is because they conduct a disproportionate amount of operations using congested resources compared to others. To address potential criticism, CDM has always endeavored to improve the situation of its members, while not making the situation for non-members.

The rest of this section will detail the workings of CDM and its counterpart TFM. Together they constitute the main mechanism by which use of the NAS is coordinated.

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[18] As mentioned earlier, this situation actually poses a two tiered organizational dilemma, to organize and then to sustain. Organizing to produce the organization to manage a CPR creates a public good (that suffers from under-production). Sustaining the CPR is common pool good.

8.1 History of Collaborative Decision Making

In the early 1990's the major airlines at the time, United, American, Northwest, Delta, Continental, US Airways and Southwest, collaboratively developed a proposal to begin sharing day-of operational data with the FAA.[19] The data is generated by each Airline's Operating Center (AOCs), which oversees day-to-day flight operations.

The airlines agreed to pay for the creation of the Aircraft Situational Display to Industry (ASDI) and provide a dedicated data feed to the FAA via VOLPE. The airlines invested in the technology to gather and transmit the data, and they pay a monthly fee for the upkeep of the data transmission line. AOCnet is the name of the system developed for transmitting this information, since it networks together data from all of the airline AOCs.

The airlines signed a Memorandum of Agreement (MOA) for Collaborative Decision Making, stating they would provide accurate data to the FAA. In return, the FAA agreed to invest in software (that it would also provide to users) to view the data on an airport-by-airport basis.[20] This arrangement resulted in a common situational awareness that has allowed both the users and the FAA to make better operational decisions when capacity is constrained. Once a two-way communication line was established, many additional uses were built off the same platform. For example, the FAA began to transmit weather and operational information back to the users at their request.

In the beginning there was significant distrust among CDM participants and the FAA, because the airlines felt the FAA was violating the spirit of the agreement. They had invested heavily in the data-sharing infrastructure; only to have the main airport capacity allocation algorithm, known as Grover-Jack, actually penalize them for providing up-to-date information. This situation was quickly remedied in the mid-1990s. Since that time, trust and reciprocity has increased considerably among the participants.

After the data exchange process became widespread, some users expressed to the FAA that they should be able to participate and exchange data via the internet, as opposed to a dedicated feed. In response, the FAA now accepts data from either the AOCnet or the internet. This option has made participation financially feasible for many smaller users who would otherwise not participate, such as general and business aviation.

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19 Future daily airline schedules could be found in the Official Airline Guide (OAG), which publishes information up to a year in advance. However day-of information can vary significantly from the published schedules.

20 The FAA contracted with a company called Metron to build the Flight Schedule Monitor (FSM). This is the software the FAA uses to allocate capacity at an airport.

CDM related activities were designed to make participants better off than they would be otherwise, without making others worse off. Over the years, the benefits of participation have been acknowledged, and as a result, CDM has grown considerably. It has evolved from a data sharing arrangement, to include working groups and advisory committees dedicated to solving congestion related problems. To some degree, it is a self-perpetuating situation. The more users that participate in the CDM process, the bigger the increase in the potential benefit pool for everyone involved.

CDM is also important because it gives the commercial aviation industry a forum for developing operating norms that are not considered collusive or anti-competitive. In most operational contexts these types of self-limiting actions would be associated with cartel behavior.

As the group has expanded, many of the initial participants have moved on to other jobs. The trust and reciprocity between users, which is a critical component of any well functioning CPR still exists, but in a slightly different form. As the group has grown, the personal dynamics and relationships that were critical to its emergence now play a much smaller role. Some tension among participants still exists, but it is mainly the result of users trying to achieve different operations goals.

Operational procedures related to CDM are still rather informal. New users or airlines have a steep learning curve because most of the operational information is not available in written form. There is no "welcome to CDM" membership packet given out when you file a flight plan. The ATCSCC has conducted training of its personnel as well as field personnel in an attempt to maintain consistent procedures and their operational applications. The user groups' representatives also try to educate their members via regional forums.

8.2 Operational Rules: TFM

In any functioning CPR system, operational rules exist which govern how a resource's *flows* are allocated among the user community. In the aviation system, these rules are known as TFM. An unwritten expectation exists that CDM participants will follow traffic management initiatives (TMIs) issued by ATC to the best of their ability. In part, this expectation exists because the users themselves have participated in the initial development and testing of these initiatives and rules as part of the CDM process.

Essentially TMIs are actions that curb user's access to resources or redistribute their use over time. Most of these actions are complied with voluntarily by the users when they are alerted to a problem. If a significant TMI is proposed, the FAA will initiate a discussion with the users most likely to be affected, to discuss and determine the exact scope and duration. User input is not always sought. In some instances TMIs are issued unilaterally by ATC. As with any voluntary arrangement some "gaming" occurs.

ATC is structured so that the size and scope of a TMI can easily be adapted to fit a given situation. The choice of a TMI is often made based on the location, duration and scope of the problem. Local TMIs are primarily implemented by individual ATC facilities. The ATCSCC facilitates activities across local facilities when actions are needed on a regional or national scale.

- *Local TMIs include*: Coded departure routes, holding and local ground stops for airport related congestion, as well as vectoring, holding, miles-in-trail, capping and tunneling for local en route congestion.
- *National TMIs include*: Ground delay programs, ground stops and holding for airport related congestion, as well as reroutes, airspace flow programs, en route spacing, and offloads for en route congestion.

Day-of actions taken by ATC that address the less than 2-hour time frame, are considered tactical, such as vectoring around weather. Actions taken to address problems in a 2-6 hour time frame are considered strategic, such as transcontinental reroutes. The traffic and capacity forecasts that feed these decisions are only as accurate as the underlying data. Therefore, it is critical, when trying to predict future demand and capacity of NAS resources, that the data be accurate. If users intentionally or unintentionally provide inaccurate data, it can influence the choice of TMI used, which can lead to additional delay and/or wasted capacity. Once implemented, all actions are monitored and adjusted as conditions warrant.

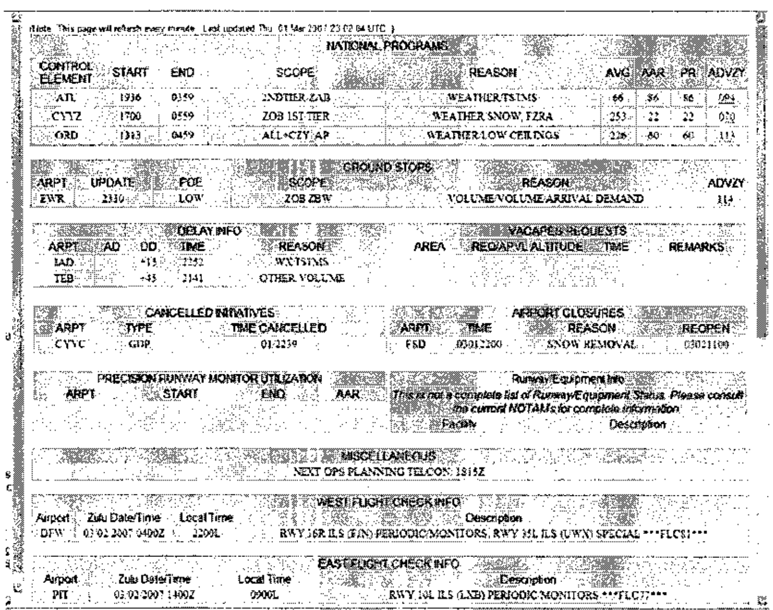
8.3 The Daily Planning Process

Approximately 84,000 flights, using 3,400 airports, occur in the United States every day.[21] In addition to actual flight activity, weather and infrastructure (equipment) can cause considerable variations in available capacity. Processing information about all of these elements is way beyond the comprehension of any one individual or group of individuals. It is also difficult for computers to process the information in a meaningful way because resource values, as well as their fungibility, are constantly changing. For example, weather over South Dakota does not have the same effect on operations as does weather over Pennsylvania.

Fortunately, the situation is not as unmanageable as it sounds at first glance. The list of resources that are regularly oversubscribed is fairly short, and weather tends to follow cyclical patterns. For example, only 50 or so airports in a year see any TMI actions. Of those 50, only 10 or so see actions on a regular basis. However, as mentioned previously, the airports and airspace that are impacted on a regular basis account for a large proportion of flights. A rough estimate of flights that use potentially affected resources would be around a quarter of the 84,000 daily flights.

[21] This approximation is based on FY 2006 OPSNET data.

The FAA has developed a website for communicating NAS status with users, *fly.faa.gov*. This website also contains a database of the national TMIs issued for the day. While the internet has solved the issue of providing information in a standard and easy to access format, there are still many challenges left, such as providing relevant information to the right people at the right time. For example Notices to Airmen, known simply as NOTAMS, vary widely from location to location. For some critical resources these notices only have a few lines, whereas others have pages of information. This makes it difficult for pilots to filter information and find what is relevant to their situation.



Source: fly.faa.gov

Figure 8-1. ATCSCC Operational Information Page

In part to combat information overload, and also to sharpen focus on particularly important and constrained resources, CDM has developed an additional forum to help users and the FAA understand the "big picture." This process is known simply as the "operations planning process." Every two hours participants from industry and the FAA get together via a teleconference to discuss NAS constraints and formulate/discuss a plan for dealing with them. Because time is a critical factor in managing the flows of the NAS, the FAA has reserved the right to make a final decision, essentially a 51% vote, in cases where the group cannot come to a consensus strategy. After the discussion, a plan is issued which outlines expected activities for the next four to six hours.

8.4 Monitoring and Evaluating Outcomes

No collaborative process is complete without review and discussion. In order for individuals of a collaborative process to remain committed, they need to know that everyone is "playing by the rules." That requires some form of systematic review and follow-up.

Users are not required to participate in operational planning telcons, nor are they required to participate in the review process. FAA facility representatives are required to attend telcons both planning and review, but it is not always possible nor is it enforced.

The review process consists of three main elements, the next day review, the end of season review, and the ongoing follow-up, data processing and reporting by the Quality Assurance (QA) department at the ATCSCC.

Next Day Review Telcons:

- First, the FAA regional operations directors discuss and review the day's events via telcon.
- Then the regional directors each hold telcons with their regional users starting at 7:30 am Eastern.
- The head of FAA operations is briefed on the previous day's issues and operations at 7:30 am Eastern.
- The FAA holds an internal review telcon for its facilities and staff at 8:30 am Eastern.
- Finally, around 10 am Eastern the FAA and users have a telcon to discuss broader events and problems from the previous day.

The QA department maintains data and sends out pre-formatted reports that often form the basis of discussion for the next-day telcons. Issues where follow-up is required are investigated by QA or one of its partners, such as MITRE or METRON. Unfortunately, the follow up process is ad hoc.

It is particularly difficult to investigate individual events since there are so many variables in play. Events tend to snowball and cross jurisdictions making it nearly impossible to identify the party at fault. No sanctions or penalties have been levied on users who misbehave or continually send bad data. On the other hand, the FAA tends to focus on safety, as opposed to efficiency. There are penalties for violating safety parameters, but no such incentives (positive or negative) exist for efficiency or equity goals.

Feedback rarely finds its way back to the front lines. If ATC personnel try a new approach to managing traffic, there is very little evaluation or feedback that occurs as a result. In fact, there is no incentive for them to try something innovative.[22] When controllers do get feedback, it tends to be negative. Pilots and dispatchers are rarely exposed to information regarding NAS performance or their individual impact on operations. In most cases, they have no way of knowing the impact their actions have on the system.

At the end of the "severe weather season," an end of season review occurs where the operational group meets in person to address some of the broader more systemic issues. Both FAA and users representatives attend this event. The group has made significant structural and operational changes in response to systemic problems raised in this venue. More recently, customer forums have formed to tackle specific regional problems as well as educate customers who are not as familiar with the process.

Overall, the process of assessment and follow-up is far from ideal. Some feel it leads to favoritism, while others feel it only works for the users who complain the loudest and most often. There is no mechanism in place to make sure feedback gets to the individuals involved in the original situation. Follow-up items are rarely, if ever, tracked and intentional gaming is rarely reprimanded.

8.5 Measuring Allocation Outcomes

As noted earlier, a common pool resource based solution tries to align incentives to achieve a socially optimal outcome. These solutions all require some type of mechanism for allocating resources. The two most frequently cited traits of a desired allocation in the NAS are equity and efficiency. However that is where the consensus ends. There is a great deal of debate over the most efficient and equitable way to run the NAS. Often it is easier to point out situations that are inefficient or not equitable, than to define the desired behavior.

8.5.1 The Importance of Equity

As noted in Table 8-1, reciprocity and trust play an important role in achieving most CPR solution. CPR solutions require users to voluntarily restrain their actions. They often do so based on the trust that others will reciprocate. Reciprocity and trust can collapse if the allocation of CPR *flows* is not perceived as equitable.

Thus, a strong emphasis should be placed on reaching equitable outcomes. In select circumstances, the collapse of reciprocity could also be used as a justification to adopt a less efficient outcome (else, the system of reciprocity could collapse, leading to a highly inefficient solution). For instance, even when arrival capacity at an airport becomes

[22] ATC personnel face stiff repercussions if they violate separation standards. In other words, there is a big downside risk, but no upside reward for trying something new.

unexpectedly available, should "pop-ups" be allowed to use it? If they are, this situation erodes the goodwill of everyone else who was issued a departure clearance time.

Equity, or its close counterpart, fairness, is much more natural to define when users participate in the production, maintenance or purchase of resources. For instance, if someone digs a well in a community, and someone else maintains it, there is a general sense that those two individuals should be entitled to its water before others in the community. In the NAS, entitlement, at least at airports, tends to be derived from precedence. The fact that there is no natural, or even logical way to distribute NAS resources will be a major hurdle in trying to implement any future allocation regime absent a fully functioning market.

8.5.2 Efficiency in a CPR

Efficiency comes in several forms. Operational efficiency refers to the ability to utilize resources for completing an activity with the least amount of physical waste, similar to water or energy efficiency. Economic efficiency refers to making sure resources go to their highest and best use (the least amount of economic waste). The first definition refers to how a resource is used, while the second definition also includes who uses it, and for what purpose. For instance, water can be used very efficiently to irrigate crops with drip systems; however, this may not be the highest and best use of water in a desert. Operational efficiency is certainly possible in a CPR, and has been increasing in the NAS with each passing year as more sophisticated technology emerges.

Unfortunately, a CPR is not likely to achieve true economic efficiency because CPR solutions do not usually involve users making payments in exchange for *flows*. Without the establishment of private property, it is difficult to determine exactly who and how much to pay on such a huge scale as the NAS.

CDM/TFM strives to improve economic efficiency by identifying situations that make users better off while not making other users of the NAS worse off (the definition of Pareto Efficiency). Thus, it can be argued that CDM improves economic efficiency over a pure government allocation. Slot Credit Substitution by users in Ground Delay and Airspace Flow programs essentially try to identify improvements in efficiency as opposed to optimal efficiency.

A focus on identifying improvements is common to many CPR solutions. Oakerson (1992) justified this situation by noting that "some degree of suboptimal use may actually be efficient when the costs of obtaining collective action are taken into account." While CDM has created several programs to enhance economic efficiency for its members, there are still many opportunities that can be found for improvement. For instance, creating credits that can be used across TFM events could enhance efficiency on a larger scale.

9 Design Principles

CDM combined with the FAA's TFM has had a positive impact on the NAS. Increased information has allowed the FAA and users to respond to capacity demand imbalances, thereby reducing delay and gridlock. But how well does the system this group has pioneered stack up to other CPR management systems and institutions? And will it be able to handle the additional traffic forecast to materialize over the next 20 years?

In addition to examining elements that are conducive to collective action, CPR literature has also focused on identifying design principles that characterize long enduring and successful organizations. Exactly why some CPR institutions will endure where others fail is still under debate. What is known is that the variables that have been associated with the emergence of organization are also closely related to the variables that favor sustainability.

The design principles have been organized into a table, with applicability to CDM/TFM briefly outlined. Below are Ostrom's original design principles from 1990. They have been generalized from observations of successful and long enduring CPR institutions.[23] Two additional variables are noted at the bottom of the table, size and homogeneity, because they are commonly discussed in relation to sustainable CPR institutions.

Only three of the eight principles are met with any stringency in Table 9-1. While collective action has been taken to reduce delay and congestion in the NAS, according to the principles below, it does not have a good chance of surviving future challenges.

On the surface, these principles seem like simple straightforward recommendations, but they are part of a self-reinforcing framework aimed at facilitating cooperative behavior. Unlike the factors that favor organization, the design principles tend to have stronger linkages and therefore must all be present to some degree.

[23] Since 1990, additional variables have been identified. Agrawal (2002) has identified up to 24 different variables and states that there could be up to 40. For the purposes of brevity, they will not be examined.

Table 9-1. Factors Favoring Sustainable Management of a CPR

<table>
<tr><th>Design Principle</th><th>Explanation</th></tr>
<tr><td>1) Clearly Defined Boundaries</td><td>Individuals with rights to withdraw resource units from the common-pool resource, and the boundaries of the resource itself, are clearly defined.</td></tr>
<tr><td colspan="2">The NAS has very clear boundaries that have been set by the FAA. Users must be granted the right to operate in the NAS by the FAA (both airlines and pilots).</td></tr>
<tr><td>2) Congruence</td><td>A. The distribution of benefits from appropriate rules is roughly proportionate to the costs imposed by the provision rules.
B. Appropriate rules restricting time, place, technology, and quantity of resource units are related to local conditions.</td></tr>
<tr><td colspan="2">A. This will be assumed; otherwise, users would not participate. For example, there are personnel and software costs associated with processing, monitoring and executing TFM actions. The delay and cost savings per incident may not exceed these costs, but overall it is expected to be favorable.
B. ATC facilities and airports regularly report on local conditions that determine capacity. Rules for allocating this capacity then become active if it is not believed to be sufficient. Unfortunately, the operational rules that exist can be very vague and subject to interpretation.</td></tr>
<tr><td>3) Collective-Choice Arrangements</td><td>Most individuals affected by operational rules can participate in modifying operational rules.</td></tr>
<tr><td colspan="2">Users have multiple avenues for participation at all stages of the process. Participation opportunities include CDM committees (which create the operational rules and programs), day-of telcons (which determine when to execute the operational rules), and the day-after telcons which evaluate performance.</td></tr>
<tr><td>4) Monitoring</td><td>Monitors, who actively audit common-pool resource conditions and user behavior, are accountable to the users or are the appropriators themselves.</td></tr>
<tr><td colspan="2">There is a great deal of monitoring that occurs in the NAS. The NAS infrastructure is continually monitored to determine capacity and projected demand levels. Flights under positive radar control are constantly monitored in civilian airspace. This data is available to users and ATC facilities in various forms. However, monitoring occurs in the NAS to ensure safety, not to police behavior. As a result, there is almost no accountability regarding user behavior. In addition, commercial users are sensitive about sharing information with others that they consider proprietary or competitive. Thus, the FAA tends to inherit the role as the primary monitoring authority.</td></tr>
<tr><td>5) Graduated Sanctions</td><td>Users who violate operational rules are likely to receive graduated sanctions (depending on the seriousness and context of the offense) from other users, from officials accountable to these users, or both.</td></tr>
<tr><td colspan="2">This does not occur, nor is there widespread support for it. TFM is a relatively new program for the FAA. Older programs related to safety and operational regulations all have monetary (fines), or behavioral incentives attached to them (loss of certification). Without clearly defined operational rules, there can be no sanctions.</td></tr>
<tr><td>6) Conflict-Resolution Mechanisms</td><td>Users and their officials have rapid access to low-cost, local arenas to resolve conflict among users or between users and officials.</td></tr>
<tr><td colspan="2">No formal mechanism exists. Most complaints are handled on an ad hoc basis typically through the review process.</td></tr>
</table>

Design Principle	Explanation
7) Minimal Recognition of Rights to Organize	*The rights of users to devise their own institutions are not challenged by external government authorities.*
This is true to a point. For anti-trust reasons, the commercial carriers cannot directly engage each other in operational discussions. General aviation and business aviation do not have these same considerations.	
8) Nested Enterprises	*Appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises.*
Since the FAA is responsible for many of these activities, it tends to execute them in a centralized/hierarchical fashion enabling relevant decision-making authority to occur at the appropriate level. Other governmental agencies can also create policies that will have an affect on the NAS and its users (i.e. security).	
Additional Factors	**Explanation**
Size	*Most researchers feel that group size negatively affects a group's ability to organize in a sustainable way. This is primarily because transaction costs increase and social norms breakdown with group size. (i.e. information gathering and production, bargaining and decision, monitoring and enforcement). However, empirical research has not led to an unambiguous conclusion.*
It is hard to draw any conclusions about the effect of group size on the NAS. In theory, the more members that participate in CDM and comply with TFM, the better it is for all involved. On the other hand, as participation increases it has become more difficult to come to a consensus on the right approach (i.e. local issues can sometimes override national concerns). The informal norms of operation have already eroded considerably.	
Homogeneity	*Homogeneity can have many dimensions, economic, values, as well as resource use.*
The NAS is made up of a very diverse group of users. Solutions to delay/congestion based problems are not easily found because users value different attributes of the NAS. For example, airlines tend to value predictability, whereas business and general aviation tend to value flexibility. These groups also tend to use resources differently. For instance, freight haulers tend to fly at night when competition for resource use is minimal. Business and general aviation tend to use reliever airports; however, these airports still share the same congested airspace with the major airport they relieve. Small operators do not usually have the incentive or the knowledge to participate in the process.	

Source: "Design Principle" and "Explanation" are taken directly from Ostrom's "Reformulating the Commons", which appeared in Protecting the Commons.

The design principles that are absent from the current system, such as graduated sanctions, conflict resolution, and monitoring of user and FAA activity, are key candidates for future progress. While these concepts are rather heretical when applied to air traffic, they are a vital part of our surface traffic system. For example, automated monitoring and sanctioning mechanisms such as red light cameras have become relatively common in congested urban environments.

There are many caveats that come with crafting a sustainable and self-reinforcing institution. For instance, the cost of monitoring and enforcing rules cannot outweigh the long-term net benefit users receive from complying with them, otherwise they will not participate. This simple example illustrates the delicate balance and interdependencies these principles are based on.

Considerable research has been done to identify factors that help increase cooperation and efficient outcomes. This information should be applied when solutions are evaluated against operational realities. For instance, one particularly interesting finding; there does not seem to be a significant difference in outcome between rewarding good behavior and punishing bad behavior (Kopelman 2002 summarizing experimental research). This is a very promising option, since the user community does not endorse punishment or sanctions related to TFM/CDM.

9.1 Likelihood of Sustainability

The goal is to create a system under which the average user views restraint and coordination as rational behavior. This is much easier said than done. CPR concepts are just now being applied to a broader range of situations. Many of the original concepts, while relevant, may need to be adapted considerably to be applied to the NAS in a meaningful way. As stated earlier, there is no magic bullet.

9.1.1 Challenges

Some of the specific major challenges the system will face as a CPR are discussed below. This is by no means a comprehensive list of challenges. It is merely a demonstration that many of the challenges the NAS is facing can be generalized as the same type of problems that plague all CPRs. In fact there may be some challenges that the NAS will not be able to overcome.

The challenges presented below have primarily been drawn from principles/factors related to the emergence and sustainability of CPRs. Some initial suggestions in response to these challenges are presented in the next section.

- *Operational Rules: Documentation and Implementation*
    - Most operational rules related to TFM/CDM are not written down anywhere. Many of the rules that do exist are vaguely worded and open to considerable interpretation. Attempts should be made where possible to tighten and expand

on these rules. Of course, operational discretion is needed and should not be taken away from a controller or pilot.

  - TMIs and their implementation are not standardized. The ATCSCC has gone to great lengths to capture some of the localized initiatives that commonly occur in response to weather and other events. However, that does not make it any easier for users and other ATC personnel to process and act on this information. Procedures can vary considerably from facility to facility. This fact makes it difficult for those who do not use the same resources on a regular basis. While most CPRs encourage localized solutions, some standardization is necessary because users of this resource are highly mobile and interact with many facilities.
  - Designing operational rules and procedures that are viewed as both efficient and equitable by all participants is very challenging. To be effective these rules must be continually adapted to new circumstances.

- *Increased Heterogeneity:* When CDM activity was first initiated, the major airlines formed a small and relatively homogenous group. Since that time the industry has become highly fractured as new business models have evolved to compete for the same resources (i.e. fractional jets).[24] This makes the process of managing resource use by consensus much more difficult.
- *Reduced Reliance on Trust and Reciprocity:* Now that CDM membership has grown, the "social capital" that was so important to its initial formation has slowly been eroded. With no one to keeping track of users' actions, they may be more inclined to "defect" as they do not feel as strong an obligation to fellow members to play by the rules. Another more proceduralized system will need to be developed to take the place of this loss, as well as increased monitoring.
- *Resource Predictability:* CPR solutions work best when the rate of change is incremental. This gives users and the institutions they have created, time to adapt to the changing conditions. The NAS is very dynamic, and thus subject to substantial amounts of uncertainty. CPR institutions may not be able to fully reconcile this phenomenon. Even if monitoring, graduated sanctions and conflict resolution are implemented in a reasonable way, they may not be very effective given the dynamic nature of the NAS.

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[24] According to the Airline Service Quality Performance (ASQP) data from January 1995 and January 2007 the amount of reporting carriers has doubled. ASQP data is collected for carriers having more than one percent of the total domestic scheduled passenger revenues.

- *Increased Level of Coordination:* Legal, challenges based on anti-trust, may be brought up if some users feel they are not being served well by increased coordination and allocation of the CDM system.
- *Managing the NAS as a CPR:* Not all resources need or should be managed as a CPR. For these resources other solutions, such as private property or government regulation, may be superior, as long as they provide equitable and efficient results.
    - Not all resources in the NAS are rival. Regulating some resources and not others on a dynamic basis is very challenging because it is nearly impossible to make sure all individuals involved in the process are aware of the operational constraints. While the ATCSCC has tried to address this on an ad hoc basis, more proceduralized mechanisms need to be put into place.
    - TFM/CDM system is not designed to handle situations where demand is chronically in excess of available capacity. In these situations, the government has stepped in to allocate arrival slots at places such as New York LaGuardia and Chicago O'Hare. The rationale given for this action was that massive delays, resulting from the open-access environment, propagated throughout the NAS, negatively affect other users, and therefore use needed to be constrained.
- *Collective Action*: Ironically, the same collective action that created CDM may also prevent it from becoming an enduring institution. The commercial passenger airlines have a very strong lobby and may oppose further efforts to regulate or restrict traffic flows in the NAS.

9.2 Recommendations

If managing the NAS as a CPR is to be seen as a viable near-term solution, implementing that solution cannot take 10-15 years. Most changes in the aviation industry are evolutionary. Very few are revolutionary. Large new technical systems and the infrastructure they require do not get implemented overnight.

It is the author's recommendation that CPR solutions be pursued for the short term, in conjunction with a longer-term vision. CPR solutions are attractive because they do not require a massive overhaul of the way the system currently works. If that much time and effort were needed to implement a CPR solution, then a more market based solution would likely result in a more satisfactory investment of time, effort and funding.

9.2.1 Short-Term Suggestions

Listed below are some very specific suggestions of changes that can easily be made and implemented today that would improve the functioning of the NAS as a CPR. Again, this is by no means a comprehensive list, but a demonstration that there is still a lot of low hanging fruit.

- Increase standardization for both procedures and information about the system. This reduces the information and transaction costs associated with operating in the NAS.
- Reward good behavior with preferential treatment (these rewards should be specific to a given set of resources). This would also create a critical secondary effect, in that airlines will have an incentive to keep their data accurate, to demonstrate they have complied with all TMIs.
- Identify specific actions that are especially detrimental to they system because they erode goodwill (pop-ups), then design procedures to prevent their use of certain resources or penalize them.
- Create tiered access to resources. If users obey the operational rules, more access is granted. Flying is a privilege not a right.
- Give users more input into how the fees they pay into the system maintain and invest in infrastructure.
- Create a structured and accountable system for feedback and evaluation.
- Increase coordination and use of Military resources (primarily airspace) to reduce system bottlenecks.
- Work toward anti-trust exemption for day-of collaboration at capacity impacted airports. By the time the operational day arrives, most passengers have already paid their fares. However the extreme delay and inconvenience they experience under the current system must still be weighed against any harm that could come from the anti-trust exemptions.

9.2.2 Long-Term Suggestions

Longer-term solutions are ones that will take more time and funding to implement. These two suggestions are primarily aimed at improving the overall design and functioning of the NAS as a CPR.

- Increase investment in technologies that allows the FAA to allocate resources at the bottleneck (arrival slots as opposed to departure clearance). This will reduce the ability to game the system and increases operational efficiency.
- Use modeling and simulation to determine if costs associated with compliance and enforcement outweigh the benefits. Use this information to improve the system design by creating an appropriately balanced system.

9.3 Is There an Ideal Governance Mechanism?

Solutions for managing CPRs are finely tuned to their users' needs and the resources they govern. Hence, there is a risk that a CPR management solution that was designed for today may not work 10 years from now unless it is able to evolve.

As mentioned earlier, there is a broad spectrum of mechanisms that govern common pool resources. Each is characterized by differing types of property and access arrangements. Some solutions are not excusive to one regime or another. For instance, CPR design principles such as monitoring and enforcement are also critical to a system of individual rights and property. If these rights are not actively monitored or enforced then the system is akin to open access.

Determining and implementing a workable long-term, stable governance mechanism will not be easy. Further evaluation of this line of research is certainly warranted.

10 Conclusion

As the amount of air traffic continues to increase, the NAS's resemblance to a CPR will become increasingly obvious. This resemblance can already be seen today as traffic and delay have once again reached record levels. The NAS exhibits a surprising degree of conformance with CPR concepts and user behavior. As predicted by the literature, users currently collaborate with the FAA to help mitigate congestion and delay. However this arrangement is not likely to last because it lacks many of the components of a self-sustaining CPR institution.

Categorizing the NAS as a common pool resource will not solve the complex problems and associated congestion. However, this categorization can help guide decision makers towards the appropriate set of solutions.

Both empirical and experimental research has greatly contributed to our knowledge in the field of common pool resource management. This study only touches the surface in terms of how that knowledge can be applied to better allocate NAS resources. However, it is our hope that this study will spark additional interest in some of the techniques that have been successfully applied in other common pool settings.

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Glossary

AOC	Airline Operating Centers
ARTCC	Air Route Traffic Control Center
ASDI	Aircraft Situation Display to Industry
ASQP	Airline Service Quality Performance
ATC	Air Traffic Control
ATCS	Air Traffic Control Specialist
ATCSCC	Air Traffic Control System Command Center
ATCT	Airport Traffic Control Tower
ATL	Hartsfield - Jackson Atlanta International Airport
BOS	General Edward Lawrence Logan International Airport
CDM	Collaborative Decision Making
CLT	Charlotte/Douglas International Airport
CPC	Certified Professional Controller
CPR	Common Pool Resource
CVG	Cincinnati/Northern Kentucky International Airport
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DTW	Detroit Metropolitan Wayne County Airport
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FLL	Fort Lauderdale/Hollywood International Airport
FSS	Flight Service Station
FY	Fiscal Year
IAD	Washington Dulles International Airport
IAH	George Bush Intercontinental/Houston Airport
JFK	John F Kennedy International Airport
LAS	Mc Carran International Airport
LAX	Los Angeles International Airport
LGA	La Guardia Airport
MCO	Orlando International Airport
MEM	Memphis International Airport
MIA	Miami International Airport
MOA	Memorandum of Agreement
MSP	Minneapolis St. Paul International Airport
NAS	National Airspace System
NOTAM	Notice to Airmen
NPR	National Public Radio
OPSNET	Operations Network
ORD	Chicago O'Hare International Airport

PHL	Philadelphia International Airport
PHX	Phoenix Sky Harbor International Airport
QA	Quality Assurance
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
SLC	Salt Lake City International Airport
SUA	Special Use Airspace
TFM	Traffic Flow Management
TMI	Traffic Management Initiative
TMU	Traffic Management Unit
TRACON	Terminal Radar Approach Control
US	United States
VFR	Visual Flight Rules

Price, David Allen

From: Gentry, Jennifer L. [jenniferg@mitre.org]
Sent: Tuesday, August 28, 2007 4:46 PM
To: Ostrom, Elinor
Subject: RE: New Commons Application - Aviation
Attachments: Final approved MP070080.pdf

Just wanted to send you a copy of the document I prepared inspired largely from your works. I already presented a small aviation focused portion to the Air Transport Research Society, and plan to submit a smaller CPR focused version to the International Journal of the Commons. The attached document is the long and detailed version for delivery to our FAA sponsor.

Thanks again for your inspiration. Some of us really do take what we learn in our college classes and try and solve real world problems. Please note the acknowledgements section.

Jennifer Gentry
Lead Economics Business Analyst
MITRE Center for Advanced Aviation System Development
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From: Ostrom, Elinor [mailto:ostrom@indiana.edu]
Sent: Saturday, March 17, 2007 7:17 AM
To: Gentry, Jennifer L.
Cc: Erling.Berge@SVT.NTNU.NO
Subject: RE: New Commons Application - Aviation

Dear Jennifer – Glad to hear the study is moving along. One possibility is the new journal on the commons that will start later on this year – The International Journal of the Commons – edited by Erling Berge. I am sending a cc of this to Dr. Berge and I hope he has time to send you a note re how to submit. I am at Michigan State right now and don't have access to my files so I can't give you the website etc. It is a journal interested in the many aspects of the commons.

Regards, Lin Ostrom

From: Gentry, Jennifer L. [mailto:jenniferg@mitre.org]
Sent: Thursday, March 08, 2007 6:45 PM
To: Ostrom, Elinor
Subject: RE: New Commons Application - Aviation

Professor Ostrom -

I have just about completed my study (one last section left). So far I am rather pleased with it. The National Airspace System (the aviation system), makes a perfect case study of users organizing to avoid/mitigate tragedy. Of course, the big question is whether it will endure or collapse as more air traffic materializes.

I am hoping to publish this in a journal. Could you suggest a peer reviewed journal that focuses on the field of common pool resources?

I also wanted to thank you for all your inspiration, I have thoroughly enjoyed reading your work as I researched this paper.

Jennifer Gentry
Senior Economics Business Analyst
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From: Ostrom, Elinor [mailto:ostrom@indiana.edu]
Sent: Wednesday, November 29, 2006 7:56 AM
To: Gentry, Jennifer L.
Subject: RE: New Commons Application - Aviation

Dear Jennifer – Wish I could recommend someone but no one comes to mind right now that is not also busier than heck. Good luck with this exciting study. Regards, Lin

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From: Gentry, Jennifer L. [mailto:jenniferg@mitre.org]
Sent: Tuesday, November 28, 2006 4:28 PM
To: Ostrom, Elinor
Subject: RE: New Commons Application - Aviation

Wow, thanks so much for your response. (I have to admit I'm a bit giddy right now, as you are what I would consider an academic celebrity. =)

I am very excited to learn this area has not been explored much.

I don't feel I am qualified to do this study justice on my own, so I was hoping to find a professor to collaborate with. I am looking for someone who could guide me in the appropriate application of CPR (while I provide subject matter expertise).

Obviously your name shows up every where I look, but I imagine you are quite busy. Would you by chance have someone to recommend? I looked up Professor Plott's bio, and I don't get the feeling he is very active anymore. I had already tried my professor at UCSD, but this topic area is no longer a big concentration for him.

Thanks again,

Jennifer

From: Todd, Nicole [mailto:stodd@indiana.edu] **On Behalf Of** Ostrom, Elinor
Sent: Monday, November 27, 2006 8:29 PM
To: Gentry, Jennifer L.
Subject: New Commons Application - Aviation

Dear Jennifer:

Your request is quite interesting. I do not know of much work on the congestion of the airways as a commons. I do know that Charlie Plott did a really fabulous article at an earlier juncture on the problem of scheduling runways. He used experimental methods. I think if you look under Plott in a Google search or something like that you will find his vita. I think it is about 20 years old, but I am pretty sure it has runway landings or FAA in the title. If you do not find it easily, send me a note and I will check in my bibliography. I am just away from that right now and will not be able to get back to it for a day.

The new commons that Charlotte Hess and I have been looking at is the digital commons. We have a new book coming out with MIT Press where we are looking at the change in technology that has affected traditional library versus modern digital publication.

You might find my book on *Understanding Institutional Diversity* just published last year by Princeton of relevance. I try to look at the nature of goods and how we can explore that with experimental as well as theoretical treatments.

Other than that early work by Charles Plott, I cannot think of anything else that would help you in your search.

Best regards,

Lin

/nt

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