BUILDING A FRAMEWORK FOR APRON PLANNING, DESIGN, OPTIMIZATION, FUTURE PROOFING AND EXPANSION

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I would like to especially thank my committee chair for his encouragement to return to the academic realm. I would also like to thank each of the members of my committee for their encouragement in specific and directed ways. While a PhD can be an overwhelming task through the encouragement of my committee, I was never in doubt about being able to contribute not only to my industry but also to the study of systems engineering. I would also like to acknowledge the support of my family especially my wife Harriet, who encouraged and helped in many little ways through out this process.

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LIST OF ABBREVIATIONS

AIAA	American Institute of Aeronautics and Astronautics
3D	Three-dimensional
FAA	Federal Aviation Administration
GSE	Ground Serve Equipment
PAN AM	Pan American World Airways
SEBoK	Systems Engineering Body of Knowledge
STS	Socio-Technical Systems

ABSTRACT

Wing, Adam, K., PhD University of South Alabama, December 2022. Building A Framework For Apron Planning, Design, Optimization, Future Proofing And Expansion. Chair of Committee: Robert J. Cloutier, Ph.D

Airports are a significant economic driver that impact local and national interests. As such, in an ever connected world, these critical components of infrastructure face a growing number of influences which contribute to systems complexity and frequently impede further development. The point of this dissertation is to discuss and highlight the benefit of systematic thinking as planners approach airport planning challenges and update the aging aviation infrastructure in many regions of the world.

This dissertation looks at a series of three papers that, examine the impact and influences of technology, distinguishes the effects of social and procedural changes, and offers one solution to simplify systems planning and integration within the aviation industry. The first paper presented is an examination of the history of Pan American World Airways through a data centered look at the growth of the fleet. The second paper examines some of the current and impending risk broken into categories, based on an examination of socio-technical systems. The final paper offers a solution a new system that could be constructed at an airport, which could simplify an aircraft turn around

process and help future proof airports for some of the expected changes that will impact the aviation industry. The solution proposed in CHAPTER V offers an example of a systemic change to the development of the apron area. This new concept integrates most of the apron area systems into a single system for aircraft loading and unloading. This work shows the need to accommodate industry changes as they develop, and clearly identifies some of the most obvious challenges and risks that face the aviation industry. This work further offers one method for solving and avoiding the costly interventions usually required to overhaul a system when emergent behavior necessitates a physical change to the infrastructure of the system.

As with the development of any dissertation, much of this document has been updated and improved actively throughout this process. While this is a final document there is always more that can be added. This provided a complete overview of the apron area though and provides a clear contribution to the aviation industry.

CHAPTER I

INTRODUCTION

Local economies are impacted by port facilities far more than most other infrastructure; port facilities include local seaports, railway shipping facilities, shipping and distribution centers and most importantly for the movement of populations airports. Though all port infrastructure has an impact on the local economy the one most likely to see large changes in the near future is the airport facilities. In the analysis of the global aviation network, there's value in approaching aviation as a historic complex socio-technical system of systems which displays emergence, memory, and functions as an indicator of international standing. By examining the aviation industry through the lens of history we are able to begin establishing trends and patterns that have developed over time as airlines have grown and contracted. Using the history of the industry as a starting point, it is possible to analyze a series of potential risk factors that the global industry may face as it approaches its 120th year. Examining and categorizing the risks associated with the evolution of the century old aviation industry, this work provides some qualitative measurement for assessing the impacts of the risks to the industry while discussing and proposing some methods to avoid that risk. After establishing risks and potential costs of risks based on the history of aviation, this work proposes a new system to facilitate the aircraft turn around with in the apron. This new system is proposed to illustrate a framework for systematically considering potential replacement systems within the airport environment. By developing a holistic approach to aviation systems, this work provides inputs for planners, operational teams, and future engineers that will start a conversation about system properties that could face changes over the coming years. This work is meant to contribute to the body of knowledge within the aviation industry by forcing the conversation about system utility and the implementation of new technology. This work is also meant to provide some domain specific application of systems engineering principles and provide a specific solution to alleviates some of the impending risks associated with technological growth in the aviation industry.

1.1 Overview of Work Presented

This works has been broken into several distinct chapters including: a literature review, a review of the history of Pan Am, an analysis of current risks facing the aviation industry, the development of a new proposed infrastructure and then a review of the systems thinking process used to develop the proposed infrastructure. Each of these chapters came from a somewhat unique goal and direction but were all developed in preparation for the writing of this dissertation.

The literature review chapter began as a mostly undirected examination of systems engineering research, especially focusing on the intersection of systems and aviation history, specifically calling on articles that focused on the apron area. In an examination of the apron area and the systems that support aviation, this study highlighted several points in the history of the aviation industry that had an impact on the development of aviation systems or on the airports in particular. This review of literature also included an examination of some of the risks associated with the growth of infrastructure within the industry. When examining risks, the scope of inquiry quickly grew to include governance and economics which are intentionally omitted from most of this work as they have the potential to become separate bodies of work. This literature review also grew as each of the papers presented in the work pulled together more references.

The review of the Historic Pan American Fleet chapter presents a full paper published by AIAA which specifically examines the data publicly available through the Pan Am historical society. This work started as an academic review of the information available but culminated in a published paper that used modern data science to clearly identify key moments and changes in the fleet data that impacted not only Pan Am but the development of the entire industry.

The review of risks chapter is also based on a paper submitted to AIAA with an expected publication date a January 2023. This paper began as a thought experiment that looked as some of the most imminent pressures that are likely to impact the aviation industry. This started with some of the most obvious social and technological change such us the need for more efficient aircraft and a desire to travel faster than currently possible, and then looked at the impact of some of the new technology that has been proposed like the use of hydrogen fuel or the incorporation of batteries or fuel cells to drive more efficient turbines. To understand the full scope of some of the changes anticipated across the aviation industry, this work focused on categorizing the changes to help define which changes would be sustainable long term. This work then looks at the impacts of some of these changes proposing a set of measures that can be used to qualitatively measure the impacts of any changes that need to be made across the entire industry.

The framework chapter presents a paper introducing and defining a new system for the terminal interface. This work began as a thought experiment looking to fundamentally alter the airport landscape through a systemic change to the framework of airport development. From this the secondary goal was to integrate as many of systems that service passengers and aircraft in order to streamline the turnaround process within the apron. This work looked at past changes to the infrastructure of airport terminals and offered suggestions on what needs to be considered when building or proposing innovative design elements at airports in the future.

The final element of this dissertation is the review of the systems thinking process that was required to propose the innovative new infrastructure design approach. This is largely a documentation and reflection on the process and the work associated with building the systems engineering model for the new apron area system.

1.1.1 Portfolio Based Dissertation

The work presented in his dissertation represent three of the papers I have written over the course of my studies into systems engineering and aviation. Having worked on dissertation in part for several years before joining the industry professionally, the body of knowledge and the work that I have collected over the years is far more broadly reaching and covers our range of topics. The three papers presented here, represent a concise grouping of work that collectively show a contribution to the way planners should consider systems thinking when designing airports. While this has been exclusive and completely isolated from my professional roles, the concept presented in this dissertation has all been shared with colleagues and will become a reference point in my professional work moving forward. The chapters of this work begin at a general airport and network level analysis in a literature review in CHAPTER II, before focusing on a specific airline, to analyses the historic system changes in CHAPTER III. The system analysis then looks at potential risks to the status quo within a specific apron area in CHAPTER IV. This work then builds on the history and current risks by developing new system to integrate sub-systems within the apron environment which can be implemented at any airport. This work is developed in detail in CHAPTER V and the resulting reflection and review of a partial framework for understanding system impacts is then discussed and presented in CHAPTER VI.

1.1.2 Overarching Themes

The work presented within this document represents the current work performed in pursuit of a doctorate level contribution to the systems engineering and systems thinking within in the airport environment. There are three papers presented each with a different focus but each supporting the development of a framework that can be used to understand the impact of change and the development of a systems view that could generate major efficiencies gains in any infrastructure reliant industry. These papers work together by building up a systems thinking approach, starting from a historic data analysis, to an examination of the current limitation of the industry systems, and then developing a new system that accommodates changes in the industry. These three distinct papers will provide a forward focused review of system design and planning within the aviation industry that allows planners to mitigate any reduction in service level while containing costs associated with reacting to system changes.

1.2 Problem Statement

Airports, like most large infrastructure are expensive and therefore tend to grow in incremental jumps and only in small areas where the infrastructure has reached the end of its life. By growing incrementally airports faces many challenges, both technically and socially, as new elements are added to the system. While some of these challenges are considered as airports continue to grow, frequently systems are replaced with similar systems, resulting in lost opportunities for innovation. When changes do manage to propagate, the lessons learned are not always shared and are often quickly forgotten or ignored especially in other regions. These lessons can be ignored out of neglect or ignorance but tend to lead to the same result, inefficiency in the airport design. Sub-systems are designed in isolation and the airports do not consider their role in the larger network. This is an inherent problem but causes more acute problems as distinct elements of the system are integrated into the larger system to achieve the intended functionality. This type of integration can result in waste in the system due to a miss match of capacity or due to restrictions within the growing system. Much of the waste can be avoided however if airports are designed and expanded systematically drawing on lessons learned from earlier projects. This can be done if the designers understand the impacts of past industry shifts and the lessons the previous industry changes can teach about dynamics within the system. Past risks can help to identify the next risks that designers might encounter. Facing new challenges early allows airport systems to be more agile and responsive, allowing them to maintain currency and continue to attract customers. Agility also allows airports to embrace a plurality of new technologies to accommodate multiple potential outcomes. Responsiveness allows airports to maintain its current customer base while responding to requests and reacting to some changes that may not have been considered in the planning process. The slow pace of airport change has presented an opportunity to consider systemic thinking to produce a more robust, agile and responsive system to allow airports to maintain currency into the future.

1.2.1 Purpose of Work

This dissertation is a series of papers focused on system change, impacts of those changes and potential mitigating factors that will help the industry experts anticipate and accommodate some of the most imminent industry changes. The goal of this work is to encourage a systematic approach to new infrastructure design and implementation at airports. It is also hoped that this work will provide a discussion point for airports that currently resist change through vigorous maintenance of the status quo.

1.2.2 Industry Lessons Learned

This work examines the historic lessons learned by examining the system wide changes that were implemented by Pan American World Airways and their founder Juan Trippe. Since the decline of Pan Am and the deregulation of the industry, most systematic changes have come from reactions to specific events that force isolated adjustments in regulations. This means that rather than examining the entirety of the aviation system, or developing new systems that benefit the industry, changes are made in seclusion altering only one element of the system at a time. Isolated changes across the aviation industry come from a lack of understanding of the interconnected system elements that have direct system wide implication across the aviation industry. While many airport planners and designers understand the specifics of their local airport and of the systems associated with the project at hand, many airports plan for the existing system ignoring the wider systemic impact of changes. This myopic focus leaves room for the development of a systems thinking framework that can be used to develop a sustainable future apron system, or even a full strategy to help develop a more efficient aviation industry as trends change over time.

1.2.3 Unpredicted Risks

Historically aviation has changed generationally as an industry. Many of the generational changes come from an innovation in only one facet of either infrastructure or enabling technologies. The changes in infrastructure and enabling technologies, have not systematically developed to support a specific future system. Many of these technologies have rather grown out of an explicit need, or a small opportunity. The idea behind this work is to highlight some of the potential opportunities available to incorporate systems thinking across the entire industry, in order to develop new infrastructure and enable the use of new technologies for sustainable, scalable growth.

By identifying some of the systems that have had the most profound impact on airport operations, this work will establish some trends that can be used to help identify and consider some of the key risks that may face the industry in both the sort and long term. This work is meant to provide insight that might help identify what would have previously been unpredictable risks to the support systems and the aviation industry as a whole.

It is important to note that while not all risks can be identified and many cannot be controlled even if they are identified, the identification of as many risks as possible will help planners mitigate the impact and help anticipate any potential major future cost.

1.2.4 Forward Planning

Though there have been generational shifts in aviation and technology seen throughout the passenger journey, airports have not fundamentally changed in more than 60 years. From an industry that used to change dramatically every 10 to 20 years after 60 years of jet aircraft parking nose in and having jet bridges extended to their port side forward door, aviation and the method by which passengers board and disembark aircraft is past due for innovative or dynamic paradigm shift. A change to the boarding process, may not be isolated however, this type of change could force a transformation not only in airport infrastructure but in airline operations. If considered in the system context this evolution in the infrastructure could lead to a network wide efficiency gain.

The goal behind this work is to help facilitate and provide a potential new framework that could be developed at any commercial airport in the near future. In short, this work provides insight to not only the past and current risks facing the industry but also provides a systems framework that can be used as a method for demonstrating to airport managers and planners that the existing system do not have to remain the status quo.

1.3 Background

Airports have operated in a relatively similar fashion for more than 100 years. While the systems within the apron and across the airport have evolved and changed over time to accommodate new technology and growing demands within the industry, there has not been a paradigm shift in the way airports develop or operate over that time. Some of the key developmental changes within the airport environment come from the changes in aircraft size and operational capability. In association with the physical changes, social elements of airport systems and emergent behaviors have developed over time. Social changes and pressures at airports directly impact policy making and therefore the development process. Beyond physical and social changes, technology has also impacted airports by altering human interfaces and directly impacting the passenger journey in the terminal and on the aircraft. These changes however have not fundamentally altered the operations of an airport where an aircraft, lands, taxis, parks, and is serviced in a stationary location. From the stationary parking location aircraft are then pushed back and proceed under their own power to reach the runway and begin their next flight.

As aviation reaches 120 years old it is valuable to begin thinking about potential changes to the structure of the industry. The goal of this work is not to solve the imminent problems that face aviation but to discuss and highlight some of the strategies that need to be considered. By examining the past, the present, and one potential future, this work is meant to offer insight and systems thinking to positively impact some of the changes in the aviation industry. While this work began focused on the apron area and looking at the turnaround of aircraft, much of this work has grown to examine the system as a whole and particularly the development of emergent behaviors and the impact of social and technological changes on airport development.

Throughout this work there are several themes that link the work on development together. The first is the need for systems thinking and the lack of system planning in current infrastructure development. The second major theme is the impact of both social and technical systems on airport development especially in a system wide context. The final major theme is simplification and unification of the systems at an airport.

Incorporating all of these ideas, this work includes three papers that culminate in a proposal for an apron system framework. To gain efficiency and to provide a new approach to an airport and apron, this work provides a plan for an integrated parasitic apron system that connects to an aircraft along its entire forward port side. This proposed system provides necessary connections between the apron and the aircraft including the connections for fuel, cargo, passengers, maintenance engineers, cleaners, and caterers; the system framework also allows the inclusion of marshaling service, power, air conditioning, heating, water, and waste services to the aircraft. Though the proposed system concept is almost as far-fetched as the circular runways that were proposed in 2014[1], this new framework develops the systems thinking approach, highlighting some considerations to help better define the needs within the aviation system. This work also helps to identify a few important areas in which planners and operators need to collaborate and plan carefully to accommodate a series of potential future outcomes.

1.3.1 History

Powered human flight began in 1903. It was not long before heavier than air aircraft were being developed into you global economic drivers. After 120 years. There is value in looking back and assessing some of the key changes that have impacted the industry and specific airlines over that time. The analysis of history takes a distinct data centric look at the inflection points based on the fleet data available for Pan American World Airways. Examining the history of a particular airline through data analysis, the goal of this work is to provide insight into historic airlines and develop a snapshot of key moments throughout aviation's history.

Replacing much of the role of marine ports in earlier time, the systems that support aviation and have developed into an international network that facilitates the transaction of goods and people fostering trade and economic success.

1.3.2 Risks

Analyzing risk is frequently done through economic measures to provide a quantitative measurement for planners, designers, and future engineers. The analysis presented in this work, however, provides a qualitative measure looking specifically at the impacts that changes could have on the airport. CHAPTER IV presents a draft of a paper on the risks facing aviation specifically looking at the disruptors and imminent changes likely to face airports around the globe. This work has developed focusing on three categories of innovation or advancement that all have the power to disrupt the status quo. This analysis builds on the historic context examining a specific airline, and identifies several key elements used to differentiate periods of time to help establish the frequency with which the aviation industry faces direct change. From the historic focus, this paper examines the current state of the aviation industry as traffic recovers from the global pandemic and analyze what technology, processes, and social influences will impact the industry in the near future.

1.3.3 Framework for Future Growth

It is not possible to future proof mass infrastructure for all potential outcomes. As such is can be cost prohibitive to try, it is therefore far more beneficial to focus on future proofing some specific elements that have potential to impact the industry. The work presented in CHAPTER V focusses on the impact of specific changes within the apron area directly adjacent to terminal facilities. The goal of this work is to provide potential new solution that could be implemented at airports to replace the existing infrastructure and help future proof against one or some of the impending changes that will face aviation as an industry. CHAPTER V provides an example in the form of a paper which develops a new proposed facility type under the framework of future proofing airport infrastructure. Through this paper, design principles are discussed and the potential benefit of integrating many of the systems of systems within the apron area are explained in the context of future proofing the airport facilities.

1.3.4 Scenario Based Introduction

Airports have been, and will likely remain, large complex systems of systems with many independent system elements. The systems at airport are often separate systems based on the level of required infrastructure and cost to maintain each of the systems. The independence of airport and apron systems requires a high level of integration. The cost and integration requirements together mean that airport systems do not change quickly and that the fundamental changes that have occurred within the aviation environment have largely impacted one system at a time. The idea behind this work is to simplify several systems and fundamentally change the way systems are integrated within the apron area. The scenarios outlined below help identify some key changes in the process and stakeholders that may be involved in the turnaround of an aircraft. These scenarios also highlight some of the key issues that planners need to consider and the broader group of stakeholders that should be considered in not only planning measures but in the future proofing of the entire airport.

1.3.4.1 Base Scenario – The Systems of Today.

The systems of today are built around the premise that all services need to come to the aircraft in order to turn the aircraft around. At any given airports more than 10 systems will have to interact with an aircraft before that aircraft is prepared for its next flight. Each of these systems has a particular location, role, and precise timing in order to minimize or optimize the ground time of a particular aircraft. The typical turnaround leaves an aircraft in a standard location while workers from each individual system swarm around the aircraft performing their specified duties. Fuelers approach and park under the starboard side wing, baggage loaders approach the starboard side front edge of the aircraft and rear cargo door, caterers wait their turn and approach the starboard side passenger doors all while the passenger jet bridge is moved into place to allow passengers on and off the aircraft. In addition to fuel baggage, caterers, and passengers there are also maintenance personnel water and sewage services and inspectors, all of which also approach the aircraft. The intricacy of the coordination that takes place in the apron displays a well-coordinated and choreographed procedure where any single element could significant delay the departure of a flight. While most airports have perfected their local system and many have found ways to gain significant efficiency, the fragility of the apron area system cannot be ignored. One trolley being left unattended without the breaks being set, can delay not only a single flight but entire network; as an example of this fragility in April of 2022 a single Qantas jet was damaged by a rogue baggage trolley; this caused a global disruption to the Qantas Dreamliner network.

1.3.4.2 Scenario 2 - An Integrated Terminal Interface.

With an integrated terminal interface system, the idea is that rather than a swarm of personnel and equipment from different systems all approaching the aircraft a single system will be used to dock and service an aircraft. This means that, rather than each system requiring a unique interface, each system would have elements within the terminal interface that could be used to achieve the objectives of that system. As the aircraft parks at the gate rather than many systems converging to begin the turnaround process a single system would approach the aircraft and would provide an interface for fueling, baggage, catering, and passengers. Rather than each vehicle being dependent on a finely coordinated choreography and being required to fit into a specific gap, each element would already be in place and would simply need a user to connect the required connectors. The system would be an integrated system that would accommodate a range of operation types.

1.4 Hypothesis

As the aviation industry emerges from the largest downturn it has ever faced, there are inherent systems changes that will begin to shape and change the ways the aviation system develops in both the short and long term. This work will provide a framework and methodological approach to categorize and measure change within the aviation industry. This measurement will provide a way of thinking to consider any changes and the impact that those changes have on the industry. By providing a way to think about future changes the goal of this work, is to provide a roadmap for aviation planners to follow as they plan for, the integration of new technologies, or accommodation of changes in the social systems.

Designing a Specific Hypothesis

- A systematic development framework can be developed to support long term planning across the entire aviation network.
- Systems thinking and data science can be used to highlight and identify inflection points throughout the history of a specific airline or across an entire industry.
- Measurements can be developed that offers support or direction to aviation planners and designers as they conceive the next generation of airports.
- Through this work of, examining history, identifying risks, and developing a specific solution, this work will develop a roadmap to systematically analyze an entire industry as it faces changes and inflection points.

Through historical analysis, it is possible to establish past risk factors faced by the aviation industry, to identify Potential future risks, and then to develop a simplified future proof integrated system for the operation of aviation. This work will follow through a historical approach into an analysis of current risks and build up a future system to benefit and simplify operations within the apron area.

1.5 Methodology and Approach

This section discusses changes in the direction of this work, some of the methods by which this study has developed over time and some of the themes that tie the three main papers together into a cohesive contribution toward systems thinking within the aviation industry.

1.5.1 Origin of Work

This work was meant to be a continuation of a master's thesis titled "*Taking a systemic Modeling approach to the Apron area at Major metropolitan airports"*[2]. This master's thesis was built around the premise that any system can be systematically modeled to identify the cheapest opportunities for optimization. This work stopped short of building a full scall operational model of the apron area but proposed that the model could help identify shortcomings of the system and point toward the best option to overcome the shortcoming in the system.

1.5.2 Identification of the Apron Area

The specific apron area focus was born out of a hole within the simulation space surrounding an airport. At the boundary of the passenger space within the terminal and the aircraft movement space of the taxiway/runway and airspace, there is a change in the frame of reference that splits many of the metrics used to measure efficiency and utility of a system. By focusing on the integration between the aircraft and ground services, a clear gap in the understanding of the systems emerged.

After some study, it became clear that the hole in simulation due to the change in the frame of refence, also meant the defining boundaries within apron areas were rather ambiguously defined. Building a frame of reference became an important task in the discussion of simulation. Discussing what elements are included in the system and what items are being processed and moved through the system, lead to a larger examination of other systems that integrate passengers, supplies, cargo and staff onto a single vehicle for transport. Looking at a series of mass transit infrastructure elements helped solidify the focus within the apron area and led to a conversation about simplification of the airport system of systems.

1.5.3 Theme of Simplification

From the qualifying exam associated with this work, a detailed review of the apron area led to the theme of simplification. With a new theme, this work found a somewhat new direction focusing on the system thinking required to construct efficient apron areas. After some directed thought it became clear that a specific infrastructure element could be developed to simplify and merge several current systems. By developing this new system with a systematic approach, a framework could be developed that would help develop future infrastructure.

1.5.4 System Rather than Framework

Building on the basic framework concept, and aiming to future proof the airport, this work is built on a thought experiment to integrate systems within the airport into more efficient, optimized systems. As this research has developed, the specific focus on building a framework for future proofing and system development, has altered somewhat, leading to the proposal of a new system in the apron area rather than a general framework. While the focus of this work became the specific system being proposed the steps followed and resulting basis for a framework can still be used to develop future infrastructure. The framework became a byproduct of the system developed in this this work and works more as an example of how to incorporate systems thinking into the planning process than as a final framework for systems development.

1.5.5 Benefit of Work

Though the future aviation systems solution presented is not developed enough to be marketed to airports globally, this work offers a clear view of a future of the aviation industry which is a clear benefit to planners and airport designers. This work further provides benefits to the aviation industry by providing a clear link between historical impacts, the current risks, and innovative thinking that can help to reshape and revitalize the industry. This work is not just relevant to the aviation industry though, it provides solutions for forward looking invitation to any infrastructure heavy industries as the global economy recovers from the global pandemic and associated down turn.

1.6 Keywords

Apron Area: the area adjacent to the terminal. The apron area (or ramp area as it is called in some areas), is the integration zone where passengers and cargo are loaded and offloaded from aircraft as they prepare for a subsequent flight. The operations within the apron are discussed in some detail in this work especially in CHAPTER V but the base function of the apron area has largely been covered in other works, some authored by me and many authored by others.

Turn Around Time: the time an aircraft is on the ground and is being actively worked on to either unload or load the aircraft in preparation for a future flight.

CHAPTER II

LITERATURE REVIEW

This literature review section summarizes a multitude of sources identifying key elements used in the examination of history and industry risks. This section also identifies some resources that pertain to the design and futureproofing of the aviation system in particular the apron area directly adjacent to the terminal area. This section also touches on some of the systems engineering elements that help in defining the scope of the system of interest and proved the direction for most of CHAPTER IV and CHAPTER V. While this section is not meant to be exhaustive, it is mean to provide the reader with sufficient background and understanding of systems and the aviation industry that the work presented in the later chapters needs fewer explanatory notes.

2.1 Airport History

The airport network around the globe, has developed in distinct historical groupings based on a variety of factors. The required interconnectivity between airports and airlines means that governance, is one of the most obvious drivers of function and the planning principles used in design and growth. The governance of an airport is determined by the time period when aviation originated in the region, and the development of airline partners. Though governance becomes a driving factor of airport development, development is also determined by specific function and availability of technology when an airport is built. This reliance on governance and technology can either limit an airport, or it can push an airport further, setting up the industry for a generational change. As technology and governance within industry change, they directly impact the physical planning principles of the airport over time.

Some of the distinctive characteristics of airport system groupings can be seen by comparing airports within a region to those in other regions around the world. For example, a comparison of the earliest airports in the United States, which developed when the postal service started exploiting the speed of aircraft to deliver mail faster, versus the early airports in Europe, which were either entirely rebuilt or were not originally build till the Second World War, highlights differences in the proximity to the city, the size and the legacy system constraints, at the airport. The growth of aviation in the United States continued in close proximity to city centers with airports often positioned downtown or near the downtown area on the water. Many of the European airports which dramatically changed thirty years after the first flights, were in areas where several runways could be constructed, and military structures could also be built. After the end of the Second World War as aircraft continued to grow and civil aviation began to expand all over the globe the primary purposes of these early airfields had to change. Over time much of the original purpose of the airports around the world has been erased through redevelopment, but some of the emergent behaviors can still be observed.

Though there seems to be some debate as to the frequency of generational change it is clear that airport change in distinct generations at some interval between 5 and 30 years.[3, 4] Each of the generational changes has an impact on the aviation industry as a whole. The question is what facet of the industry do these changes, impact the most? When passengers started taking flights along with the mail, the postal air carriers were forced to design and build passenger facing facilities. Each airline however, got to make decisions on how they wanted to incorporate passengers on their aircraft. The original incorporation of passengers onto flights was only one of the events that impacted the development of the industry. In the United States, the system of airports was recognized in the 1946 Federal Airports Act as the government began to respond to the growth in the airline industry.[5, 6] The laws enacted in the United States provided for funding and pushed local development of airline infrastructure to support the growth of aviation.[5] This funding and the rules set up to govern the systems allowed the local authorities to direct local development. The airport and the airline decision making has continued to influence airport development and the resulting combination of decisions has led to each airport manifesting as a unique set of systems at one end of the passenger journey.[5] It is not enough for an airport to be a single node in the airport system though, it must be a part of the network and aligned with an airline partner or partners in order to grow and expand its offering.[7] Most airports expand offerings by incorporating technology, and local culture into the passenger journey or incorporating more systems into the airline turn around process. This extends the impact of the airport, connecting them to the economic wellbeing of the local region they serve, offering both employment and economic incentives for an area.[8]

As time and technology change, in aviation, the generational changes that the infrastructure goes through must be supported with investment and maintenance.[4]

When passenger jet travel was introduced in 1951, on the De Havilland Comet, the industry was pushed to implement new standards that would shape the development of aviation thereafter.[9] Some of the changes required were simple like the need for thicker glass in terminals, to withstand the pressure from jet blast, others were more invasive however like the need for jet bridges to get passengers up to the height of the aircraft door. The implementation of these changes at airports however, was expensive. To support the first wave of major changes needed to support the industry, as it began to see jet travel, the United States government paid more than $1.2 billion to modernize the national aviation infrastructure while they also enacted protocols to unify the United States airport system in the Airways Modernization Act of 1957.[5] The process of supporting the development of airports has continued despite some major changes in carrier networks. As airlines grew, many large carriers discovered that the most efficient model for passenger operations was a hub and spoke model that allowed the transport of more people to more places over series of connecting flights. As technology has developed and aircraft have gotten more efficient, the preferred airline model has shifted. The technology changes coupled with the deregulation of airlines in 1978, changed the demand on infrastructure further.[5, 10] As the demand and structure of the industry changed in the United States and globally, the aviation network changes impacted many airports, which required changes in the supporting infrastructure including those systems found in the apron area. The changing infrastructure needs forces a continuous investment into the infrastructure. It is estimated that the United States alone will need $128 billion worth of infrastructure investments over the next five years which has climbed from estimates of $71.3 billion in the five year leading to 2017.[11] This investment will allow the necessary updates to infrastructure and facilities to cope with expanding demand. This doesn't take into account the likely shifts in the travel market after Covid however this figure only includes the estimate to expand infrastructure to cope with forecasted demand the same way it would be processed today.

Currently the movement of aircraft and the flow of passengers, shapes how investments are distributed. This work is meant to add to the body of knowledge of aviation and provide insight into the gap between where aircraft are moving and where passenger facilities meet the aircraft. By completing this work, the goal is that the framework developed will help define how the $128 billon infrastructure investment should be spent to best support the growth and changes in the aviation industry.

2.2 Apron

An airport apron is a complex series of systems that must integrate in an appropriate timely manner to facilitate the turnaround of aircraft. Around the world, aprons are distinct based on may factors that are both physical and operational. The primary purpose of the existing series of systems is to facilitate an efficient, Aircraft Turn Around (turn) for the airline customers. In order to facilitate the efficient turn, there are several things that must be in place or available in close proximity. To illustrate some of the major elements associated with a turn, the Boeing Dreamliner is being used as an example. The images show below in Figure 1. Service Layout of a Standard Boing 787-9 Aircraft - Source Boeing Airport Planning Manual and Figure 2. Terminal Operation Turntime Analysis; Boeing 787-9 Aircraft – Source: Boeing Airport Planning Manual [12] offer insight into the complexity and integration required to turn around a Boeing

787 aircraft based on the Airport Service manual. These images are used to identify each of the recommended services for a single aircraft turn. While not an output these images are being used to show the advantage simplification of the systems in the apron area.

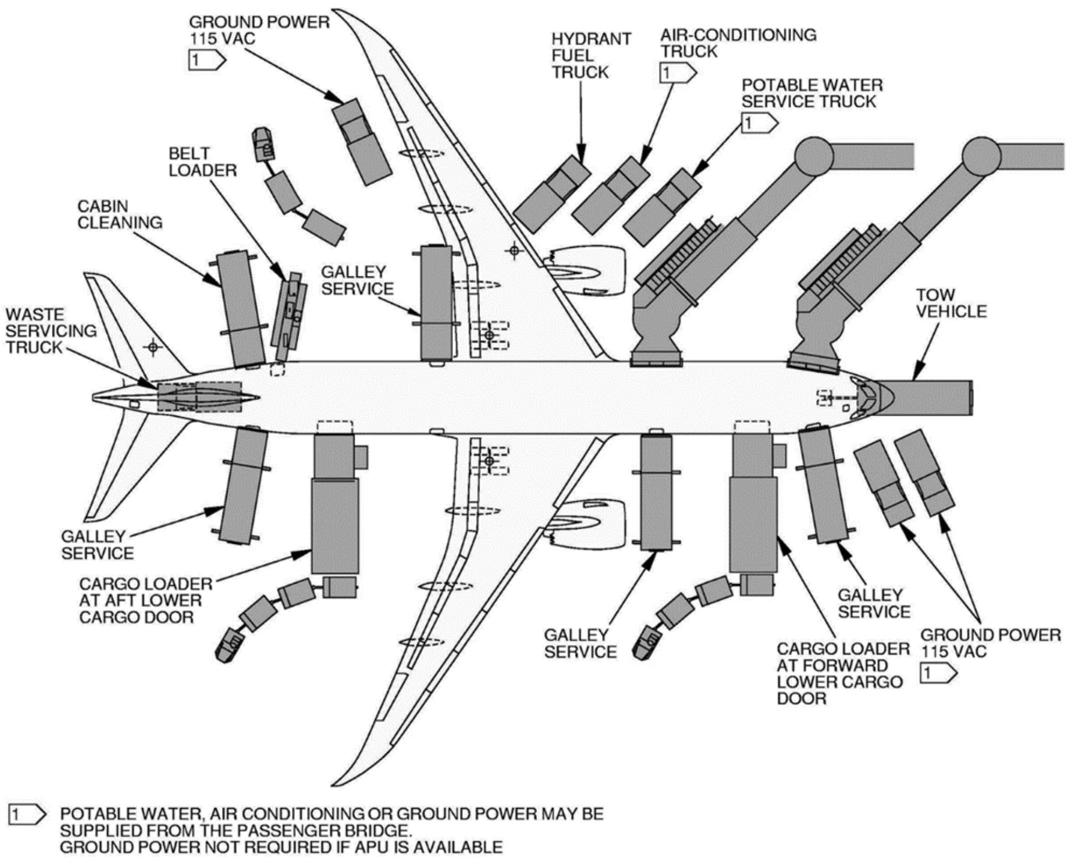

Figure 1. Service Layout of a Standard Boing 787-9 Aircraft - Source Boeing Airport Planning Manual

For a standard turn of a single Boeing 787 Dreamliner aircraft Boeing has provided reference showing 18 distinct service vehicles. Though some of the vehicles identified interact with the same external systems, this diagram is still representing a series of at least 10 systems that interact with the aircraft in the apron. This does not include any additional services that the airline requires or elects to offer such as premium passenger transfer and maintenance facilities.

A list of the services provided is listed below:

- Waste management
- Cleaning
- Cargo loading
- Gallery service
- Fuelling
- Air conditioning
- Potable water service
- Towing
- Ground Power
- Passenger Boarding

In addition to the standard layout Boeing also provides a timeline of the standard turn around process. By providing the standard layout and Gantt chart of standard turnaround time, Boeing offers a snapshot of the complexity involved in turning an aircraft. This information will be referenced in the generation of the full frameworks as this provides the base set of requirements that need to be included in a system to turn wound an aircraft. This diagram also shows the critical path identifying the cargo loading and unloading as the time critical element in this turn around process. While this requires some critical assumptions this analysis does indicate that the simplification of the cargo and baggage loading could reduce the required ground time of the Boeing 787.

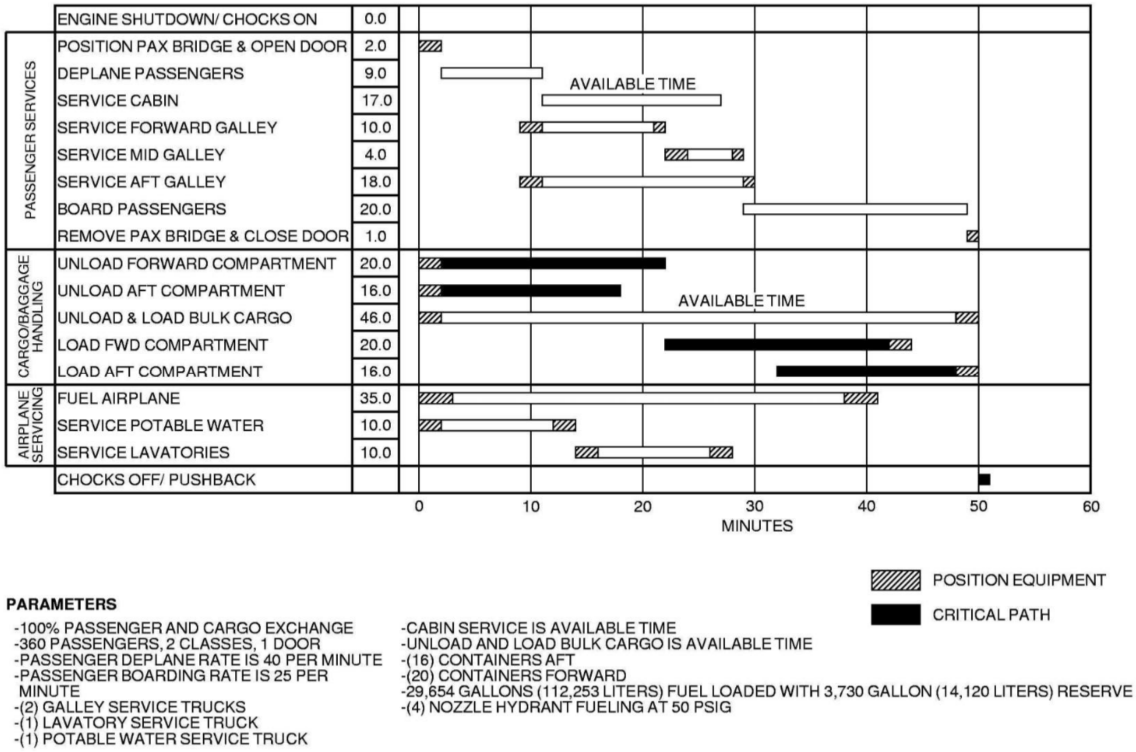

Figure 2. Terminal Operation Turntime Analysis; Boeing 787-9 Aircraft – Source: Boeing Airport Planning Manual

2.2.1 Variations

While many elements within the aviation industry have changes throughout the years the general requirement within the apron area have largely stayed the same since the introduction of commercial jet traffic. This section discusses some of the variation that can be observed in the apron area and also highlights some of the limitations in the predictability of the variation based exclusively on external factors.

2.2.1.1 Runway Size Variation

The relationship between the runway and the apron has far more to do with the required size of the apron than the service provided (and the variation thereof); runways and specifically the controlled throughput of aircraft, determine the number of aircraft stands needed. At a well-designed airport, the maximum number of aircraft on the ground on a “busy day” should match the number of available stands at the airport[1] and traffic scheduled should not exceed a specific throughput capacity of the runway[13-15]. This means that there should be a balance across the airfield between the runway and the stands available in the apron. This also means that except for major urban airports, the number of stands at a typical airport is less than the theoretical peak runway throughput. There are some case where the number of stands can vary from the optimal balance, and may exceed the theoretical throughput[2], but generally a runway has a fixed maximum throughput, and the number of stands grows to meet the total demand which is largely driven by the airlines schedule up to the ultimately capacity which is capped by the runway throughput. While the number of stands is related to the runway throughput it is also valuable to note that the number of aircraft on the ground is directly related to how quickly they are processed at an airport. If an airline turns an aircraft in 20 minutes, they can get more aircraft on a single stand than an airline that take closer to an hour between flights. This quickly gets into some further nuances of gate planning that fall outside of the scope of this work.

[1] The demand for the number of stands is up for some debate by industry professionals. To reduce costs most airports do not plan to accommodate all aircraft that can be on the ground at the absolute peak; instead, many airports plan for a busy day that represents the assumed traffic load. According to the FAA designers should select the peak month average weekday when determining a design day, while the IATA recommendation is for 95th percentile busy day.

[2] The most direct example of a deviation of the balance of stands is in India, where every aircraft flagged in India is required to have a dedicated stand at its base airport meaning there are almost always more stands than there is runway capacity. The opposite is true at many large hub airports especially airports that are constrained like New York LaGuardia or London Heathrow, these airports have optimized the runways so far that they frequently end up with aircraft congestion on the ground waiting for a gate to become available.

In addition to the impacts of runway operations on the size of the apron, runway sizing, positioning (relative to the apron) and number of exits, all of which are also largely outside of the scope of this work, are valuable to consider and useful to understand. Runways have a set of legally standardized minimum widths that define, not only which aircraft are allowed to operate, but also classifies the airport. If the runway does not meet the minimum width, the airport will not be certified for air traffic operations. Because the width is standardized, the size variable is the length which can limit some aircraft from taking off.[3] The length is usually based on the land available and cost constraints, most commercial airport construct runways as long as possible within their financial limitations. Runway length, and direction calculations and length extension decision, are carefully considered due to their expense and their ability to limit operations by excluding types of aircraft from landing or departing. It is important also to consider the position of the runway as it can limit the height of an object (even aircraft tail height) within specific envelope called the Obstacle Limitation Surface(OLS); the restriction on height of aircraft tails within the OLS usually has limited impact within the apron because it is usually far enough away to be outside of the restricted zone; if a designer or operator has constructed an airport that conflicts like that, they have done it very poorly. The OLS is more frequently obstructed by other obstacles in the local airspace, such as buildings or landscapes. The final element that has some impact is the ease of use of the runway and specifically a pilots ability to reduce their time on the runway. When there are more exits the operational capacity of the runway goes up because aircraft do not

[3] High, Hot, and Heavy are the three variables that frequently require more runway length. The relationship between these three can be seen in service manuals for all major commercial aircraft. m

require the runway for as long. This leads to a higher throughput and there for the potential for more aircraft on the ground and a larger apron. Even when considering the runway from multiple points of view, the conclusion remains the same, a runway does not play a defining role in the variation of services offered in apron operations, it is far more indicative of the apron's size.

2.2.1.2 Primary Apron Variation

There are four primary contributors to the variations in services provided within the apron area. Though the four items listed here are not the only factors that impact variations in service, they are however the factors that can most closely explain variations in services. The four most distinct factors that impact services offered are:

- Airline Operational Model – LLC VS FSC
- Fuel Required
- Doors Used
- Cargo Hold Containers

2.2.1.3 Key Variation in Apron Variation

Each of the four key factors listed above that impact apron operations and services, ultimately impact total time an aircraft is on the ground. These factors can either limit the required aircraft turn time or increase the require turn time. The airline operating model for example, determines the time available thereby generating a level of urgency based on the schedule. Some airlines can turn a narrow-body aircraft around in 15-20 minutes (and they do) if they have appropriate staffing levels and are prepared; in many cases airlines avoid minimum turn-around times, in favor of building more resilience into the schedule.[4] So even though an airline can turn the aircraft in 15-20 minutes, they are more likely to provide 45 minutes to an hour for the crew to turn the same aircraft. This buffer allows airlines to better maintain the schedule especially later in the day when the airline may need to absorb network delays. Scheduling is an operational consideration, which is entirely dependent on the airline's operating model; operating models can largely be simplified to two distinct types of carriers Low-Cost Carriers (LCC)s and Full-Service Carriers (FSC)s. An LCC wants each of their aircraft flying for as much time during the day as possible. They do this by reducing the extra services provided both on the ground and in the air, stripping out as much excess cost as possible. The cost cutting differentiates these airlines from FSC, which are less worried about the tight turn arounds and are usually more interested in continuity of service, meaning they are more likely to accept a short delay to make sure extra passengers arrive at their destination.

Ignoring the differences in these operational models, and looking instead at specific airlines, turn time and operations do vary based on size of aircraft. They are seldom directly correlated, however. In the case of increasing size, the most direct impact of the increased turn around comes from increased cargo capacity and increased fuel requirements. Larger aircraft consume more fuel for a given flight, meaning they have to "uplift" or take on more fuel. Like with fueling your car, the fuel system throttles the amount of fuel dispensed from the hydrant system to maintain safety. So, for aircraft like the A380 super jumbo the limiting factor for the aircraft's time in the apron is fuel load

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[4] "Aircraft Turn Times" is the subject of numerous papers including three that I have written. I however no longer believe that simulation is an appropriate method for quantifying turn times to generate more efficiency. Though an aircraft could be turned at one airport more efficiently, if the schedule cannot be altered later the aircraft will inefficiently be left at another airport in the network for a longer period of time

required. As an example, a standard A380 Super Jumbo has a standard fuel capacify of 323,546 liters of fuel[16]; a hydrant fueling system can deliver up to approximately 3,500 liters per minute of fuel per pit [17]; so in order to fill all ten fuel tanks of an A380 the airline needs a minimum of 92 minutes of fueling (This can drop to 48 minutes if two fuel trucks are available to fuel through two ports – i.e. right and left wing). Even with 550 passengers on board, the A380 Airport service manual suggests the de-boarding cleaning and boarding process can be accomplished in 66 minutes. This represents an ideal situation however and airlines that fly the A380 are not likely to turn an aircraft in only 60 or 90 minutes. At airports like Dubai, the A380 superjumbo aircraft are frequently on the ground for a minimum of 120 minutes. (a supplementary paper has been drafted on the limitations of fueling and airport fueling systems, this paper is available upon request). It is worth noting here that the volume of passengers and cargo on larger aircraft are not the limiting factor because frequently larger aircraft are serviced using multiple doors. If all 550 passengers on an A380 had to exit through the same front door as all 189 passengers typically do on a standard B737[18], it would take more than the expected three times longer due to the congestion but on an A380 it is common to load/unload from 3 doors keeping the passenger processing times in line with the smaller aircraft. The final key variation that impacts operations is the containerization of cargo and baggage. Small aircraft only have loose cargo holds, larger aircraft however carry cargo and baggage in ULDs or "cans," which aggregate the cargo and baggage prior to its loading on the aircraft. There are many more factors that could have an impact the operations of the apron and the turnaround process, but the elements presented here represent the most critical variances in the passenger aircraft turn around process.

To further explain the variation in apron area operations the following table provides a list of the major considerations and the impacts.

Table 1. Elements That Impact Airport Turn Around Operations

Elements Impacting operation	**Specific Example**	**Description**	**Impact**
Hold Containers	ULDs	Consolidates baggage and cargo into discrete units rather that allowing free cargo to be loaded into the aircraft	Reduces cargo loading / unloading time at aircraft
	Loose Cargo	Most all aircraft have loose hold areas sometimes they are the entire cargo hold other times it is one specific area in the aircraft	Increases cargo loading / unloading time at aircraft
Location of Main door	Mid plane entry	Allows a diffusion of passengers after their entry into the aircraft	Reduces PAX Loading Time
Number of Passenger Doors	Front and mid doors	Allows separation of passengers or diffusion of passengers prior to entry onto the aircraft	Reduces PAX Boarding / Deplaning
Boarding system	Loading Bridges	Simplifies movement of passengers keeping them on a similar level and off of the apron	Simplifies PAX Boarding / Deplaning but can delay start
	Air Stairs	Stairs are simpler to position and connect to the aircraft and do not rely on aircraft positioning or precision operation to prevent damage	Speeds up marshalling process
	Mobile Lounges	A vehicle that is used to transport passengers from a lounge directly to an aircraft loading door. Often on scissor lifts that can raise to meet any aircraft and deliver distinct groupings of passengers to or from an aircraft	Simplifies boarding process but can complicates deplaning and marshalling process

Table 1, Cont.

Fueling system	Hydrant system	Pressurized system allows higher volume of fuel to be loaded into aircraft	Reduces over all fueling time
	Tanker Trucks	Slower system that can only load the volume of the truck and pumps at a slower rate	Increases over all fueling time Simplifies marshaling
	Number of fuel points	Loading from more than one point is possible on larger aircraft	Reduces over all fueling time
Stand Position	Terminal Gate	Stands along the face of the terminal allowing direct access to the aircraft for loading and deplaning but they also put the aircraft very close to physical obstacles under its own power	Reduces time to Unload/Load Increases marshalling time
	Walk out gates	Are further away from the terminal allowing more freely flowing operations but passenger must walk from the terminal	Increases load time
	Remote Stands	Aircraft parked far away from any infrastructure meaning that everything must be transported to the aircraft	Eliminates marshalling but most complex loading logistics

2.2.2 Constants

The only constant factor in apron operations is that no two flights will be totally identical. Airlines will operate similarly for most of their own flights so there will be an operational similarity but over all there is very little that will always be similar. The below list continues four operational constants that mostly hold but includes an exception for three of them.

Table 2. Four Operational Constants

Constant	Exception
Passenger & Cargo Loading/ Unloading	At the origin or the destination of a flight all passengers and cargo must be unloaded, at least most of the time. There are some exceptions like if the cargo is going on the next flight too, it can sometimes be left loaded on the aircraft. There are some operations however where an aircraft has to stop to pick fuel or new crew, where nothing/no-one gets on or leaves the aircraft. This is far more common for smaller aircraft without the fuel range for longer trips but is also common for international flights where any loading or unloading would subject the entire aircraft to customs and border screening. *
Fueling	Most of the time aircraft need to 'uplift' fuel for their next flight but there are some cases where an airline elects to fly with enough fuel for the return or next flight already on board.
Marshalling	Jet aircraft usually need to be pushed back away from the terminal and provided with power and compressed air to start their engines. In some layouts, there is enough space for the pilots to start an APU and then power the aircraft forward out of its parking position eliminating the need for a push back or ground power or air.
Exiting the Runway Area	Though mostly outside of the apron area, the path of an aircraft as it exits the runway takes it directly to an apron or parking stand. The exception is “touch and go's”, or training flights but these do not touch the apron area

**Pilots still usually have to do a walk around and will have to be able to exit and re-enter the aircraft which will usually require stairs.*

2.2.3 Other Considerations for Apron Operations

In addition to the main system wide variations, the below list includes other operational considerations within the apron area.

1. Height of aircraft door (Range from 8 - 30 feet)[16, 18, 19]
2. Layout of Main landing Gear
3. Weight of Aircraft

4. Wingspan Aircraft
5. Engine thrust – Jet Blast is damaging and dangerous so aircraft can only use their engines in certain areas.
6. Range of next flight – impacts fuel load, and catering needs but can also impact other services
7. CBP rules – international clearances are frequently required. In most countries there is both immigration and emigration checkpoints
8. Number of galleys
9. Jockeying allowed – Aircraft on the ground and the servicing of the aircraft become far more complex because an airport does not operate in a first in first out configuration. Aprons and airports operate in a more Jockey style environment, where aircraft are able to leapfrog one another in departure queues and services can be prioritized by airlines and operators, accordingly.
10. Environment – different climate conditions require different operations like de-icing in cold climates

Variation is one of the only constants in the apron area. Though size of aircraft is a factor in determining operational variance, the runway does not impact the apron operations directly. The operations, within the apron are most direct impacted by, the operational model of the airline, the total fuel required for the next flight, the location and number of doors used and style of the cargo hold. The factors that are mostly consistent are, the loading and unloading, the fueling, the marshalling, and movement away from the runway. In addition to factors that cause variation there are also a series of consideration when providing services to aircraft; while this section does not include textbook level detail for all of the variations in the apron area, it provides a relatively comprehensive list of considerations that will be referenced through-out the development the proposed apron area system and the corresponding framework.

2.3 Governance

Organizations and enterprises face several managerial challenges as they grow to include multiple, organizational, functional, and operations frameworks. One of the most important and sometimes obvious frameworks is the oversight structure or the method by which an organization is organized and governed. There are many different organizational and governance structures that have developed throughout history and across many industries. Of the many unique governance structures, there are two primary governance structures that are seen most frequently in aviation. The first governance style is public entities which are run by governments or quasi-governmental organizations; these organizations are designed to provide public benefit and utility in particular market sectors. The second governance style is private corporations, which largely focus on profits and advancement within the particular market.[20] In addition to private corporation and government entities, there are two more distinct governance structures including, not for profit or voluntary community-based organizations, and specialized ownership funds. In addition to the four unique governance structures there are also a variety of governance styles that fall in between these structures. After introducing airport governance (in 2.3.5 Governance Structures) the following five sub-sections briefly describe each of the governance structures including a list of some benefits and concerns about each governance style, specifically within the airport market. Each section also includes some examples of airports that operates under the defined governance structure. While this discussion stops short of identifying an optimal governance structure for an airport, the concluding remarks offer some thoughts on the advantages of mixing and matching some of the key elements of governing structures.

Many organizations can be clearly categorized into one of the four unique governance categories based on the product or service they offer. While it is beneficial to look at individual examples of organizations in each category, there is also value in looking at an example of organizations that can fall into any of the categories such as airports. This section discusses some of the high-level concepts that help define and differentiate governance within airports.

At the highest level, governance of airports relates to ownership and financing structure and has an impact on economic and operational responsibilities.[10] Governance also has substantial impacts on economic performance operational performance and customer relationships.[3] While many airports within the same region operate under similar governance structures relatively few airports have the exact same governance structure. This is largely due to the interrelated relationships between the ownership and operational structure at an airport. The interrelationship of ownership and operational responsibility also means that governance is a fluid and constantly changing structure as airports grow and adapt.[21] The rest of this section discusses ownership of facilities, the financing of large airport infrastructure, the impact of perceptions and connectivity between the airports. Each of these facets of governance is described below and then discussed in each example provided in the following sections.

2.3.1 Airport Ownership

Ownership is the most obvious proxy for the governance of an airport, but ownership is not a guarantee of one type of governance. In most cases the ownership is only one facet of the airport's governance. As with most organizations, most airports are either public entities or privately held corporations.[22-25] In the case of airports however, there are several additional models that appear in different regions of the world. The third most common airport ownership structure is a combined private public partnership which benefits from some of the advantages of both public and private ownership structures. The final two common types of airport governance are non-profit airports and special interest controlled airports.

2.3.2 Financing

Construction costs for most airport infrastructure is prohibitively high without a definitive guarantee of future value. It is uncommon therefore, for airports to be developed exclusively by private organizations without economic and government support. This is not to say that all airports are governmental organizations, but rather that almost all airports rely, at least to some degree, on financial support from a nation or local government entity. Construction of initial infrastructure creates assets that continue to develop overtime yielding long-term local benefits. The initial cost of infrastructure construction also comes with upkeep and maintenance costs that can be prohibitively expensive to maintain. Monumental terminals are more expensive to both construct and maintain for example but are more highly regarded by the traveling public.[3]

2.3.3 Perception

One of the key factors that helps identify the governance structure at airport is the response to, and focus on, managing the public perception. Public airports tend to change based on feedback, reacting to shifts within the industry. Private corporations tend to push changes that benefit the financial bottom line; while this is often proactive, private corporations do not always invest in innovation without clear financial incentive. Not-for-profit airports are required to reinvest revenues, so the airports are always changing and implementing innovative technologies. This continuous reinvestment means that not-for-profit airports are far more proactive than private corporations. In contrast to reactive public airports, economically oriented private airports, and continuous changes of not-for-profit airports, special ownership airports are the most proactive as these airports are always growing and adding elements that differentiate their product on the world stage. For each of the governance structures the impact of public perception and feedback from actual customers, impacts the investment and growth of the airport in unique ways.

2.3.4 Connectivity

With the introduction of jumbo jet travel in the 1970s airport development changed as the facilities now needed to accommodate significant growth in passengers. In addition to the sharp growth in passenger numbers, the aviation industry also began to face a deregulated environment. This growth and changing customer base led to more competition in the aviation market and a reduction of service in many regional areas. Where airports were once connected and guaranteed certain traffic levels, airlines were more willing to cut service or consolidate traffic onto fewer flights. The shifting market meant that some airports saw a reduction in traffic where others benefitted from new types of airlines. As the new airline market developed after deregulation, the governance structure of some of the newest metropolitan airports let them build specifically to attract new airlines and direct traffic to specific markets. This connectivity between airports directly impacted further governance as new airlines began to express opinions within the airport development program.

2.3.5 Governance Structures

2.3.5.1 Public Airports.

The earliest examples of airports were privately funded experimental airstrips or military airfields. These early examples of airfields would not support the traffic of today. As aircraft got heavier and the aviation system grew, investment in the infrastructure that supported the aviation system became far more important. Military and private airfields were quickly taken over by public entities and local governments which, with some early airlines, invested in infrastructure.[26] The need for investment pushed most airports toward public ownership, which prevailed for the remainder of the 20th century. As airports incorporated more technology and continued to grow, the costs for construction continued to rise. In order to cope with the growing costs, many airport authorities and public entities began to seek alternative funding solutions to help maintain and grow airport infrastructure. The pursuit for funds led to the utilization of existing assets, for example car parking becoming a primary source of revenue and the exploration of new sources of revenue such as incorporating more concessions. This was not always enough however, so public entities that owned airports began to seek private investment to prevent the airports from decaying. In a financially minded efforts, a portion of the airports around the world especially at major hubs, begin to consider full privatization. According to ACI, in 2016 more than 86% of airports are still entirely publicly owned.[3]

Benefits

- Shared costs
- Public benefit
- Not a marker driver
- Not beholden to share price or financially motivated boards

Concerns

- Political
- Reliant on Public funding
- Socially dependant

Examples

Almost all US airports are still publicly owned. There are a variety of differences in the control mechanisms, but the two most common examples of airport ownership structure, in major metropolitan markets, are direct municipality oversight, and specialized management through port authorities. Direct oversight can be seen in Chicago where the city government is responsible for operation of both city airports (it was 3 b3fore the mayor ordered the illegal demolition of the third one in 2003). In contrast, in the New York metropolitan area six of the major airports are owned and operated by a cooperative quasi-government port authority organisation called the Port Authority of New York and New Jersey. This organisation was set up in public trust to operate and maintain facilities that connected the New York metropolitan area in both New York and New Jersey. While both of these organisations are publicly owned and provide examples of public ownership of airports their direct oversight and the operations of the airport differ significantly.

Links for more information
https://www.panynj.gov/airports/en/index.html
https://www.chicago.gov/city/en/depts/doa.html

2.3.5.2 Private Airports – For Profit Corporations.

One of the consequences of deregulation of the airline industry was the introduction of a competitive landscape for airlines. As the main supporting infrastructure for airlines, airports quickly also faced the competitive pressures that changed the industry.[3] To help finance some of the required changes, new sources of funding were needed outside of government budgets. In some regions this funding came from the government through other means, but in most areas the political will to invest in infrastructure was lacking. This led to a search for alternative funding sources. In much of Europe, and throughout Australia, municipalities that owned the airports began the process of selling the assets and operational rights to private stakeholders. These new private corporations took control of the assets and were able to invest large amounts of capital into the existing and new infrastructure to make the airports into competitive players within the new aviation landscape. While public ownership is still the predominant form of governance, there has been a global movement toward privatization to help support the growing cost of infrastructure.[21, 25, 27-29]

Benefits

- Proactive
- Forces more competition

- Provides more pathways for local stakeholders to get financially involved
- Airports began to buy shares in other airports

Concerns

- The primary goal of private corporations is to drive profits and revenue to achieve the most value for current assets.
- Fear of monopolies - Need to regulate [10]
- Limited incentive for investment in capacity projects without direct financial benefit
- Price growth – can be frequent or annual if not regulated
- Consolidates power of airports to wealthy companies
- Prolonged Asset life cycle. [21]

Examples

There are several examples of privatized airports with different structures. One of the largest and clearest examples is the dynamic relationship between the six different airport corporations that control each of London’s six airports. Because these corporations compete for passengers and traffic, all the London airports are far more focused on continuous improvement to maintain market share. While London is one good example of private competing airports, there are several additional regions that also operate privatized airports. Private airports make up more than 30% of the airports in

Europe, more than 25% in Latin America and the Caribbean and more than 10% in Asia-Pacific.[3]

Links for more information
https://www.heathrow.com/company/about-heathrow
https://www.stanstedairport.com/about-us/
https://www.gatwickairport.com/business-community/about-gatwick/company-information/ownership-management/
https://lutonrising.org.uk/
https://www.londoncityairport.com/corporate/Corporate-information/the-team#

2.3.5.3 Non-Profit Airports.

Airports are highly commercialized assets that have the potential to bring incredible wealth or large controversy to a specific area. In some markets, to avoid the political process and potential pitfalls of the social concerns of privatization, specialized airport authorities have emerged. Moving further away from the governing oversight body than public entities, but avoiding private financing, these non-profit organizations became community-based organizations aiming to provide optimal value for the local community by isolating airport profits and using all assets to benefits the future infrastructure development.

Benefits

- Avoid potential social and political fallout from airport operation
- Not beholden to shareholders
- Innovative
- Local

Concerns

- Less oversights by authorities
- Easily influenced by lobbyists
- Reliant on external industry

Examples

Canada is the only country that has actively pushed airports toward independent non-profit status. According to the Canadian Airports Council, airports across Canada were transferred to not-for-profit status in the early 1990s.[30] Despite concerns about the impact of the transfer, airports in Canada have shown social and fiscal responsibility. These airports have also largely succeeded in achieving self-sustainability as required by the national regulations. Due to their success, not-for-profit airports have been given autonomy over their spending and development. This has provided an opportunity for Canadian airports to develop and deploy several new technologies without the need for a specific financial return. One of the more interesting examples of innovation from the not-for profit airport is the high-speed travelator, which no longer operates due to safety concerns. There are several advantages of local management, and the not-for-profit airports seem to take advantage of many of those benefit to the local community. Non-profit governance, though uncommon in airports, has proven a viable and competitive governance structure.

Links for more information
https://canadasairports.ca/about-canadas-airports/airport-governance-and-accountability/

2.3.5.4 Special Interest Privately Owned Airports.

In many regions especially the Middle East, select individuals or specific select groups have purchased or gained controlling stakes in local airports. These individuals or groups are often wealthy or political, for example a royal family or real-estate tycoon, and are usually focused on financial diversification. As these specialized groups have invested more heavily into growing airports, one of the trends that has developed is a push toward opulence, and globally connected infrastructure. Starting at the end of the 80s and continuing to today some of the airports that have developed under the control of a royal family, for example, have grown from nothing into the largest airports in the world. Airports like Dubai and Abu Dhabi have been developed specifically with global passengers in mind. This has allowed specific focus on premium travel and hub connectivity to connect the far regions of Asia with European and US markets. Following some of the examples provided by early airline such as Pan Am and British airways the middle eastern carriers and airports have developed in tandem to support the largest international passenger jets operating today allowing them to connect thousands of passengers to any airport across the entire globe.

Benefits

- Seemingly unlimited funds
- Usually has a partnered airline
- Proactively seeking the best new technologies
- Frequently architecturally pleasing
- Growing beyond logical limits

Concerns

- Tied exclusively to owners' wealth
- Often developed without a plan
- Nepotism
- Illogical and conflicting goals are not uncommon

Examples

Several middle eastern airports have developed in competition with one another over the past 40 years. These airports have grown alongside of airlines and city states that have emerged as powerful global centres of trade, travel, and commerce. When looking at these airports the defining factor is the rapid expansion and the focus on the wealthy premium traffic through the use of opulent finishings across the facilities. Dubai International airport for example has expanded rapidly with a focus on frowning the hubbed airline model with the largest fleet of the largest aircraft in the world. Singapore has also seen direct investment from private groups into the facilities like the oculus and the butterfly garden. These facilities are meant to wow passengers transiting through the airport as well as passengers arriving in Singapore as tourists.

Links for more information
https://www.dubaiairports.ae/corporate/about-us/biographies/hh-sheikh-ahmed-bin-saeed-al-maktoum

2.3.5.5 Public Private Partnerships.

The public private partnership (PPP) model is a hybrid governance model meant to expedite funding and provide quick benefit to the airport without fully privatizing all of the public assets and to maintain the function of airports as public utilities[31]. In this ownership model between private and public, airports fall on a spectrum of organizational structures. The PPP is a tool to help inject funding into airports by allowing more investors to take a stake in public enterprises. These partnerships have developed out of an acute need for funding to overhaul the aging infrastructure, much of which (at least in the US) was originally developed around the same time as the introduction of jet aircraft. Many of these passenger facilities have an estimated useful life of approximately 20 years, US facilities are therefore past the theoretical end of their useful life.[4, 21] The general agreement for public private partnerships is that the private corporations is given the rights to set and collect facility usage charges in exchange for their investment in construction and operation of the specific facility for a set period of time.

While the PPP is one form of privatization, many airports also utilize private contracting staff. The use of private contractors allows airports to share responsibility for both operations and finances. In the United States, up to 90% of airport staff are employed by private firms rather than directly by the airport. [3]

Benefits

- Shared costs
- Public benefit
- Access to quick capital
- Not beholden to share price or financially motivated boards

Concerns

- Less Regulated
- Reliant on Market forces
- Incentive to prolong asset life

Examples

There are a variety of examples of partnership governed airports form all over the world. In France, Toulouse Balagnac airport is held under a lease by a company that is 50.01% owned by the local authorities. In India, Delhi international airport is leased to a private consortium for a period of 30 years. These types of lease agreements and funding agreements help attract capital investment to grow the airports and provide the ability for growth but also come from limited incentive to maintain the facilities toward the end of the lease.

Links for more information
https://www.icao.int/sustainability/pages/im-ppp.aspx
https://www.icao.int/sustainability/PPP%20Case%20Studies/PPP_Airport_France.pdf

2.4 Socio-Technical System.

The integration between social and technical systems provides a very specific and pointed area for the study of complexity, conflicts, integration, and system design. This section explores some of the definitions that bound the scope of socio-technical systems studies and then looks at some of the application of modelling and simulation that help designers and engineers, analyse the needs and operational behaviours of social and technical systems under complex conditions. The final portion of this section looks at some of the implications of the interactions between social and technical systems within the aviation industry and the rationale for building the model that will be presented in this study.

2.4.1 Background of Socio-Technical Systems

The term "Socio-Technical System" originated in the study of coal mine efficiency after the second world war; the domain quickly grew to help define the complexity of human interfaces with an emerging and ever-changing world of technology[32, 33]. In the context of this research the best definition for defining socio-technical systems is a slightly altered version of the definition provide by Baxter[34] of the intersection of organizations, systems and users. To make this definition more general a slightly broader definition is, systems at the intersection between a human in the loop systems (the social system) and any system with at least one technological impact or components (the technical system). This definition comes out of conversations and research as well as course materials presented during the semester long socio-technical systems course. While this definition pulls elements from a variety of sources, this definition is still too broad to define a specific set of systems; to limit this definition additional reference materials were reviewed beginning with the Systems Engineering Body of Knowledge (SEBoK)[35, 36].

2.4.2 SEBoK Essential Elements of Socio-Technical Systems

According to the SEBoK there are few formal definitions of "socio-technical systems"; the term refers to a variety of different facets of engineering, depending on the domain[36]. To define the term that is more ambiguous in a lot of literature, the SEBoK authors identify four key areas of study within socio-technical systems. These areas of study are:

- **<u>Human Factors and Ergonomics:</u>** This is the study of how human interfaces and layouts of system impact both the people and the system. As stated by Corlett, human factors and ergonomics 'modify the relationships of power between people and things, or people and people.'[37] In the case of systems, the study of human factors and ergonomics relates to control and influence of a socio-technical system.
- **<u>Organizational Design</u>**: The design of an organization and the operational behavior that a particular design elicits, has a major impact on an organization's operational systems. In the business world, as organizations grow, so too does the complexity of the organizational design, which tends to shift goals toward financial growth and stability[32, 38]. The growth in complexity in turn, tends to lead to more complex behavior within the social and technical aspects of the organization[39], while a shift toward profitability tends to limit the autonomy and innovation by forcing uniformity[32]. Impacts from organizational and human interface factors, also then define how an organization shapes and builds

systems and incorporates technology. These organizational design factors can therefore either push a company toward innovation or hold them back.

- **System Design:** Unlike organizational design a system design pertains to a specific system or function and is less likely to evolve with the organization. The optimal system design strategy, incorporates system designs at the origin of system planning, this allows the best outcome for the designers and engineers of the system[40]. Systems design must also accommodate the complexity of both the social system and the technical systems as the unique elements merge to form a complete system. When systems are designed well, the system's behavior is predictable, if there are limitation in the system design, new or unexpected behaviors might emerge. These behaviors, both planned and emergent, impact the system design.
- **Information Systems**: Information Systems is the term used to identify the technological elements of the system that gather, process and relay information to users, managers, and other system elements. As autonomy and scalability take larger roles in the social systems the technology tends to become more ubiquitous but also more opaque meaning that less of the information gathered is being displayed but the system is gathering more information on the behavior of not only the system but the interacting social constructs[41, 42].

2.4.3 Other Defining Factors of Socio-Technical Systems

There are several additional elements that expand and help define what makes a system a socio-technical system. Some of these elements have come from readings from the materials presented in the socio-technical systems course, while other have come from a general literature search focused on a variety of different elements of systems engineering. Some of the potentially unique attributes are grouped into general categories below because some of these elements are more fluid, but each of the identified elements have some descriptive value to add when discussing socio-technical systems.

- Small Operational Groups: working groups that can be given freedom to operate independently can provide better results and have inherent social advantages to offer the overall technical system. [32]
- Connectivity: This can be a physical or electronic connection but any system that connect humans has inherent social and technical attributes. [43]
- Autonomy: This is related to the small working groups and relates to the ability of a group to operate within the system to achieve local efficiencies. This specific attribute can be easily hindered by regulations, standardization and economics (specifically capitalism). [32]
- Systems of Systems: as multiple systems integrate, there are social and emergent properties that begin to develop. Using the five elements of systems of systems identified by Maier[44], there is clear overlap between systems of systems and socio-technical systems
- Complexity: is a benchmarking tool to measure the relative interaction between elements in a semi-quantitative way. This is more relevant in systems of systems,

but Righi provides a list of 13 characteristic of complex systems that help to define the complexity of socio-technical systems. [45]

- Bottom-Up System Design: is identified as a defining characteristic of a socio technical system as the bottom up system integration tend to face integration issues whereas top-down systems are managed avoiding some of the emergent properties and potential negative consequences of system design and integration. [32]
- Anthropological Interfaces: this refers to the interfaces between societies' complex infrastructure and human behavior, especially the interaction between different infrastructure and any group that has an impact on the system operation, growth, design, or end goals. I.E. any sort of project (especially transportation) that attracts public funding. [44, 46, 47]
- Unique, Interacting Elements: these are elements that collaborate with both societal and technological systems rather than just humans interfacing with the system; this is a complex bi-directional interaction rather than a simple human interaction, so it moves away from the human interfaces and ergonomics referenced above.
- Macro scaled systems: this refers to the systems that exceeds the typical local boundaries I.E. social or physical networks. [38, 48]
- Robustness or Resilience: socio-technical systems have some element of robustness that can be measured by analyzing the network or connectivity of the system. If there are critical nodes within that system, there is a higher likelihood of outages and systems failure [49, 50]

It is important to point out that while these elements all provide some insight into the definition of a socio-technical systems, not all socio-technical systems will meet the basic definitions in each category. It is more likely that most socio-technical systems will only meet some of the elements listed.

2.4.4 Personal Definition of Socio-Technical Systems

Based on my understanding of socio-technical systems, the readings for the socio-technical systems course and a selection of the SEBoK recommended articles[35, 40, 48, 51], I believe that best description of a socio-technical system is: any system that incorporates a human interface which, provides some level of control or influence over the entire system, and incorporates inputs from more than one user or group. The plurality of system-influencing inputs adds complexity to the system and creates the socio-technical interface. Dissecting this definition, a bit more, if an input from a user must work with/ or around/ or against another input (or inputs) and can impact the full system rather than producing a single outcome it adds complexity meaning any multiple input system can be viewed as a socio-technical system. This means that all large networks and individual elements of infrastructure are socio-technical systems due to the interactive and collaborative nature of communication, construction, and design.

Using a specific aviation example, the pilot interface in an aircraft does not inherently make an aircraft a socio-technical system, but the collaborative nature of working with a secondary pilot and a computer makes a multi pilot aircraft, a socio-technical system. Using the description of pilots in planes from Whitworth [43], he says if the pilot is seen as a part of the system, the system can be viewed as both a human in the loop system and a socio technical system. I believe even with a single pilot being considered part of the system, the system is still a simple technical system because it still works in isolation. If, however, a single pilot is in communication with air traffic controllers the aircraft and pilot become a part of the aviation network making it an element of the greater socio technical system.

> If we look outside aviation, the user interface on a soda machine does not make it a socio-technical system even though the users determine what soda they want and through repeat sales they define when the machine is empty. Though absurd, if that same soda machine had the ability to alter what is stocked, how it is positioned and the price of a soda based on the input of the customer and social environment, then the machine could be considered a socio-technical system, because the combination of inputs adds to complexity.

2.4.5 Modeling Socio-Technical Systems

Sociotechnical systems can be modelled and simulated in a variety of ways. The SEBoK identifies four unique modelling approaches for socio-technical systems: quantitative modelling, agent based modelling, economic modelling, and system dynamics modelling[36, 52]. The validation of this work focuses on agent-based modelling where a stimulus or input is measured by observing the response or output after a series of agents performs a pre-defined procedure to recreate(approximately) a specific process. By modelling different types of agents, agent-based models can explain and help identify emergent properties and predict the impacts of specific changes to the systems. The goal of this model, like all agent-based models, is to interrogate the dynamic characteristics of the system to measure an equilibrium, in this case of a hypothetical airport[39, 52]. By building simulation models like the one that will be presented in this work, engineers and planners are able to foresee, and adapt to accommodate emergent behaviors as the system or organization develops[53].

2.4.6 Socio-Technical Systems of Aviation

The aviation industry is a complex socio-technical system of systems, which has faced constant change over the past 120 years. Despite constant pressure and continuous change, aviation as an industry tends to resist transformations[54]. With a series of integrated elements including a ground-based infrastructure network, modelling is performed on many elements of the aviation system already. Starting with an example that defines and models the complexity of the aviation system, we can look at the resilience of the network and a measure of connectivity [8, 50, 55, 56]. We can then turn our attention to evolution of aircraft and airline development and specifically look at the impact of jet traffic on the aviation industry [26, 57, 58]. When looking at the impact of jet aircraft, there is also value in examining the impact of the changing financial landscape within the aviation environment[59]. Most pointedly in the United States but also elsewhere, since the 1970's the regulations governing airline operations and financing changed which forced the entire aviation system to adapt and accept new operational procedures[60-62]. The impacts of the financial and regulation changes altered not only the technical airline systems but the airports as well and gave communities far more influence over their local airports further incorporating social systems into the airport. As airports continue to face the changing technical and social landscape, the socio-technical implications will continue to impact the operations and procedure across the entire aviation industry.

2.4.7 Physical Systems – Socio-Technical Implications

Over the past 100 years not only have the aircraft and the airport systems developed, but so to have the passengers and staff. The passengers of today are not the same passengers of 20 years ago and the demands and focus of these passengers have changed the airport environment. LEK consultants attributes the changes to the rising percentage of millennial travelers that are making up the global work force (LEK estimate millennials will make up 76% of the global workforce by 2025).[63] With the changes in demographics, the environment of the airport must also change, some of the suggestions include providing, more interactive space and more information to engage the passengers. The same data and interactive environment has also ventured outside of the terminal, into the cockpit with the use of electronic flight bags[64] and onto apron with the digital service tags. The end users desire for interaction with the system, can be strengthened through embracing the technology available and targeting the end users through process engagement.

2.4.8 Socio-Technical Concluding Remarks

While this section covers a wide section of information on the study and modeling of socio-technical system, this is not an exhaustive search and does not cover any specific topics in great detail. This limited review of socio-technical systems is based on a literature review that was meant to support the creation of an agent-based model in the context of the socio-technical systems course. This section therefore focuses on defining socio-technical systems in the context of modeling and specifically within the aviation domain. For more information, please refer to the sources referenced below or request a copy of my qualifying exam where I provide some additional detail on a number of socio-technical areas.

2.5 Airport Capacity

This section discusses capacity of airports as a three fold measure of capacity, which can be limited by any of three major elements. It is important to note that capacity can be further limited by any number of sub-systems at airports. It is also valuable to distinguish capacity as what a system is capable of versus demand which is the available traffic to utilize the available capacity. This section is not meant to provide an in depth examination on the measure and quantification of capacity but is rather meant to provide a bit of context on the balancing of capacity that is required to gain efficiency in an airport context.

2.5.1 Airside Capacity

Airside capacity is an easily calculated value that can be modeled by discrete service queuing models. Though the actual capacity can vary based on several factors the general throughput of an airport can be determined statically. This is shown in ***Airport Cooptative Research Project (ACRP) Report 79: Evaluating Airport Capacity***.[65] As with many of the reports and work performed by the National Transportation Research Board(NTRB), ***ACRP Report 79*** also comes with an associated model for determining airfield capacity. The model and the report offer insight to airfield characteristics that impact the total airfield throughput without offering suggestion on how to mitigate delays or gain more capacity from the existing system. The suggestions to gain more capacity or reduce potential delays comes from more distinct academic studies of traffic flow models. Gupta et al for example, take into account active runway crossings to analyze delays at airports offering suggestions to mitigate the delays by decreasing the number of runway crossings.[66] Others such as Polsyb[67] and Zhang[68] suggest pushing demand out of peak periods by changing pricing schemes to charge more for peak times. Others suggest that a more active operational intervention is a better approach like Balakrishnan et al[69], who offer a model to control push back of aircraft, systematically preventing delays by reducing all traffic on the ground. Jung et al offer more background on the approach to control the airfield by studying Dallas Fort Worth airport.[70] Other papers such as Mehndiratta and Kiefer[71], and Swaroop et al[72] suggest limiting delays at airports by implementing restrictions particularly in the number of aircraft allowed to operate at the airport in a particular time period. Many of these methods require a more integrated systems approach to the control of the airside operations. While many of these studies have their merits, and offer valuable suggestion to reduce delays and congestion, they would be more beneficial if they looked at the entire turn around process, to balance the number of aircraft on the ground against the services available.

Though the majority of the work done on airport capacity, delays and the modeling of traffic will fall outside of the scope of this work it is valuable to understand the flows of traffic and the schedule patterns that persist at airports, especially at hub airports and how growing traffic is managed. [73]

2.5.2 Terminal Capacity

Unlike airfield capacity, which is a relatively static throughput of aircraft, that will not change without the addition of infrastructure, terminal capacity is more fluid and dynamic. A static throughput for each individual element of the terminal can be predicted, but due to the nature of human service and the number of elements involved that have a distributed range of service times, the total terminal system capacity is varied and highly dynamic. IATA offers a range to measure the adequacy of capacity called Level of Service(LoS).[14] LoS defines how comfortable passengers will feel when passing through each of the terminal processes, these are based on some standard processing rates and wait times. In addition to LoS for processing facilities, IATA also offers standards for the quantity of space and number of seats per passenger within the terminal. These figures provide basic guidelines but do not determine a total capacity. In order to define total capacity other references, must be consulted. The most specific is the local fire code and safe evacuation standards which limit the number of people allowed in a space based on a number of fire exits and stairways. When designed appropriately the restriction from fire codes and outside regulation should not be in question.

As with airside capacity, the terminal capacity measures, will largely fall outside of the scope of this work. The measurement of throughput and the LoS range, however, offer some guidance for the creation of future frameworks, which will likely factor into my thinking as I develop this framework.

2.5.3 Apron Capacity

A measure of apron capacity is somewhere in between the static airside capacity (number of aircraft per time period) and the dynamic terminal capacity (up to a range/density of passengers). The apron capacity is rather a function of service times and the capacity of the runway system and the terminal and passenger processing system. Mirković and Tošić have proposed an hourly apron capacity as a function of runway capacity.[74] Though, the method provided offers some insights to the interconnected systems, it fails to measure the apron capacity as a dynamic function rather than a single static hourly rate. While it is enticing to measure all elements of a system with static figures plugging in variables and values that allows for the easy assessment of the peak operational values, the reality of the apron is far more dynamic than a static model can accommodate. The capacity of the apron is more likely to fall within a range of potential capacity figures. The range of the capacity is also impacted by perceived capacity and the adjacent facilities; not just including the terminal but also systems like the fuel system and service facilities.

While determining a capacity measure is not the primary focus of this body of work, this will be a part of developing the framework as executives and decision makers tend to focus on top line numbers before adopting new approaches or permitting new methodologies at airports.

CHAPTER III

THE HISTORIC PAN AM FLEET: A DATA SCIENCE REVIEW OF THE HISTORY OF PAN AMERICAN WORLD AIRWAYS' FLEET AND ITS CHANGES OVER TIME

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Pan American World Airways (Pan Am) is still viewed as one of the most iconic and innovative airlines despite its demise almost thirty years ago. This is largely due to the ubiquity of the airline in pop-culture and its technical and operational contributions throughout the history of aviation. Pan Am was one of the major players in aviation not only in the United States but also around the world. While the history of Pan Am was not always the brightest, the once unofficial U.S. flag carrier still holds clout even though many fliers today are too young to remember the days of the Pan Am clippers. Despite its demise, Pan Am was the prototype for most of today's modern airlines and had a hand in shaping the industry that we have come to know. This work is a brief historical look at the growth of Pan Am and an examination of the fleet, through data analysis. The data used and the visualizations created in this work, help clearly distinguishes several periods of the companies' history and can be used to identify industry trends that led to the aviation market of today. This work

offers opportunities for further investigation including, offering the graphics generated to compare airlines and their shortcomings. Standardized graphics provide a method of comparing companies across the industry, by incorporating data science into historical analysis of the industry. The use of data science provides insight into the history of some of the legends and founding members of the global aviation industry and provides a method of comparing airlines.

3.1 Introduction

Data and analysis play a major part in the modern aviation industry. With more data points being generated than ever before in aviation, analytics can help shape the industry today. What is less know is how modern data science techniques can be used to analyze the history of aviation especially when focused on specific airlines and the impact they have had on the modernization of the industry. Early aviation has its roots in the original commercial air mail routes that created the aviation industry in the United States[58]. While many of the early airlines like the St. Petersburg-Tampa Airboat Line, (largely credited as the first US airline), American Trans Ocean Airline, (the first U.S. airline that lasted longer than six months) and Long Island Airways(Juan Trippe's first attempt to found an airline) flew only briefly[58, 75], others such as Pan American Airways (Pan Am), Western Air Express and Western Airways(later, Transcontinental and Western Air or the predecessor to TWA) were precursors to modern airlines. Many of the early aviation companies survived for long periods of time and shaped what the industry would become. Today, in the United States, there are 18 major airlines (defined as airlines with annual revenue over $1 Billion US), and 41 minor airlines, according to statista[76]. Three of the current major airlines can trace their origins to the early days of aviation, their dominance over the market however has come in the more recent history, the largest transition coming about after the abolition of the Civil Aviation Board in 1978[58]. United, Delta, and American are the most well know U.S. flagged airlines today, but these airlines barely compared let alone rivaled Pan Am and Trans World Airways before deregulation[77]. The distinguishing factor was not the appearance of the dominant airlines in popular culture though, their dominance was a direct result of their innovation and expansive route networks as the industry faced the competition of deregulation[78].

To demonstrate the power of data science, and its use to highlight historic changes at an airline, the authors of this work elected to trace the history of a single airline. While TWA and Pan Am, were rivals and could both be the focus of this historical analysis, the authors of this work focused primarily on the influence of Pan Am and its leader Juan T. Trippe. This focus on Pan Am as a single airline allows the use of data to decisively identify turning points in the history of the airline and enabled the authors to develop a comprehensive picture of both the rise and the sudden fall of Pan Am through data analysis.

3.2 Historic Review of Pan Am in Literature

3.2.1 Juan Trippe and the Leading Edge

Pan Am, and Juan Trippe throughout his tenure as the leader of Pan Am, pushed the aviation industry forward. In his own words "By each successive step, aviation is advancing to that potential ideal of a universal service for humanity."[79] Believing in his mission, to bring air travel to all of humanity, Trippe kept Pan Am on the leading edge of technology, in the air and on the ground[80]. Making it clear to business partners and friends alike, that he wanted the best, and would not be afraid to make commitments to competing aircraft produces, Trippe ordered aircraft from any company that would commit to meeting his requirements[78]. In 1931, Trippe requested a flying boat that could accommodate four crew members and had a range of 2,500 miles; two manufactures offered options Martin offered the M-130, and Sikorsky offered the S-42[78]. Trippe ordered both. This was only one set of requirements that Pan Am released during its history. The most famous was a challenge Juan Trippe gave to Bill Allen of Boeing. Pan Am wanted to fit twice as many passengers on a single aircraft compared to the existing 707 aircraft. Trippe is famously quoted saying "If you build it, I will buy it." [81] That challenge, and pledge, led to the birth of the first jumbo jet, the Boeing 747. The requirements that Juan Trippe and Pan Am issued, defined more than one generation of aircraft, but the 747 was the turning point that allowed for all people to travel by air[58]. The issuing of a public challenge to an aircraft manufactures is not common today, but it is accomplished in the form of a Request for Information(RFI) or a Request for Proposal(RFP)[82]. With only two large modern manufactures, many airlines make fleet purchasing decisions on cost and standardization rather than issuing an open challenge to the manufactures. Airlines still have some power though and can demand specific attributes, Qantas for example has challenged Airbus and Boeing, to produce an aircraft that can travel from the east coast of Australia to New York and London without stopping and while carrying a "viable payload"[83]. While issuing challenges was the practice that kept Juan Trippe and Pan Am on the leading edge of aviation, modern airlines are more focused on cost when issuing new challenges. With an Airline focused on cost it is now up to the manufactures to produce successive steps for the future of the entire industry.

3.2.2 Early Years

Pan Am was created through the consolidation of three airlines that merged in 1927[78]. Aviation Corporation of America, Atlantic, Gulf and Caribbean Airways and Pan American Airways each had assets that would be required to begin air mail service from Miami to Havana, but none of them had everything required[84]. The merger took place to meet the conditions of the contract issued by the United States Postal Service for Foreign Air Mail (FAM) Route 6[78]. This route began mail service from Miami, Florida to Havana, Cuba in October of 1927. As the traffic began Pan American Airways based their traffic from Key West from their seaplane base[78]. The growth of traffic, forced Pan Am to shift operations north to Miami from Key West in 1928[78]. By the fourth year of operations, Pan Am was already growing fast enough to issue requirements for new aircraft. With the introduction of the Martin M-130 and the Sikorsky S-42, three years later, Pan Am was able to construct the largest airport in the world at that time, with modern amenities including a viewing platform and a restaurant[78]. This growth and the early international influence earned Pan Am a reputation as an influential interwar airline that would go on to be one of the largest international airlines in the world[85].

Pan Am's route network grew from its early sea plane bases outward connecting further cities up and down the North and South American Seaboards[84]. To facilitate the speed of expansion, Pan Am hired Charles Lindberg (the already famous aviator) to help establish the growing South American route network[78, 80]. After the southward expansion, the next step was for Pan Am to begin flights across the ocean. With growing air superiority and an expanding network of routes, including the first European flights, Pan Am was one of the first international carrier to appear in the waters of Southampton with early seaplane aircraft[85]. From its earliest days as an international carrier Pan Am was spreading its influence around the globe.

3.2.3 World at War (World War II)

With the outbreak of the second world war, Pan Am Airways began to serve the allies by offering support to the troops in Africa as early as June 1941[86]. Though the United States would not enter the war until the bombing of Pearl Harbor in December 1941, Pan Am was already serving the war effort in Africa and preventing the expansion of German interests through South America[86]. In the 14 years since its founding, Juan Trippe built Pan Am into a global airline, with a reputation as one of the greatest airlines in the world and one of the founders of commercial aviation. Through its experience, Pan Am also had the foresight to prepare for the eventuality of war. Clipper pilots had secret order in the case of an attack and the facilities around the globe were prepared to support military aviators should the need arise[86]. As Japan drew the United States into the Second World War, the support systems that had facilitated Pan Am’s transpacific flights, were severed, forcing diversions in all the commercial traffic across the Ocean. Due to the attack on Pearl Harbor, the military supply routes across the Pacific to support the “oriental front”, were also diverted and were rerouted through South America and Africa meaning the supply flights touched down on four continents. Later routes were also developed as Pan Am and its subsidiaries were contracted to deliver supplies, aircraft and parts to the British the Republic of China, and the Union of Soviet Socialist Republics[86]. In addition to Pan Am's voluntary war effort, in December 1941 all civil aircraft were also conscripted to support the war effort to help meet the demand for military transport[86]. Following the conscription of all civilian aircraft, all aircraft assembly lines across the United States were also pressed into service to support the need for military aircraft. Pan Am's support of the war effort and the influence of aviation helped bring about the end of the Second World War.

3.2.4 Modernization of Commercial Aviation

After the end of the Second World War, a surplus of military pilots and aircraft returned to the United States. Both the pilots and the aircraft quickly joined the civilian airlines and became the backbone of the aviation industry[80]. In addition to an influx of aircraft and trained crews, Pan Am also benefited from the global network of runways left behind at the end of the war. Moving away from the original fleet of flying boats, Pan Am moved toward land based aircraft to take advantage of the expanded global infrastructure[87]. The innovation that Juan Trippe pioneered through Pan Am's Southward expansion, also continued after the conclusion of the war. Maintaining the radio and weather station network built before and during the Second World War, Pan Am also expanded the system of ground stations across it's entire route network. As the United States military pushed aircraft development further Pan Am lead the expansion of the global aviation network and the development of civilian jet traffic[58] by agreeing to be the launch customer for the 707, originally ordering 25 of the first American jet. The new jet aircraft allowed Pan Am flights to fly more than 100 miles per hour faster than the De Haviland Comet and up to 5,000 nautical miles in a single flight [58, 84]. The speed and the size of the 707 allowed further development of international routes especially from the new Pan Am world terminal in New York which opened in 1960[78, 80]. As the industry continued to grow Pan Am proved once again that they were leaders in the global aviation community.

3.2.5 Jumbo Era – Launch Customer of the Boeing 747

Due to the success of the 707, Pan Am was eager to continue its international growth. This led to the famous challenge to double the number of passengers on a single flight when Juan Trippe pushed Boeing to develop the 747[80]. With Pan Am’s inaugural flight of the 747 in January of 1970, the age of the jumbo jet, and the beginning of mass travel was born[81]. With the ability to carry 360 passengers 4,620 nautical miles, the jumbo jet introduced the ability to transport large numbers of passengers across the Pan Am International route network[81, 88]. The 747 and the variety of fares offered sustained Pan Am’s dominance as the industry continued to grow.

3.2.6 Decline of the Airline

Despite the growth and expansion of the Pan Am network, into a global empire, and the reputation as the most experienced airline, Pan Am began to hit turbulence soon after Juan Trippe retired from the airline in 1968[77, 78, 80]. The rise in the price of petroleum and the economic recession that took place in the 1970's began to drain the resources of Pan Am[78]. With the 1978 de-regulation of airlines in the United States, Pan Am and nine other mainline carriers quickly lost 13% of their cumulative market share to smaller carriers[62]. In an effort to slow the loss of passengers and compete with the smaller airlines in the United States, Pan Am began to look for strategies to build a domestic route network[77, 79]. To gain a domestic route network, Pan Am made a bid to purchase National Airlines[78]. Rather than helping Pan Am to grow however, the merger further burdened the airline, with a more complex fleet, dueling company cultures and stifling debt. After the struggle to merge the airlines, the new Pan Am was unable to remain competitive which forced the airline to liquidate assets to maintain cashflow[77]. The final blow, that ultimately drained the remaining resources and influence of the once influential airline, was the 1988 bombing of Pan Am flight 103 over Lockerbie Scotland[78, 87, 89]. Though the bomb that doomed the flight was placed in the hold by Libyan terrorist[89], the investigation and trial took more than ten years, during which time blame was placed on the airline which led to its collapsed[90]. This failure, of one of the largest U.S. airlines, highlighted the need for airlines to take a more active role in their own security. This delegation of responsibility also forced an industry wide intervention into the ownership practices which pushed airlines to divest some assets. With blame for the bombing of Pan Am 103 and the struggle to maintain cashflow even after liquidating assets, Pan Am met is demise at the end of 1991. The majority of the remaining Pan Am aircraft, ground assets and slots were sold to Delta Airlines.

3.3 Research Statement

This work is part of an exploration of the Pan American World Airways contribution to the systems that facilitate the modern aviation industry. This work looks at data science as a tool for comparing airlines and companies over their history, with a keen focus on examining corporate changes within the company. This study focuses on the impact of changes in Pan Am's fleet composition over time. The authors are submitting this work as a case study into the use of data analysis when examining the impact of technology and innovation into the history of a specific company, in this case Pan American World Airways.

3.4 Data Source

Gathering information from the early days of aviation can be difficult as much of the history has been subsumed during mergers or lost when the airlines ceased operations. Much of the information about the earliest airlines has therefore been lost to history, with only some brief or vague reference materials available. The most common source of information for these early airlines are personal accounts as retold by secondary sources. In the case of Pan Am, however in addition to the many personal accounts available, the paper documentation from the companies' New York headquarters is now available through the University of Miami Library's special collections. A majority of the data publicly available is print media that has been scanned into library collections. The University of Miami library credits their collection’s digitization to funding provided by the National Historical Publications and Records Commission. This work provided a set of resources that was useful in building a profile of Pan Am and validated many of the general observations provided in first person accounts; it is also worth noting that the University of Miami collection proved to be a valuable resource for more in-depth studies.

Over the course of this research the authors have also found that some authors like R.E.G. Davies[84] have made an effort to compile as complete a datasets as they are able in the form of books that outline the fleet of aircraft. For this analysis, the base data being used was compiled by John Steele in a published work titled "Names of Pan Am Clippers: 1934-1991 by manufacturer and model" which relies on "Pan Am - An Airline and Its Aircraft," by R.E.G. Davies[84]; Nathan Andrews - Boeing 307's; John Leutich - Airbus A310's; and Daniel Siragusa - Airbus A310's [91]. This dataset was selected as it is the most comprehensive look at the Pan Am fleet found by the authors during the early research for this work.

3.5 Method of Processing

The base data used in this work was predominantly a list of aircraft registrations. This data set included the name of each aircraft and provides the year of delivery and the year of retirement of most of the aircraft Pan Am owned. With 844 aircraft across 33 different aircraft types, the first step in this process was to generate some specific groupings of aircraft types to provide a categorization. Based on the history of the airline the first category of aircraft is sea planes; this group includes all the flying boats that Pan Am used prior to and during the Second World War. The next category is the land-based, propeller driven aircraft which largely appeared in the fleet to replace the sea planes and expand the Pan Am network as the airline grew. As Pan Am entered the jet age, four grouping of jets are identified for categorization of the Pan Am fleet. Based on historical perception and importance of the aircraft to the airline and the industry the Boeing 707 and the Boeing 747 are independent categories while all other jet aircraft are broken up into wide-body (more than one aisle) and narrow-body (single aisle) aircraft. These categories and the counts of each type were used to generate a Gantt chart showing when each of the categories made up a portion of the fleet and a set of spark lines identifying the peak number of aircraft in each fleet category. The combination of these two charts resulted in the first graphic in our study of data science. This graphic can be found inFigure 3. Gantt Chart of Pan Am Fleet By Category.

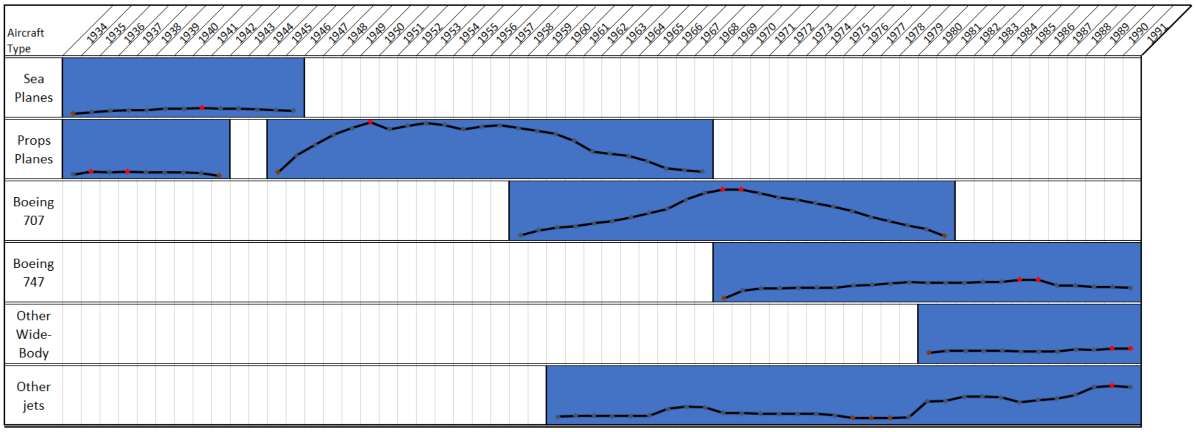

Figure 3. Gantt Chart of Pan Am Fleet By Category

The Pan Am aircraft data set was supplemented with operational data for each aircraft type, from operations manuals and published statistics from the Pan Am Museum. Combining the statistics available into a full dataset for the entire Pan Am fleet. For each year a series of twelve statistical figures were generated that could be shown on a timeline. These statistics fall into two categories. The first are the counts of aircraft in the fleet based on the original data set; these included a count of the aircraft delivered and retired, and then the total number of aircraft in the fleet broken into the distinct categories. In addition to counts of aircraft, three other statistics were generated which were the average speed of the entire fleet, the average seat capacity across the entire fleet and the average range of the entire fleet. These three average statistics are shown in Figure 4. Average Pan Am Fleet Statistics.

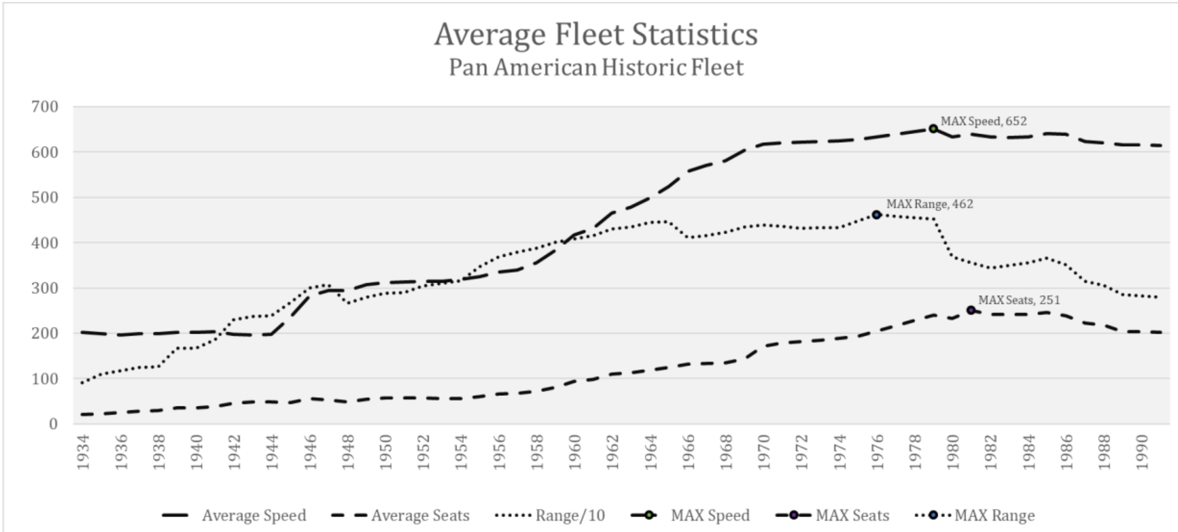

Figure 4. Average Pan Am Fleet Statistics

Plotted in Figure 4. Average Pan Am Fleet Statistics, are the average speed, the average seats and the average range divided by ten, across the entire Pan Am fleet from 1934 to 1991. This figure also identified the peaks for the average speed, seats and range. Averaged statistics provide generalized information about trends in the size, range and capability of the aircraft in the fleet. It also helps identify the trends over time which impact the airline and the industry.

3.6 Processing of the Data

Taking Charles Joseph Minard's graphic, "Mapping Napoleon's March, 1861," as basic inspiration, the authors used the fleet data from Pan Am to generate a series of graphs. To generate a compelling graphics, the averaged statistics generated were taken as a base value and the total number of aircraft in the fleet are shown centered around the averaged statistic. By combining the simple counts with the averaged fleet statistics, the generated graphics provide a more compelling story that clearly identifies changes in the total Pan Am fleet and the years when those changes would have impacted the industry.

Starting with the average speed of fleet and the number aircraft, Figure 5. Pan Am Fleet Centered on Average Speed is the projection of the fleet growth and speed, this grows up till the aircraft approach the speed of sound before plateauing. Next, we look at the average seats available in Figure 6. Pan AM Fleet Centered on Average Seats which provides an indication of potential passenger loads; this second projection peaks and then falls showing the introduction of smaller aircraft back into the fleet. The final projection graphic generated in this analysis as shown in Figure 7. Pan Am Fleet Centered on Average Range, which is plotted around the average range of the Pan Am fleet. This final graph shows significantly more variation, allowing the easy identification of new aircraft and distinctive changes in the airlines' strategy over time.

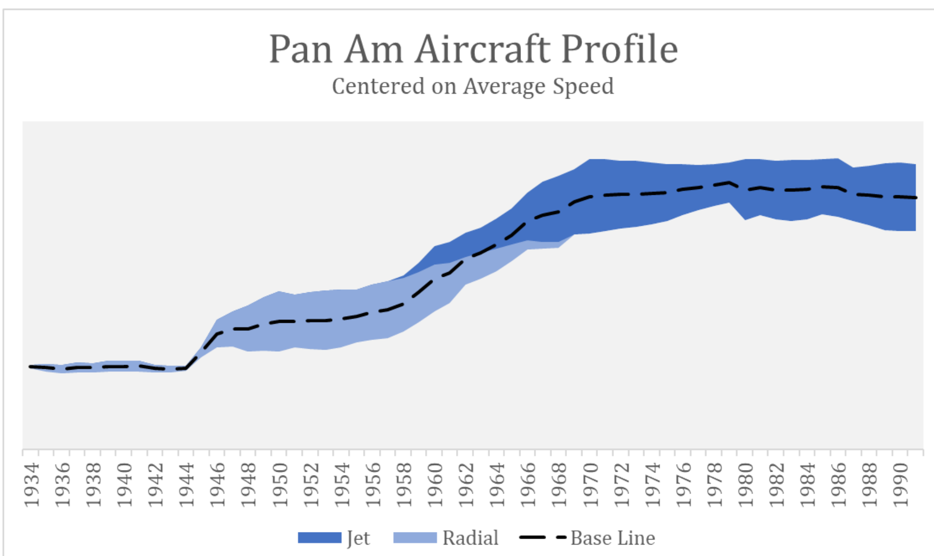

Figure 5. Pan Am Fleet Centered on Average Speed.

The speed and size of the fleet grows continuously till the introduction of jet traffic. This indicates that the Pan Am fleet reached an average speed that approached the speed of sound. The limitation in speed shown in Figure 5. Pan Am Fleet Centered on Average Speed is indicative of the limits in commercial aircraft which have not increased in the average speed in nearly 60 years. This is still true of commercial aircraft today which are currently limited to travel at subsonic speeds.

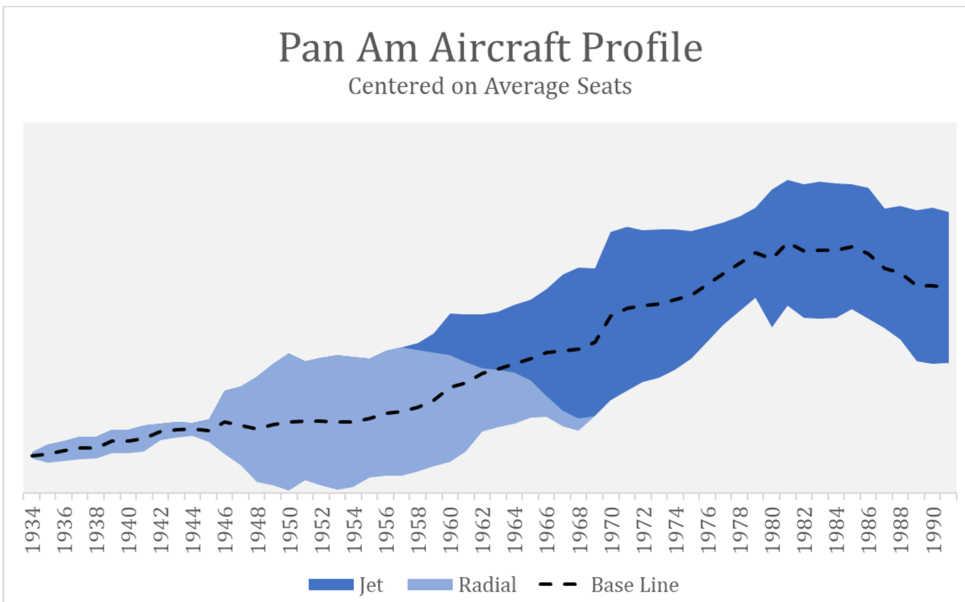

Figure 6. Pan AM Fleet Centered on Average Seats.

The growth in the average number of seats across the Pan Am fleet, reflects that innovation and growth of aircraft in the fleet. This growth continued as a clear strategy right up till the merger with National Airlines when the average number of seats across the entire fleet begins to drop which represents the addition of the smaller domestic aircraft.

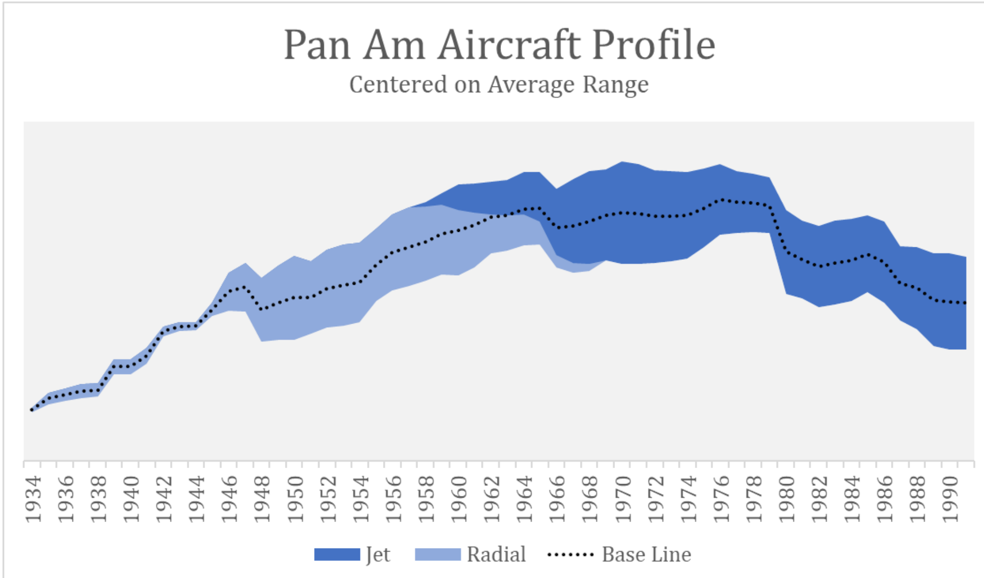

Figure 7. Pan Am Fleet Centered on Average Range.

The variation in the average range of the entire Pan Am fleet are more dramatic than the changes in the speed or seat numbers as can be seen in Figure 7. Pan Am Fleet Centered on Average Range. As New aircraft entered the fleet, sharp changes can be seen in the graphic which indicates not only a change in the fleet but also a change in technology and company strategy.

3.7 Distinctions in the Data

These graphics show the number of aircraft in the fleet as a representation of the growth and decline of the airline. The three distinct variables allow one to identify the most telling transitions and trends.

3.7.1 Reduction in Average Speed

The first clear trend is the stagnation in the average speed of the Pan Am fleet. Due largely to limitation in the advancement of technology, the speed of aircraft has been limited to the sound barrier with very few exceptions, this limitation is largely similar for all airlines. In addition to technology, governmental regulations have also constrained supersonic aircraft meaning there was limited incentives for development of new aircraft.

3.7.2 Reduction of Average Seats per Aircraft

Next is the shift away from the growing seat numbers. Pan Am was usually a leader in the aviation industry creating or leading new trends and the shrinking of their average aircraft is no different; this can be further seen in the reduction of larger jet aircraft today as airlines largely move away from the mega hub airports, instead preferring to travel point to point on smaller more efficient aircraft.

3.7.3 Reduction in Range

The third trend is the reduction in range at the introduction of new technology. At the introduction of both land-based aircraft and jet aircraft, the average range quickly dropped; a third drop followed Pan Am's Merger with Nation Airlines when a full range of new aircraft were incorporated into the fleet.

3.7.4 Additional Trends

Looking closely at the series of graphs created, two additional trends emerge. The first of these new trends is the far larger positive impact of the introduction of the Boeing 707, as compared to that of the Boeing 747 which the airline is more frequently known to have helped create. The final trend is the definitive stagnation point and even the beginning of the decline of Pan Am following the retirement of Juan Trippe. The clear identification of these trends through simple graphics shows the power and benefit of using data science to analyze historic airlines.

3.8 Discussion

The graphics presented in Figure 5. Pan Am Fleet Centered on Average Speed, Figure 6. Pan AM Fleet Centered on Average Seats and Figure 7. Pan Am Fleet Centered on Average Range, could have been generated using any number of statistics; the defining attribute in these graphical representations of the history of Pan Am is that we are using clear quantifiable figures specifically about the fleet. Other statistics that were considered in the generation of these graphics included financial performance, passengers transported, and routes flown. Taking the fleet as the primary statistic however kept the statistical analysis focused on assets and operational potential rather than results which are flexible and can easily shift on any given day. Then basing our quantified statistic around and averages statistic allowed for an easier comparison that considers both the leading edge and the legacy aircraft that serve the airline. The graphics presented are meant to be a starting point for further analysis that can be taken further by researchers interested in examining further the historical context of an airline through data analysis.

3.9 Conclusion

This work is meant to show a series of graphics that represent the changes over time of one of the aviation industries greatest airlines, Pan American World Airways. Talking the fleet as a starting point, these graphics are meant to demonstrate the power of data to track an airline over the course of its history. Through the narrow historical lenses of, the fleet of Pan Am, this study looks to identify key points in the history of the airline and provide a method by which other airlines or other companies can be shown as graphical representations of events throughout aviation's history. Combining a series of factors and creating a series of graphics that can be objectively examined and reproduced, the authors are offering data science and analysis as a tool to explore the history of aviation the way it was used by Charles Joseph Minard to analyze Napoleon’s march.

3.9.1 Final Concluding Remarks

This chapter is an examination of the historic state of the aviation industry, specifically through examining one airline’s fleet. Looking at historic data from Pan American World Airways, this work highlights some of the major changes that took place as the global aviation industry developed and identifies the impact that individual changes can have on the industry. This work touches on many of the operational changes within the industry and identifies some of the operational impacts that those changes have forced. This work further offers a way for systems engineers to examine the historical context of an industry as well as the events that defined the systems as they exist today. While this work is primarily based on a historic airline it is possible to use the same approach to examine other infrastructure intensive industries to produce insights that will help define the requirements of the system and the planning parameters moving forward.

The work presented in this chapter was submitted to the AIAA Sci-Tech Forum, was peer reviewed and published in January 2022 and can be found by following the below bibliographic information.

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CHAPTER IV

RISKS IN CHANGE: A REVIEW OF RISKS FACING THE AVIATION INDUSTRY AND A METHOD OF EXAMINING IMPACTS

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There are three categories of interrelated changes that directly impact aviation as an industry. Technological changes are the most obvious changes that have the potential to directly impact the industry, they can also force the most extreme changes as they can have physical and chemical impacts on infrastructure. Social changes have a less obvious impact on aviation systems, but are just as important in shaping the direction of changes and the development of the industry. The final category of change is process changes where new technologies or changes in the social construct of air travel are implemented. Any of these three categories of change can force a system wide change but sustainable macro change across the industry comes from all three categories, and must impact technical, social and process elements within the system. A change that falls into any two of the categories can also lead to macro change but in many cases, it takes a changes impacting all three categories to propagate throughout the entire industry. This work discusses the ramifications of

each category of change and provides specific examples of some of these changes in the past and some potential changes that are likely to impact the aviation industry. This work also discusses the implications and interconnected elements tying technical, social and process changes together. As a specific example, this work examines the history of aviation fuel and analyses the impact that changes in the fuel, type, infrastructure, demands or quantity have had or can have on aviation systems. Focusing on one subsystem this work is able to look at the past changes and potential future changes of the systems and provide some quantifiable metric that can be used to compare these changes across the industry. In the discussion section, the quantifiable metrics are further discussed as the basis for future work to establish a singular quantifiable metric that incorporates several elements including the cost, the disruption, the required external infrastructure, and any potential benefit of implementing systemwide changes. By tying process changes together into the socio technical system planning process this work is meant to help define another element to consider in the study of Socio-technical systems.

4.1 Introduction

This work is based on a brainstorm in conjunction with a doctoral qualifying exam, this work was originally answering a question about historic changes and generational system gaps at airports. At the conclusion of the qualifying exam, a suggestion was made to turn a series of slides on historic changes and risks facing the aviation industry into a paper. To build that paper the examination of risk returned to a previous examination of the history of aviation through a focus on Pan American World Airways[26]. This led to a collection of both historical cited changes and hypothetical future changes that could cause large scale transformations that would define a new generation of air travel. Starting with a background and literature review section this work looks at a series of definitions that help define a scope of inquiry when looking for potential scenarios where changes could impact the entire aviation industry. After examining some of the literature on changes, particularly in aviation, this work offers a review of the aviation fueling systems as an example of a changes that impacted the entire aviation industry by enacting technical, and process changes that impacted social perception and therefore the social system. From the examination of the current aviation fuel systems, this work looks at future risks that may impact both the used of fuel and the distribution of fuel which could impact not only the aviation industry but also adjacent industries that support air travel. The discussion then offers some thoughts on how to generate a quantifiable measure of risks posed by changes to the system. This quantification will help airports think systematically about impacts of changes to any airport system and will highlight the need for long term growth strategies that address all the system elements across the full airport. By suggesting a strategy to assess the full impact of changes, the authors are hoping that this work will form the foundation of future studies into cohesive unified system plans that can be implemented at airports all over the world.

4.2 Background and Literature Review

Six original hypothetical changes that would transform the aviation industry were presented in the first proposed concept that mad up the foundation of this work. In conjunction with these six concepts presented, in the qualifying exam, the scale of the aviation industry was explained as a part of an interconnected network of systems. This led to the idea of categorizing changes at airports. This work was also built alongside a study of socio-technical systems. With the obvious overlap between the two studies, the authors began to examine a variety of sources that define socio-technical systems and then began to clearly define airports a socio-technical system based on size, infrastructure demands and social dependencies. As this work continued to develop it became important to offer details about airports' social and technical qualities that lead to the aviation industries resistance to change. In conclusion this section outlines how the categorization of change could help precipitate some of the needed changes that will be required to transform the aviation industry into a more sustainable long-term form of transportation.

4.2.1 Scale of Systems of Interest

Aviation systems are often vast complicated systems themselves but are often only elements of the larger sprawling networks of technology and infrastructure that make up the aviation industry.[10] It is the scale of the systems therefore that necessitate the systems thinking focus.[92] If one element of a vast network fails to perform its specified role the entirety of the system network can be negatively impacted.[93] By studying the past impacts, planners can begin to understand, predict and account for the impacts of their planned interventions on the aviation industry. Taking on the entire aviation industry in one examination of change, has allowed a generalized categorization of not only historical changes but also the forthcoming changes that are likely to impact the entire industry in the near future.

4.2.2 Socio-Technical Systems

Systems can be defined in a variety of ways including by scale, purpose, elements, and design. Systems can also fall into a definable category such as political, economic, technical, or social systems. Each type of system has unique characteristics and interacts with other types of systems in distinctive ways. In the context of this work the two most important categories that impact all airport are social systems and technical systems, or what is frequently defined as a socio-technical system. All airports fall in the category of socio-technical systems because they are part of large infrastructure networks and because airports themselves fall into the overlapping region of social systems and technical systems.

There are a series of defining element that are used to define a socio-technical systems. The term “Socio-Technical System” originated in the study of coal mine efficiency after the second world war; the domain quickly grew to help define the complexity of human interfaces with an emerging and ever-changing world of technology[32, 33]. In a more generalized context however, the best baseline for defining socio-technical systems is a slightly altered version of the definition provide by Baxter[34] of the intersection between organizations, systems and users; the general definition is: any system at the intersection between a human in the loop systems (the social system) and a technical system with at least one technological impact or components (the technical system). This definition comes out of both reading and observation in the context of a semester long study of Socio-Technical System and is loosely based on course materials and articles found from a variety of sources. This definition is too broad to define a specific set of systems though, so to limit this definition, this work begins with the Systems Engineering Body of Knowledge (SEBoK)definition of Socio-Technical systems as presented below [35, 36].

4.2.2.1 SEBoK Essential Elements of Socio-Technical Systems.

According to the SEBoK there are few formal definitions of "socio-technical systems"; the term refers to a variety of different facets of engineering, depending on the domain[36]. To define the term that is more ambiguous in a lot of literature, the SEBoK authors identify four key areas of study within socio-technical systems. These areas of study are:

- **Human Factors and Ergonomics:** This is the study of how human interfaces and layouts of system impact both the people and the system. As stated by Corlett, human factors and ergonomics 'modify the relationships of power between people and things, or people and people.'[37] In the case of systems, the study of human factors and ergonomics relates to control and influence of a socio-technical system.
- **Organizational Design**: The design of an organization and the operational behavior that a particular design elicits, has a major impact on an organization's operational systems. In the business world, as organizations grow, so too does the

complexity of the organizational design, which tends to shift goals toward financial growth and stability[32, 38]. The growth in complexity in turn, tends to lead to more complex behavior within the social and technical aspects of the organization[39], while a shift toward profitability tends to limit the autonomy and innovation by forcing uniformity[32]. Impacts from organizational and human interface factors, also then define how an organization shapes and builds systems and incorporates technology. These organizational design factors can therefore either push a company toward innovation or hold them back.

- **System Design:** Unlike organizational design a system design pertains to a specific system or function and is therefore less likely to evolve with the organization. The optimal system design strategy, incorporates system designs at the origin of system planning, this allows the best outcome for the designers and engineers of the system[40]. Systems design must also accommodate the complexity of both the social system and the technical systems as the unique elements merge to form a complete system. When systems are designed well, the system's behavior is predictable, if there are limitation in the system design, new or unexpected behaviors might emerge. These behaviors, both planned and emergent, impact the system design.
- **Information Systems**: Information Systems is the term used to identify the technological elements of the system that gather, process, and relay information to users, managers, and other system elements. This is one of the four defining elements of a socio-technical system according to SEBoK because as autonomy and scalability take larger roles in the social systems, the technology tends to

become more ubiquitous but also more opaque meaning that less of the information gathered is being displayed but the system is gathering more information on the behavior of not only the system but the interacting social constructs[41, 42].

4.2.2.2 Other Defining Factors Identified in Literature.

There are several additional elements that expand and help define what makes a system a socio-technical system. Some of these elements have come from literature on the history of socio-technical systems while other have come from general research into the different elements of systems engineering. These additional elements are grouped into some general categories below. Many of these elements are more fluid, but each of these categories listed has some descriptive value to add when discussing socio-technical systems.

- Small Operational Groups: working groups that can be given freedom to operate independently can provide better results and have inherent social advantages to offer the overall technical system. [32]
- Level of Connectivity: This can be a physical or electronic connection but any system that connect humans has inherent social and technical attributes. [43]
- Autonomy: This is related to the small working groups and relates to the ability of a group to operate within the system to achieve local efficiencies. This specific attribute can be easily hindered by regulations, standardization and economics (specifically capitalism). [32]

- Systems of Systems: as multiple systems integrate, there are social and emergent properties that begin to develop. Using the five elements of systems of systems identified by Maier[44], there is clear overlap between systems of systems and socio-technical systems
- Complexity: is a benchmarking tool to measure the relative interaction between elements in a semi-quantitative way. This is more relevant in systems of systems, but Righi provides a list of 13 characteristic of complex systems that help to define the complexity of socio-technical systems. [45]
- Bottom-Up System Design: is identified as a defining characteristic of a socio technical system as the bottom up system integration tend to face integration issues where as down systems are managed, avoiding some of the emergent properties and potential negative consequences of system design and integration. [32]
- Anthropological Interfaces: this refers to the interfaces between societies' complex infrastructure and human behavior, especially the interaction between different infrastructure and any group that has an impact on the system operation, growth, design, or end goals. I.E. any sort of project (especially transportation) that attracts public funding. [44, 46, 47]
- Unique, Interacting Elements: these are elements that collaborate with both societal and technological systems rather than just humans interfacing with the system; this is a complex bi-directional interaction rather than a simple human interaction, so it moves away from the human interfaces and ergonomics referenced above.

- Macro scaled systems: this refers to the systems that exceeds the typical local boundaries I.E. social or physical networks. [38, 48]
- Robustness or Resilience: socio-technical systems have some element of robustness that can be measured by analyzing the network or connectivity of the system. If there are critical nodes within that system, there is a higher likelihood of outages and systems failure [49, 50]

It is important to point out that while these elements all provide some insight into the definition of a socio-technical systems, not all socio-technical systems will meet the basic definitions in each category. It is more likely that most socio-technical systems will only meet some of the elements listed.

Airport are Socio-technical system based on both the definition provided by Maier [94] and by the additional elements that make a system a socio-technical system. Airports integrates the technology systems, the passenger interfaces and the organizations that operate within the industry. Airports also fall into the category of macro, bottom-up, unique, complex and systems of systems which means that they posses several additional qualities that define them as socio-technical systems.

4.2.2.3 The Status Quo – A "Large Systems' Resistance to Change.

Aviation like all systems experiences some regular changes and adaptations. These come from the adaptation in people and the emergence of new behavior within the systems.[53, 95] Large systems are resistant to change and can often even reinforce the resistance to changes over time. Networking, expanse, integration, commonality, jurisdictional boundaries, complexity and sunk costs all factor into a systems' level of resistance to change. These variables are a good start to describing resistance to change, it is valuable however, to put these all into context. For a case study on resistance to change, we will examine each of these variables within the aviation industry.

4.2.2.4 Aviation Variables That Resist Change.

- Networking – With discrete nodes that each must provide a standardize set of services, a network resists changes as each change would have to propagate across all nodes within the network. Changes either must be backward compatible or must change across all nodes instantaneously. In the case of airports this means that any changes would have to take place at all airports or would need to be introduced gradually in a way that would allow cross compatibility with earlier systems.
- Expanse – the larger the system the more elements of the system must accommodate a change. In the United States alone there are more than 20,000 registered airports according to the FAA's Airport Data and Information Portal. A change in any single element such as the fuel used by aircraft, will require a role out of a new system at each of the airports that accept aircraft with the new fuel. The more airports that accept the aircraft, the more airports that will require the new system.
- Integration – The more systems that are integrated together the harder it is to change a single element. Again, with the fueling system, the plumbing for the pressurized fuel system is integrated within the apron surface and is therefore unable to be isolated, updated or changed in its current configuration without substantial infrastructure interventions.

- Commonality – the more common a system is the more resistant it is to change. On aircraft almost all jets are fitted with a common fueling nozzle. This existing fuel nozzle set-up resists the introduction of anything new that would negatively impact a fuelers ability to fuel an aircraft, inversely however, changes could provide safety against introducing a new fuel into an existing aircraft.
- Mixed Jurisdictional Boundaries – with different jurisdictions controlling different systems and parts of the network, changes need to be enforced on a macro scale to take effect rather than on a micro or individual scale. It is not enough for one airport or airline to begin to make changes, the changes need to be driven by a more influential group such as the FAA, IATA or ICAO or even the fuel providores.
- Complexity – As the aviation system has developed new elements have been deployed around the existing systems to accommodate new technologies. As new system elements are incorporated, the layering of technology, the changing interfaces and the emergent behaviors have increased complexity in the support systems exponentially. As with many system architectures, the consequence of the complexity are unintended interdependencies between the system elements that cannot always be described or explained.[96]
- Sunk Cost – The expanse of airport infrastructure accumulates as new infrastructure is added to the airport facilities. As the costs add up, an airport's wiliness to change or write off sunk costs diminishes.

In large distributed networked systems, like aviation, potential infrastructure changes need to propagate across the entire network in order to effect sustainable changes. The cost of this propagation often exceeds practical means of the entire system.

[54] While large change quickly become impractical due to cost, some smaller changes are practical and often even required to maintain the customer base. The defining factor in this study is the difference in industry changes and advancements verses the industry disruptors or changes that would dramatically alter the industry from the standards of today. Disruptive technologies are discussed by examining four disruptive technologies in an appendix. It is also discussed that the nature of a disruption is that the changes or innovation are often unforeseen or outside of the confines of the specific industry of focus.

4.3 Changes

As the systems that make up the aviation system resist change it is valuable to categorize changes that could potentially impact the aviation industry. Three major categories are defined to help group changes, and for each category there is a brief discussion on the impact that changes can have on the aviation system. The first category of changes are the technological changes or advances in technological elements of the system; technological changes would include any new hardware, software, physical equipment or change in structure or chemistry. For the sake of this work, the technology changes discussed focus on changes in aircraft, and changes in the fuel used by the aircraft. The next category is the social changes; these are changes in the preferences of passengers, the social views of passengers, and even types of passengers this could also include other stakeholders like the local community near the airport and the organizations that operate on or near the airport. The final category of change is the changes within the processes of the aircraft turned around, the passenger journey or the way a process is undertaken. Process changes are the third category of changes which are impacted and shaped by both technological and social changes. It is only when all three categories of change are overlapping that a system experiences a sustainable system wide change.

4.3.1 Technical Changes

Technology changes shape and make possible new system elements that expand and grow any industry. These technology changes can be advances in the science or in the understanding of an element of the industry or can be a more efficient or new system element. The defining factor is that technology allows new functions, an improvement in efficiency or better transfer of information to other industry partners.[40] In the world of computers a technology change can be a faster processor or and more nimble graphics card or it can be a new method of performing a particular task like the introduction of ARM processors. These advances may be trivial for most people outside of the industry, but they may facilitate a new transaction or open new possibilities within the current environment. Aviation is no different than any other industry, technology changes impact the industry in both direct and indirect ways and are not always obvious to the stakeholders especially the passengers. In the case of aviation there have been some key technology changes through history that progressed the industry to where it is today but there have also been new technologies that have been embraced to support efficiency gains. These changes also help to foreshadow the some of the potential future changes that could be faced by the aviation industry. Below a series of historic technical changes are listed and briefly explained. These changes are followed by some potential future technology changes that may have an impact on the aviation industry. The final category lister are some of the un intended behaviors that emerged with all of the changes in technology. While it is clear that some technology changes are for the better it is worth noting that many of these change have also come with drawbacks.

4.3.1.1 Historic Technical Changes.

The list of historic technology changes is not meant to provide a full history but is instead meant to provide some key examples of changes that impacted the industry. Some examples of technology changes are the introduction of the jet engines into civil aviation with the introduction of the de Havilland Comet in 1952.

- Introduction of the Jet Aircraft – the first commercially operating jet aircraft was the de Havilland Comet which first joined a commercial airline in 1952. This began the jet age leading to a generational change in aircraft propulsion.
- Standardization Jet Fuel – most turbine engines could run on any variety of fuels. The standardization of fuel came in 1956 as companies attempted to standardize processes and procedures while making air travel safer and more reliable.
- Introduction of 747 and multiple class travel – Juan Trippe of Pan Am and Bill Allen of Boeing ushered in a generational change in the way people flew by introducing an aircraft with the capacity to fly the common person to leisure destinations. The size od the aircraft opened up the possibility for more passengers to fly further and democratized air travel.

- Containerization of cargo and Luggage – As aircraft got bigger there was a need to turn them around faster. This led to the advent of the standardized aircraft Unit Load Device (ULD or can) for loading luggage faster and mor efficiently

4.3.1.2 Potential New Technologies.

This list of potential technology changes is made up of changes that have all been speculated about or written about in online forums or news sources. This list, like the historic changes is not meant to provide a comprehensive list of potential future technology changes but is rather meant to highlight some of the most commonly appearing or most likely technology changes that will impact the aviation industry.

- Plane shapes – Aircraft have begun to shrink from the peak of the 747 and the A380 as aircraft shrink, there is also a push toward more fuel efficiency. One of the many suggestions to gain fuel efficiency is to alter the shape of the aircraft to improve aerodynamic forces.
- Fuel Technology – Jet fuel has been standardized for more than 60 years and continues to be produced in a similar distillation process from crude oil. As with many petroleum-based products there is a search for replacement fuels to provide a similar energy density and concentration.
- Mechanics of flight – Either supersonic or even hypersonic flights might soon be possible. As the speed increased, the mechanics of control and the trajectory of the aircraft will require alteration.
- Stops required – the number of stops required for any given flight is directly impacted by range of new and existing aircraft. As seen with several new generations of aircraft

before, as new types of aircraft join the fleet, the average range of the fleet tends to drop before climbing again.[26]

4.3.1.3 Emerging Technology Trends.

Many advancements in science and the capability of the technology already appear in the industry and have shaped the ever-changing industry or directed the growth of aviation.

- Acceptance of Emerging Technology – There is a more common willingness to accept new technologies which means that they appear in the aviation system more frequently than in the past. While many of these are not causing generational changes they are altering the airport experience in smaller ways like the introduction of new security screening machines or the introduction of RFID baggage tags.
- Retention of Clients by integration of technology (Xu)[97] – Some airlines have introduced technology into their own products to entice customer to return. Some examples of this include the introduction of RFID baggage tags and the support for personal Bluetooth headphones on aircraft.

4.3.2 Social Changes

Social changes and the impact of social changes tend to have a relatively limited impact on short-term infrastructure changes within the industry, but can dramatically impact the long-term facility by defining goals and planning parameters. Social elements have a far more visible impact on the passenger space even in the short term and can therefore appear more influential in specifically shaping some aviation trends far more visible acknowledged as factors within the aviation industry. These two somewhat divergent types of social changes present a dichotomy, invisible long term impacts and highly visible short term influences on airport systems. That makes social changes both easy and incredibly difficult to define and present. To help simplify the conversation , social impacts are broken into two categories: the short-term social impacts of the traveling public, and the long-term social impacts of the local community. Social impacts can result in changes as small as the installation of a television screen or public Wi-Fi, to far more wide-reaching changes such as the abandonment of a planned parallel runway. As with technology changes below is a list of past changes in the social elements of the airport system, a list of potential future changes, and a list of emergent social properties within aviation systems.

4.3.2.1 Historical Social Changes.

- Introduction of Leisure Passengers – as more passenger began to fly the nature of the journey changed resulting in a reduced level of service.
- Introduction of Business Class Passenger – to bridge the gap between the first class and leisure passengers the middle tier of passengers was introduced. These middle tier passengers were the business class passengers.
- Standard duration of trip of passenger – as the leisure passenger began traveling on the same aircraft, the average duration for passenger trips began to drop. Travel was no longer a long journey only for those who had many weeks to go away, holiday destinations began to cater for shorter stay vacation traffic.

4.3.2.2 Current and Imminent Social Changes.

- Passenger expectations – despite the lower fares and dropping of first class travel, passengers are expecting more from their flights.
- Concern for the environment – some travelers are concerned enough that they are opting for other more efficient forms of transportation such as trains or busses.
- Passenger interface with the aviation system – Many of the "touch points" in the aviation system have not changed recently. The implementation of passenger tracking and specific product sectors offers some opportunity to change the way passengers interact with the aviation system as a whole.

4.3.2.3 Emerging Trends.

- The changing generational passengers – there has been a shift in the past several years toward the younger generation of airline passengers. The current statistic indicates that millennial travelers make up more of the traveling public than any other age group and they are shifting the demands on the industry. [63]
- Environmentally conscious passengers – as with technology the trend of environmentalism is shifting the social dynamics of the industry the same way it is shifting the technological advancements.

4.3.3 Process Changes

Process changes in aviation are the changes that take place when adjacent or old technologies are integrated into the existing systems to add functionality or efficiency. These changes implement technologies or procedures that might not have otherwise been involved in the aviation industry or make it possible for new technologies to become a part of the systems that provide services to an airport. Process changes can impact the passengers and staff or can be exclusively in an airline operations field. Process changes can also be far more global or network oriented rather than a specific technology or social change that would impact one element of the system. Take for example international quarantine restrictions that were put in place throughout the COVID-19 pandemic. The implementation of quarantine facilities dramatically altered passengers ability to transfer through specific locations or even to travel at all. Quarantine facilities are only one example of process changes that have impacted the aviation industry. Similarly to technical and social changes process changes are listed below as historic changes and potential future changes.

4.3.3.1 Example of Past Process Changes.

- Security – the introduction of different levels of security have happened based on historic events. Each time an event precipitated a change new technology had to be include in the security process to better secure the passenger journey.
- Quarantine – facilities have been built on the assumption that there would only be small numbers of passenger requiring quarantine. As has been shown during the Covid 19 pandemic larger facilities or contingencies may need to be considered.
- Market expansions and contractions
- Airline models – as new passenger classes were introduced the method for accommodating the new classes of travel had to change and incorporate new processes to transport the new class of passengers.

4.3.3.2 Potential Process Changes Anticipated.

- Growing and emergent markets – as new markets continue to emerge or to appear process may need to change to accommodate new or different groupings of passengers
- Expanded quarantine requirements
- Faster aircraft with shorter range requiring more stopovers
- And as market forces change airline models are likely to continue changing through economic and financially advantageous operating models. These are the changes in process

4.3.4 Overlapping of Change – The Ven-Diagram

Each of the tree elements of change described above are interrelated, and when all three occur they create sustained and long term changes. A change in social systems, technical systems or process systems can have significant impacts on the full system, but the more influential changes come from the changes within the overlapping interrelated systems elements. As the three major system types overlap, four new interactive areas are created that help to further define changes.

The overlap between technical system and process systems are usually the areas of production and distribution. These systems are most heavily influenced by improvements in financial or temporal performance of the system. Changes in technical and process systems also don’t have the social impacts to consider which makes it possible for change decisions to be made by small groups of stakeholders. I.E. manufacturing processes where management can make a change without fear of customer anger. The trade off is that in more technical systems, process changes can sometimes require years of planning and infrastructure interventions. This can mean there is a disincentive to implement these technical-process changes. I.E. updating roads or water systems is costly and takes time.

The overlap between social and process systems are frequently shortcuts in the systems process or changes in the system requirements. A proposed process that skips several steps May be more convenient or easier but if the technical systems are not changed to support the new social-process, gaps can appear in safety, and systems reliability. I.E. the American Airlines crash in Chicago when maintenance crews simplified the engine removal process ignoring warnings in the aircraft service manual. In many social systems, the process elements change far faster than in technical systems, leading to some of the most prevalent emergent behaviors. While these changes can be convenient, they are not always prudent and often have more significant long-term consequences. I.E. adding one more gate at an airport or letting students walk wherever creating cattle paths through campus killing the grass.

The overlap between changes that impact social and technical systems are well documented compared to the other two. In the study of socio-technical systems, the overlapping elements have interacting impacts that directly tie many changes together forcing a system wide change. The factor that is not referenced is the need to affect a process change in order to sustainably impact the entire socio-technical system. While it is possible to have the technology and social will to change a system without the process behind the system many of the desired changes are never brought to fruition.

The final set of changes are the sustained changes that have an impact on social, technical and process systems. It is the overlap between social, technical and process changes that makes sustainable system change possible.

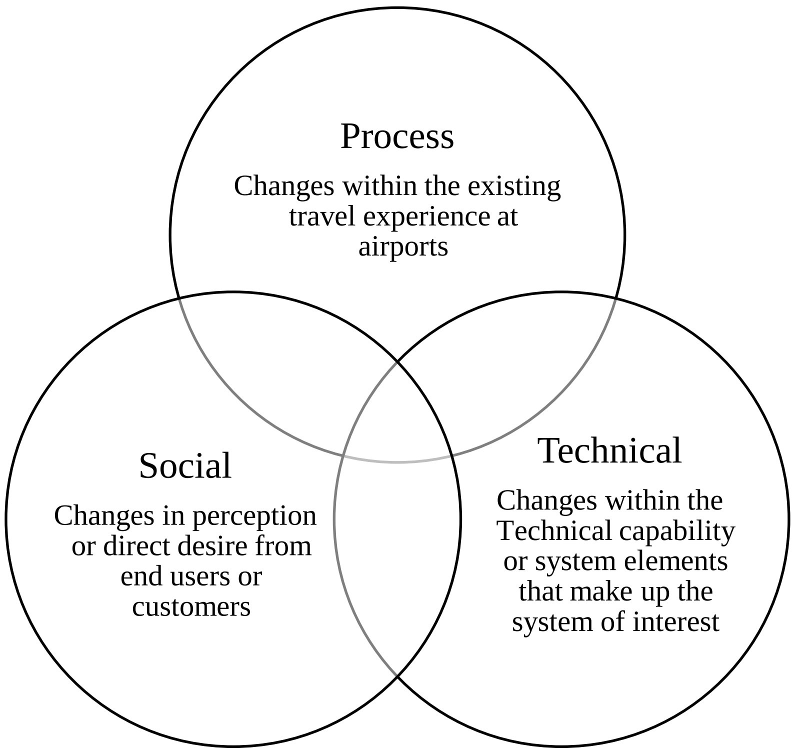

Figure 8. Ven Diagram of Inter-Related Changes

4.3.5 Generational Changes

In many industries the sustained changes only occur in increments often marked by clear dynamic shits that can be defined as generational shifts. In aviation generational shifts occur between every 5 - 20 years according to Graham and Baldwin.[3, 4] A series of generational changes often occurs after major disruption events. Given this trend in the aviation industry and series of additional changes can be expected in the next 2 to 5 years. The authors are not attempting to identify the changes, that will make up the generational shift, it is clear however that social, technical and process changes will all play a part in the inevitable generational change that will shape the future of the aviation industry.

4.4 The Fueling Systems

As an airport systems example to highlight the three categories of change, this section examines the aircraft fueling system. As a required component of the aircraft turn around, the fueling system is an integral part of any airport and is therefore a perfect example of a system that is subject to social, technical and process changes. The ubiquity of fuel systems at airports also means that fuel systems have a history, a sunk cost, a resistance to change and yet the fueling system is one of the most likely systems to experience a generational change. The fuel system is only one system that has social, technical and process elements that combine to make up the functional system but is a good example of one subsystem at an airport that is crucial to operations of an airport.

4.4.1 Social Implications

All elements of the airport are subject to social influences especially the elements that have a direct impact on emissions and the potential for contamination. Fuel is one of the most obvious systems therefore that is subject to social opinions. In the case of the fuel system social opinions not only define the way the system is secured and laid out, but also directs the research into future fuel types.

4.4.2 Technical Implication

The rea are a number of technical considerations when looking at the fueling systems at airports. The fuel itself is a technology that must be considered. Jet fuel was standardized in 1956 but still comes in several different forms depending on the region or intended use. The chemistry of fuel is only one example of the advancements in technology that change the fuel systems at airports. Fueling systems require networked piping systems which include pumps, tanks and monitoring systems to maintain flow of fuel and resilience to the full system should something go wrong.

4.4.3 Process Implications

Two major processes can be identified in relation to the fueling system at airports. The first is the supply of fuel through petroleum processing and the transportation of that fuel to the airport. This process is largely controlled through standards and by the oil companies that supply fuel to airports all over the world.[98] The second process associated with the fueling system is that of fueling aircraft on the airfield. Fueling an aircraft is complicated less by the simple act of pumping fuel into the aircraft and more by the pure volume and resiliency required across the fueling system. In order to fuel an aircraft in a reasonable amount of time the fuel system must constantly be under pressure to provide the volume of fuel needed across the airport. The need for pressure and the risk involved with fueling aircraft requires a variety of safety systems which complicate the systems process. These processes are highly dependent on demand and adaptation but have not seen a recent change.

4.5 Discussion

4.5.1 The Future of Change

As with any industry the future of aviation is very difficult to predict. Forecast and trend lines tell us that aviation will continue to grow after a recovery period from COVID-19. Global trends also tell us that the number of passengers will continue to increase and get younger and younger every year. To handle many of those trends some assumptions have been made in the past. Certain companies and airlines have bet on larger aircraft carrying more passengers, others have bet on smaller aircraft carrying fewer passengers more efficiently longer distances. while both options offer potential advantages to specific passengers no single direction can be defined as the best solution for the entire industry.

4.5.2 Scale of Change – Change vs Disruption

Covid-19 has challenged a number of industries forcing key stakeholders to examine their internal practices, their external offerings and the long term future off entire industries. Aviation has been one of the hardest hit industries as international boarders have closed and travel restrictions have prevented the networks from continuing to connect people and cargo around the globe. This temporary disruption to the aviation industry has highlighted the impact of not only shock events but also the changing environment and landscape of commercial travel. As seen in the early retirement of several aircraft types from airlines across the world (See A380, 757 767 and united, American, delta, emirates, British airway, Lufthansa, Singapore, air France etc), the impacts of shock events not only alter an airline's plans but can also reshape the operations of the entire aviation system. When the disruption stems from a direct shock events like Covid-19 there are immediate and unpredictable impacts whereas changes are from gradual shifts in opinion or industry operation are more manageable and predictable.

As the aviation industry begins to emerge from the largest disruption to commercial travel since the second world war, there is value in identifying some of the most obvious threats facing aviation today. While there is a fine line between changes and disruptors within an industry, the definitions below attempt to highlight the distinctions and provide clear example of each that could impact that aviation industry.

4.5.3 Changes

Changes represent the emergence of technology or the integration of specific technology into the existing system or network that would systematically work with or along side existing infrastructure and technologies. This type of change may be the integration of security into the passenger terminal experience or the introduction of the glass cockpit in aircraft. Changes can also be generational changes to replace or supplement the existing technologies like in the case of radio navigation equipment being replaced by microwave navigation equipment or GPS navigation equipment. These changes would not cause an immediate disruption to the current operation of the system but would cause a gradual change over time. These gradual changes would reshape elements of an industry but would not make the industry obsolete. The original list of six risk factors, which is below, all fall into the category of changes that would integrate with the aviation system in some way. None of these changes would force an overhaul of the entire aviation system but each has the potential to heavily impact the aviation industry.

Potential Changes to the Aviation Industry

- Fuels types used in aircraft
- Aircraft types - Shape, size, and speed all have an impact when looking at aircraft
- Flight Mechanics - parabolic trajectories
- Airline operating model - hub market vs point to point
- Emerging markets - impact of India and China
- Quarantine rules and requirements

4.5.4 Disruptors

Disruptions are changes that have the potential to remake an industry or make it obsolete. These changes can replace a primary function or some major elements of the system of interest in such a way that the current support systems no longer provide services to the industry. In the aviation industry the most obvious disruptors would come from the change or offering of other forms of travel for example an increase in the prevalence of railroad use, which would shift passenger traffic away from air travel. Several additional disruptors are listed below. Each of these has the potential to disrupt the industry just as much if not more than the introduction of the jet engine into commercial aviation more than 60 years ago.

Potential Disruptors to the Aviation Industry

- Circular Runways – if new airport designs are implemented the industry will have to change dramatically.
- Trains – high speed rail is a direct competitor to short and medium haul flights
- Ballistic trajectories – faster travel would likely require more vertical take off positions which would require a change in the set up of airports.
- Planeside Lounges
- Shape of aircraft

4.6 Conclusions

Sustainable change must impact, technology, social and process systems in order to create a long term impact in the aviation industry. By examining changes in each of the three categories and showing the overlap, this work is meant to highlight the interrelated impact of changes in a socially connected technological and process driven transportation industry.

The work presented in this chapter is meant to represent the current state of the aviation industry looking at not only the current risks facing airlines and airports, but what imminent risks can easily be identified and planned for in the shorter-term future. This work looks back to historic changes as identified in the Historic Pan Am Fleet chapter and builds on some of the key risks that face the industry as traffic levels recover from the shock events of the COVID-19 Global pandemic.

This work is a copy of the draft extended abstract that has been accepted to the 2023 AIAA SciTech conference for publication and presentation as part of the Conference in January 2023.

CHAPTER V

A NEW SYSTEM CONCEPT AND FRAMEWORK FOR TURNING AROUND AIRCRAFT: A FUNDAMENTAL CHANGE IN APRON DESIGN AND LAYOUT

This chapter is based on a body of work aimed at developing a new apron area interface system. This work explores the development and potential uses of the new apron area system being proposed. This work then follows a similar format to the academic paper introducing the circular runway concept.[1].

This chapter highlights the systematic development of the new system and the supporting framework. This work is being targeted for publication in the Aviation Management Journal. The goal is to submit this work for publication after my graduation from this program.

5.1 Abstract

The work presented in this chapter represents the initial concepts and basic validation process used to analyze a novel system to simplify the aircraft turn around process within the apron area. This work represents a final portion of work toward a doctoral degree in systems engineering and has been written for inclusion in a dissertation. As this work represents an academic study it is offered not as a final concept

for implementation but as a systematic approach to updating an antiquated system. Though conceptually sound, the system presented represents only one potential option to update to the turn around process. By offering this system framework, the authors intend to start a conversation about system resilience through generational changes at airports and encourage planners and designers to look at wholistic systems solutions that simplify the current practices rather than replace the current system elements. The system framework that is proposed in this work is a solution that can be used in place of the current boarding systems at existing airports or could form the foundation of a greenfield airport where operations could be transformed from the inception of the terminal.

5.2 Introduction

Aircraft boarding and the turn around process has been largely the same since the introduction of jet bridges shortly after the introduction of the original passenger jets. While there is some variability in the boarding process the current practices are dependent on the airport and the governance structure, which means that there has not been a systematic shift in the turn around process since before the deregulation of the aviation industry in 1978 in the United States.

As jet travel continues to be the normal for of air travel, many of the airports that support the large network of airline routes have reached a point of relative maturity, This makes changes in the industry increasingly expensive to implement and leads to stagnation in many of the support systems. The system presented in this work is meant to facilitate and support some of the impending changes as outlined in CHAPTER IV.

5.3 History of Boarding

The boarding of aircraft has changed based on the size of the aircraft, the shape of aircraft and type of aircraft, and a variety of airline specific variables. While there is some variability in the boarding process, even across some airports, aircraft have largely been loaded from the forward port side for most of their history. The port side boarding process followed the earlier nautical tradition because many early airline flew seaplanes. As the industry grew and new aircraft and infrastructure was developed the tradition of boarding from the port side remained.

In the early days of land based commercial aviation, most airlines began as cargo and mail carriers. As passenger airlines developed, almost all aircraft were small and carried a very limited numbers of passengers. The first major commercial land planes boarded from the rear as the tail was usually closer to the ground. Tail dragger aircraft were the norm with larger engines that would pull the plane horizontal as it accelerated down the runway. As aircraft grew, and the design of aircraft changed so the tail no longer sat on the ground, the boarding process became similar for the front and rear of the aircraft. As a aircraft grew allowing a increase in total passenger numbers, many airlines began looking for more convenient ways to load passengers and cargo simultaneously. To split the passengers and cargo many airlines moved passengers to the forward door of the aircraft. At the same time a new generation of aircraft, all of similar size, and shape allowed the standardization of the boarding process.

The use of air stairs on the front entrance to an aircraft and the standardization of size of aircraft allowed the evolution of the passenger boarding system in the 1960s into the modern day image of jet bridges. The earliest jet bridges were fixed walkways at the

Pan Am World terminal building in New York. Jet aircraft were taxied to a position adjacent to the fixed walkways and passengers were boarded on the walkways. As more airlines began flying jet aircraft jet bridges became more common across airports around the world. While some airports continues operating with stairs as a more reliable, flexible and cheap option, most locations began using fully covered, passenger boarding bridges that connect passengers from the terminal directly to the jet aircraft.

After the introduction of jet aircraft, the speed of change in aviation slowed. While new technology is continuously being developed, the general speed, size and shape of the aircraft of today has remained based on some of the fixed assets and sunk cost associated with aviation. Jet bridges are one of the many sunk infrastructure costs that has not changed, despite the continued growth in both aviation and technology. The lack of development in the boarding process has left the boarding hallways that can be seen at most airports, as narrow corridors through which passenger travel in narrow cues as they file onto or off an aircraft. Jet bridges are so ingrained in the development cycle of airport that rather than developing new systems some airports have opted to add additional jet bridges, to increase the service offered to passengers to enter or exit larger aircraft. While the additional space is more valuable for larger aircraft it begins to highlight the question: Is the extra boarding area only needed for larger aircraft? Delta Airlines is currently testing multiple gate boarding from two doors in Cincinnati, and several jet bridge manufacturers have developed larger products including a jet bridge that is 12.8 feet across. While this type of bridge is more expensive it provides more comfort and efficiency in the boarding process.

5.4 Introduction of the New System

As seen in several papers including Wing [2, 26] many elements of the aviation industry have not changed significantly in the past 60 years. Over that time aircraft speed has remained relatively constant, the number of passengers per aircraft has dropped, and the range of the average aircraft has remained relatively constant. These consistencies have grown from a limited incentive to update infrastructure, as new infrastructure was not required to accommodate the newest generation of aircraft.

The lack of investment and infrastructure has led to the decline in the level of service[5] and the stagnation of the systems that connects the passenger terminal to the aircraft. The passenger connection is only one part of the systemic problem of 'lack of evolution' within the aviation environment; passenger boarding served only as the launching point for the system developed during this work. The conceptual design grew from a prompt to fundamentally change the way systems at an airport are developed and structured. The concept defined has been refined through several iterations with both academic and industry feedback leading to some of the conclusion offed in the final section of this chapter.

Building on the efficiency and comfort of the larger jet bridges, the initial concept presented in this work is an integrated system wide aircraft interface that is meant to more efficiently turn around aircraft. The most obvious change to the traveling public is the passenger boarding facility that will stretch the length of the forward section of the aircraft. Passenger boarding therefore, provides the first point of validation to show

[5] Level of Service is a concept meant to provide a graded range for all of an airport's facilities. This can tell designers if their facilities are over designed or under designed for the traffic that the forecast predicts will use the given facility.

efficiencies in the passenger boarding processing. The new extended passenger facility also provided the opportunity to incorporate more services into the passenger facility. The extended area provided an extended footprint that can incorporate cargo processing, utility servicing, and fueling service, all of which has the ability to improve the overall efficiency of an airport. This chapter explores the new system and provides some promising results on the testing of the system elements which could be further developed into a working system for future airports.

5.4.1 System Overview

The system is meant to work similarly to a jet bridge of today, moving to meet an aircraft. The system will be much larger however, stretching between thirty and fifty feet in length. The new facility will be more like a multi study mobile room rather than a hallway. While mechanically the extension to meet the aircraft will be similar to the jet bridges of today, the rest of the system will contain more of the support systems needed to turn around an aircraft. The passenger level will be the second level, so passengers are more in-line with the level of the aircraft they are boarding or departing. Above the passenger level will be mechanical connections including a pressurized fuel system to replace the current buried fuel system. Below the passenger level a corridor for staff and maintenance personnel is adjacent to a second mechanical corridor that will contain preconditioned air, air conditioning/heating, electrical, water and waste conduits to connect to the aircraft's service ports. Also on this lower level will be an area designated for the movement of baggage and cargo, to connect to the existing baggage system. The system is meant to incorporate as much of the turn around process into a single system to help simplify the traffic in the apron and reduce the need for external services in the apron.

5.4.2 Passengers

The passenger boarding process of today can be completely reimagined if you consider a new layout of the passenger boarding lounge. Starting with the extension of the passenger area, the dynamic passenger boarding process will be more like those of a train or tram where passengers can enter from several points along the vehicle which helps streamline the process for the majority of the passenger. Like the current passenger bridges, the new terminal facility will be designed to allow the isolation of different groups of passengers. The system can also help eliminate some of the need for long queuing processes at the gate. With the use of some existing technologies, the passenger boarding process can be transformed into a more efficient process where passengers can be boarded through multiple doors, through a more open lounge area. The passenger lounge area can then be extended almost to the edge of the aircraft providing more area for passenger circulation, queuing and document or screening checks. By extending the passenger boarding areas, the proposed system provides a clear advantage over the single passenger boarding bridges at most airports today.

5.4.3 Cargo

With an extended passenger facility, there is an opportunity to extend the cargo and baggage system on the lower level of the facility. The Baggage and cargo facilities at many airports already rely on automation for the sorting and screening systems to process the volume of baggage and cargo that tend to fly on commercial aircraft. Much of the baggage systems are relatively concentrated however and baggage is loaded into cans or carts before it is driven on the road system out to the side of the aircraft. The extended area below the passenger facilities provides an area for baggage to autonomously shuttled closer to the aircraft. Rather than loading baggage into trollies to be driven to aircraft, suitcases and even ULDs can be transported directly into the aircraft without the need for baggage or cargo trains. This simplification allows a reduction in the number of vehicles requires on the apron. The incorporation of passengers and cargo services provides a compelling argument for the systems integration offered by this new system.

5.4.4 Mechanical/Utilities

Passenger and cargo connections are the most obvious services, but they can almost be seen as the customers of the aircraft rather than a service to support the aircraft. The services are more behind the scene and are more mechanical in nature. At the simplest of airports the first service is fuel. Aircraft fuelling has been relatively standard since the standardizations of Jet A and Jet A-1. These jet fuels are petroleum based fuels that most closely resemble kerosene or diesel fuel. Most all commercial aircraft rely on these petroleum based fuels to power their turbine engines. Fuel is only one of the fluids that needs to be loaded or off loaded from the aircraft however, aircraft also require water, oil, and sewage removal. In addition to fluids aircraft also require electrical connections while on the ground to power lights, aircraft controls, computer systems and air conditioning/ heating. This also means that the power required maintains the lines of communication between the pilots in the aircraft and the tower or the controllers.

Providing the mechanical connections required allows the proposed system to replace several of the existing systems.

5.4.5 Fuels

Most aircraft today are turbine power and use standardized fuel, and fuel nozzles. The standardization serves the global industry well in that a jetliner can land at almost any airport and be fueled by the local ground crews. This uniformity has prevented innovation in fuel types and the fueling system as a whole however, because there is limited incentive for innovators to design a new system or implement the use of a new fuel as the system would not support its use without significant intervention. By placing the fuel within the new proposed system, the new system would prevent the system from needing to be buried or highly pressurized. In addition to simplifying the current fuel system this would also provide some resilience should anything within the system change. Fuel is also one of the elements most likely to change as the aviation industry faces continued presser to de-carbonize. By removing the pressure on the petroleum fuel system and opening up opportunities for other systems to be implemented, the inclusion of the fueling system quickly became one of the largest opportunities associated with the new system.

5.4.6 Power

While on the ground aircraft requires a continuous power source to keep the lights and air conditioner running almost continuously. In many airports locations today, the airlines maintain their own power source by running an engine on the aircraft (This is often done with an Auxiliary Power Unit or APU) these engines are inefficient and maintenance heavy. The solution offered to airlines today is to connect their aircraft to ground power, though environmentally friendly, connecting to ground power and air, can be slow and is hard to justify on shorter turn around times. This highlights a concern raised in this process around an airline's reluctance to yield control of any part of the turn around to another entity.

5.4.7 Water

Water and sewage is another pair of closely related mechanical connection that needs to considered. Though these connection are only briefly required they are important to consider especially when larger aircraft look to turn around after a longer flights. By including these services within the new system, it is possible to further reduce the number of vehicles required to turn an aircraft.

5.4.8 Communications

More of the communications today is wireless than ever before. This does not take away from the need to support data links and connect ground staff to aircraft staff. The goal of listing communications as a connection in the new system is to protect the ability to add new pathways that may be required in the future.

5.4.9 Taxiways - parking flows and directionality

The proposed system was originally meant to support a new parking layout where aircraft parked parallel to the terminal face rather than perpendicular. In this layout aircraft could potentially power into parking bays and out of the same parking bay without the need for a push back tractor. This also meant that there would be less impact on traffic flows from aircraft having to be pushed backward onto live taxiways. This type of layout has the ability to reduce delays and congestion especially at airport with narrow taxiways. As the system has developed the benefit of parallel parking though still possible needed more geometric evaluation. The geometry of the proposed system is examined in the limitation section of this work.

5.5 Future Proofing

After gathering a variety of opinions on the proposed system one of the advantages of radically rethinking the infrastructure at airports is that the system is more likely to accommodate a range of potential future outcomes and new technologies. The first major ability to future proof is the ability to accommodate more than a single fuel without the need for specialized trucks full of each types of fuel, or the total destruction of the apron accommodate a new fuel system. As the fuel is meant to travel above ground, the system can accommodate a variety of new alternative fuels including both liquid and pressurized fuel options that have been considered. The next potential future proofed option was the ability to accommodate a variety of aircraft even if they differ from the standard tube-shaped fuselage. Jet bridges today often have fixed components leading to fears that new aircraft will have wing spans that conflict with the existing jet bridges. In the case of the Flying V aircraft proposed by TU Delf,[99] though you can get the jet bridge to the aircraft there is some question if it will safely allow passengers to board. The new system will meet and entire edge of an aircraft whether it is fuselage or leading edge of a wing. The final future proofed advantage of the new proposed system, is that the design which is mean to keep aircraft parallel to the taxiway rather than turning them perpendicular, allows linear expansion in logical growth patterns rather than some of the random growth of gates seen at other airports. While this proposed system is not flexible it does lead to specific and intentional growth patterns.

5.6 Validation of System

In order to validate the proposed new system a series of quantitative and qualitative methods have been employed to provide both numeric and explanatory benefits of the new system. While not all measurements of the system are consistent and validated, the methods presented in this section provide a positive picture of some of the key benefit of the new system. While there is always more that can be done to prove or disproved a benefit of a system, this work is meant to take the academic study far enough that designers and planners will at least consider the new layout and system elements in the design processes.

The first method used to measure the proposed system is simulation. Simulation is employed to look at passenger boarding, across the entire system. In addition to dynamic simulation, an assessment of the number of ground vehicles required to turn an aircraft around is provided. This assessment of the number of ground vehicles is used as a quantifiable measure of the reduced demand for ground service vehicles if this system were to be implemented. These two measurements provide clear quantitative indication that the system being presented in this work provides a benefit to the airport stakeholders. In addition to the two quantified measurements of the benefit of the simplified system, this section also provides a set of qualitative measurements of the benefits of simplifying the system. While only a small number of the potential measurements of the system are provided here, the benefits of system thinking in the design of a simplified integrated system can clearly be seen in this work.

5.6.1 Simulation

5.6.1.1 Tool.

The simulation tool selected for use is called NetLogo. NetLogo is an open source, agent-based coding language design specifically to model and emulate existing processes based on user input code. Simulations built in NetLogo can be as complicated or as simple as the user desires, but also allow easy adaptations of the code to include elements from other models or new elements either within the main code or as subroutines that can be easily toggled on or off. An example of a subroutine that was added and can be toggled on or off is the ability to turn on or off a premium lounge. This ease of adjusting the code to allow changes to the model and its behavior is one of the key benefits of the open source agent-based modeling.

The NetLogo tool breaks the agent base model into three distinct panes. The first pane or window is the user interface. This pane is for running and displaying actions within the simulation. The second pane is a location for the designer to add commentary on the model providing more detailed instructions or insights to the end-user as they explore and run the model. This is the location where the designer should communicate to the user how to define key inputs to the model. The final page is the coding window where the designer and user may input specific variables and design the routines that use all of the variables defined in a user interface. This final pane is where all the actions and the behavior of the model is defined. Like most coding languages, NetLogo has some specific patterns that make the language easier to use like designing sub routines, it also has a few shortcomings like a difficulty building a repetitive function that can handle errors.

NetLogo was selected for use in this work because it is an open-source free software that appears to have a reasonable representation of human behavior in a relatively open environment. Some other options were considered to model passenger behavior in an airport environment but many of the domain specific tools work off a goal based model that leads to passengers walking in straight lines to a similar area and then standing around waiting for another trigger. NetLogo provides an opportunity to see how passenger end up moving more aimlessly around the terminal space before they are called to the gate, lounge or to board their flight.

5.6.1.2 Passenger Boarding Simulations.

A series of two NetLogo simulations have been constructed to represent the passenger boarding process in a standard commercial aircraft. The first model is meant to represent the current system where a single jet bridge is used to facilitate passenger boarding. This model is built to represent standard passenger behavior assuming queuing and some basic personal space, speed, and randomized setup variables. This model has been calibrated against the average passenger boarding process sited by Bachmat and Van Landeghen [100, 101]as well as measured against the Airport service manuals provided by both Boeing and Airbus. The model has also been qualitatively validated by several industry professionals that build simulation in the airport environment for airport clients all over the globe. In addition to the set up variables a series of features have been built into this model that are largely for reporting. The reporting features include a heat mapping feature, a passenger trace feature, and a numeric output on a timeline showing the passenger boarding rates and the time it takes the passengers to board the aircraft. While the reporting variables have been helpful in calibrating the simulation, the primary output of this simulation is the total time to board counter that records the total time required to board all passengers from the terminal area. This serves as a base case assessment which the proposed new system will be measured against.

The second model builds on the first simulation by moving from the single jet bridge to an elongated gate lounge area that would meet the entire forward end of the aircraft. The primary change this model presents is the addition of an area for passenger queuing, mingling, and processing as they move toward the aircraft boarding door. The second simulation provides a sub routine for passengers who get to the gate early where they slow down and wait closer to the boarding gate. The model also contains the same spacing, speed and set up variables as well the reporting features. The way this model is constructed allows the user to make some qualitative and quantitative assessments of the new system. This second simulation also forms the primary quantitative comparison for the new system to be compared to the base case.

<u>5.6.1.3 Variables Assumed.</u>

There are a series of variable that are assumed in the coding and several other that are set from the user interface. The variables assumed in the coding are meant to be static to prevent variation in the behavior of the passenger in the model. These static variables include things like the range of walking speed which is set to between 0 to 3 meters per second for all passengers, and the variation in a passenger heading. The variable that the user can change are the ones that would alter based on a specific flight or specific airport, such as the number of passenger or the split of premium and non-premium passengers. Both of the models used in this study assume a standard passenger profile that include 25% premium passengers on a total passenger load of 200 individual. In addition to the passenger load both models have also included a person bubble of 4 square meters (roughly 3 feet in each direction) and a premium lounge. For this work the heatmap and passenger tracing variable were ignored and passenger acceleration and deceleration rates have been copied from previous models that set the passenger walking speed acceleration and deceleration to a normalized reaction time rate as taken from an open source walking model in NetLogo's model library. All of these variable can be changed in the user interface through the input boxes. In the base simulation the user can also adjust the location of the jet bridge to change the behavior of the passengers as they mingle within the available terminal space.

By keeping each of these variables constant, the only variable being altered is the size and shape of the space provided for passengers to board the aircraft.

5.6.1.4 NetLogo Procedures.

The procedures used to define the model's behavior in NetLogo are broken down into small distinct procedural groupings. Rather than explain the specific function and each individual equation, this section describes the way the function are designed and the way they are intended to work. The full code is provided in APPENDIX

Appendix A: NetLogo Code should the reader wish to interrogate the code further. The NetLogo model will also be made available to anyone who wishes to review the model or build on the current work.

The first set of procedures is the “SETUP”, procedures where an aircraft is placed, the lounge is drawn, the walls are drawn, the patch color of each different element is set and then passengers are generated randomly within the terminal. In the simulation model that represents the new system the procedures to draw the walls involves a subroutine where a pair of agents walks along the exterior of the terminal to draw an angled wall before passengers are generated within the space. As passengers are generated, a function has been built that iterates through placing one passenger at a time and checks if the new randomly generated passenger is placed within the personal bubble of another passenger, and if the new passenger is within any other passengers’ bubble, the function places that agent again.

After the “SETUP” procedure is completed and the agents’ representing passengers are generated, the “GO” procedure allows the agents to move about the space in random patterns. This process is directed for the premium passengers as they are moving toward the lounge. All economy passengers move randomly about the space however, bouncing off the walls to keep them within the defined area. The bounce procedures were one of the more complicated elements of the code as the redirecting of a dynamically moving object required a duplicated test of the patch ahead. The bounce function also required a different function if the agent was hitting a vertical wall vs a horizontal wall as NetLogo does not have a reflect function built into the base code. This is a repeating function that continues until it is ended by turning it off or the "Call to Gate" function is initiated.

The "Call to Gate" function draws all passengers toward the gate area while trying to maintain their personal bubble. This often leaves passengers further from the gate as there is too much congestion for them to move into the immediate gate area. This mirrors the reality seen in many airports, passenger congregate near their gate but often spill into common areas, corridors or retail areas that are further away from the gate as they wait for boarding. Like with the "GO" function the "Call to Gate" function is a repeating function that continues until all passengers are within a predefined gate are or the "Board" function is called.

The next process is the boarding process. The boarding process is a series of functions that board premium passenger in one grouping and boards economy passengers in a second set of functions. The first button associated with this is the "Board Premium" button that will board premium passenger and then if directed by the "Full board?" slider will then follow with the economy passengers. These two groups can also be boarded simultaneously by pressing both the "Board Premium" and the "Board Economy" buttons. Boarding both groups will complicate the procedure however and will slow some passengers down. The boarding process forces all passenger agents to join a queue by following the passenger who is next closest to the gate. The passenger then follows the queue to the gate where they walk down the gate onto the aircraft where they leave the model or in the language of NetLogo "the passenger turtles walk down the jet bridge and die." The boarding functions are like the "Call to Gate" and the "GO" function in that they are repetitive until a condition is met which in this case is that all passengers are aboard the aircraft.

5.6.1.5 Quality Control and Calibration.

These passenger boarding simulations are based on a final model built during the socio-technical systems course. The base models has been quality checked for logic, functionality, and completeness of process.

The initial simulation was built to emulate the movement of passengers within the terminal building in a broad systematic sense. To validate this process however the model had to be calibrated against real world measurements of passenger behavior in an airport. The first calibration was on the hard coded variables, starting with passenger movement variables. This was done by assuming one patch was a meter and one tick was a second. The model therefore limits passenger walking speed to between zero and three meters per second, setting an average between one and two and a half meters per second.

The model was then calibrated for queuing. It was assumed that passengers would begin forming queues based on those around them that they perceive are closer to the gate. This means that queues are non-linear and develop based on concentration of passengers rather than closer to the boarding gate itself.

Finally, after having the dynamic passenger movement calibrated, the total throughput time was taken as the actual measurement of the simulation. To validate the outputs of the simulation the final throughput figures were compared initially agist an assumed passenger boarding time of approximately 20 minutes (1,200 Seconds); this value comes from both observed passenger boarding times on similar sized aircraft and from industry experience where 20 minutes is assumed to be a good approximation of the time required to board a narrow body aircraft. While passenger boarding times in reality can be highly variable, the average of 20 minutes has also been checked against a series of boarding time values presented by both Airbus and Boeing in their Airport Service manuals. The validation from the aircraft service manuals can be seen in Table 3. Average Boarding Times by Aircraft as given by Manufacturer Manuals which shows a series of average values which have been gathered from the Airport Planning Manuals[12, 18, 19, 102, 103].

Table 3. Average Boarding Times by Aircraft as given by Manufacturer Manuals

Aircraft	**Passengers**	**Terminal Boarding Time**	**Enroute Boarding Time**	**Rate (Pax/min)**	**Notes**	**Seconds If Assumed 200 PAX**
787-8	274	11.7	11	25	2 door	512.41
787-9	360	20	11.5	25	2 door	666.67
787-10	411	21.7	22.9	25	2 door	633.58
A350-900	315	10		15	2 door	380.95
A350-900	315	22		15	1 door	838.10
737-7 MAX	150	12.5	13.8	12	1 door	1000.00
737-8 MAX	162	13.5	8.3	12	1 door	1000.00
737-8-200	207	17.3	19	12	1 door	1002.90
737-9 MAX	215	17.9	19.7	12	1 door	999.07
737-10 MAX	230	22.1	11.5	12	1 door	1153.04
757-200	186	21	12	9	1 door	1354.84
757-300	243	27	16	9	1 door	1333.33
A320	150	13		12	1 door	1040.00
A320	180	7.8		12	2 door	520.00

This table shows that the average time to board 200 passengers based on the cited passenger boarding figures, through a single door is around 1110 seconds or 18.5 minutes. While these values fall on the lower end of the values generated by the simulation the figures presented by the manufactures are based on optimistic boarding rates with limited dynamic measurements. The current system model has been iteratively run with small adjustments to make sure that the model matches an average of about 20 minutes to board all 200 passengers.

5.6.1.6 Results.

Each of the simulation models have been run 400 times with the premium lounge turned on. Both of these models can also be run with the premium lounge turned off which will result in similar results. The output of this simulation effort is show across three histogram of passenger throughput times, which measure the total time required to completely board 200 passengers from the call to board till the final passenger is on board. Each set of 400 runs has been collated into histograms based on a 30 second bucket size. The two unique sets of results are shown in the histogram below presented in Figure 9. Current System Boarding Time Histogram of Simulation Results and in Figure 10. New Proposed System Boarding Time Histogram of Simulation Results.

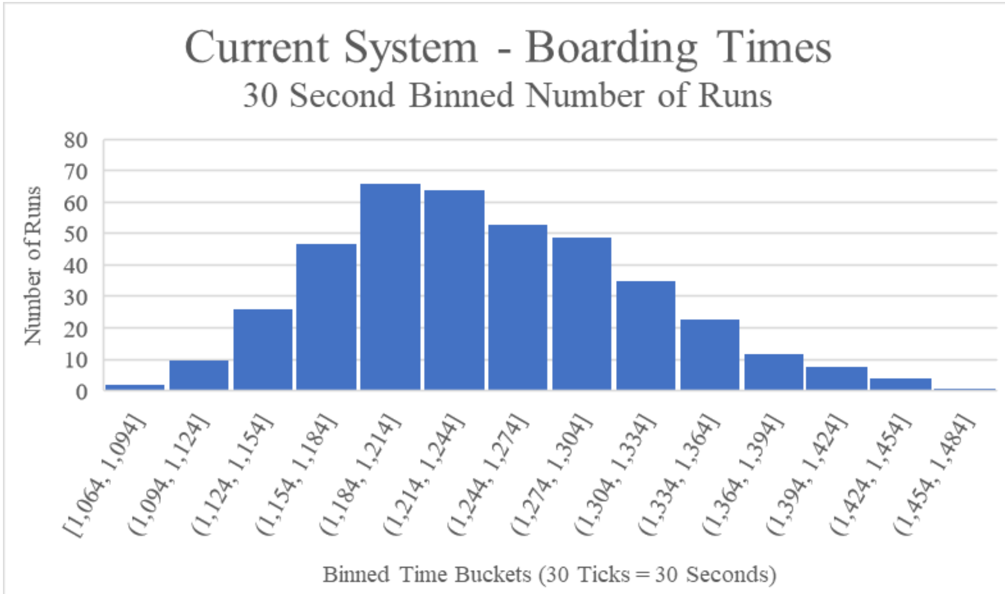

Figure 9. Current System Boarding Time Histogram of Simulation Results

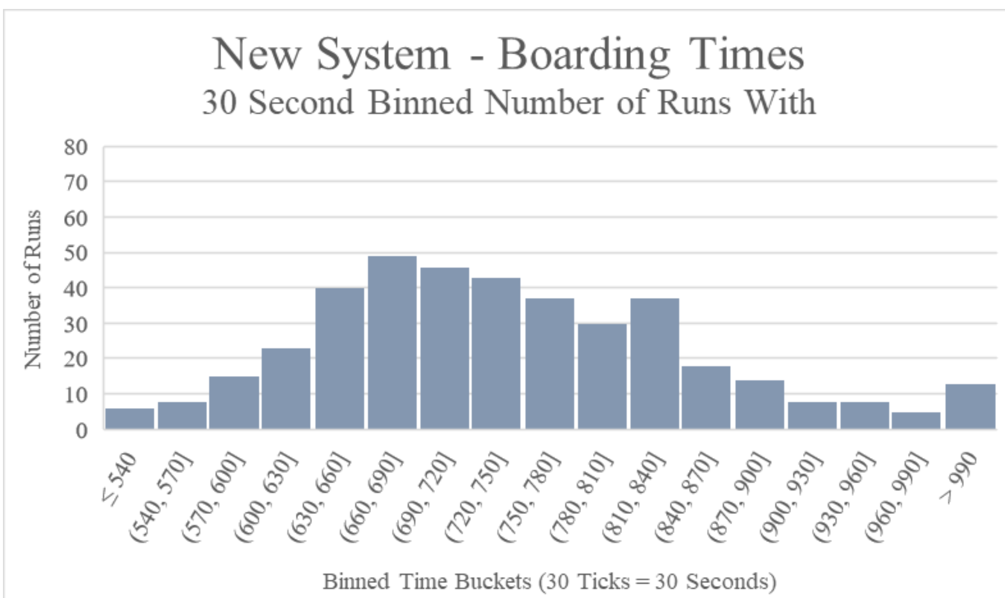

Figure 10. New Proposed System Boarding Time Histogram of Simulation Results

The new system is clearly showing a decrease in the total boarding time required for 200 passengers to board a single aircraft. This quantitative measurement of the new system is helpful in justifying continued study into the proposed simplified system concept presented in this work. To help compare the two sets of results a third histogram has been generated showing the results for both simulation on the same timeline. This combined histogram is shown below in Figure 11. Combined Histogram - Current System vs Proposed System Time to Board Comparison.

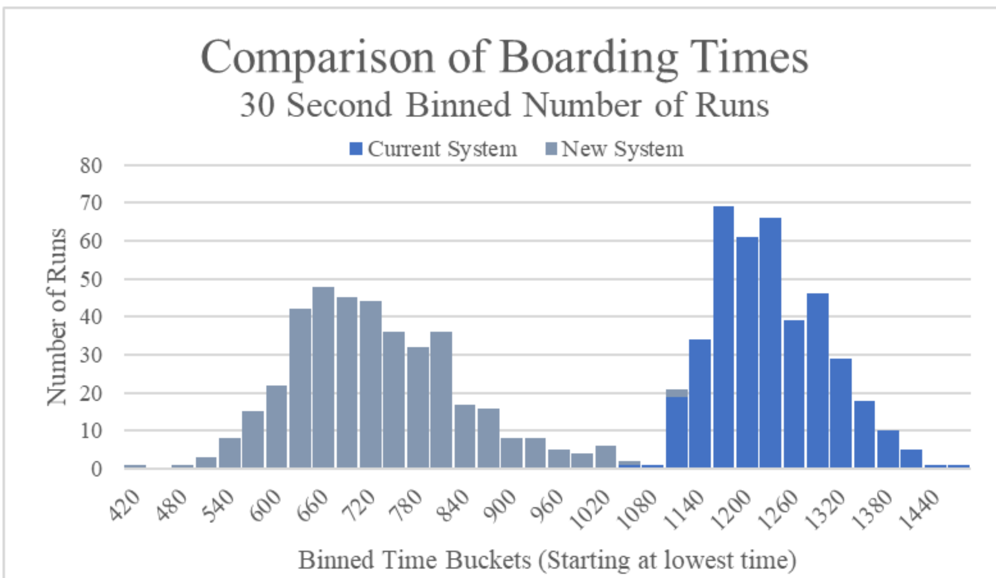

Figure 11. Combined Histogram - Current System vs Proposed System Time to Board Comparison

5.6.2 Static Measure of Vehicles Required

The number of ground vehicles needed to support the turn around of any aircraft can be measured quantitatively by assuming a number of variables. While this measure will be far harder to validate, as vehicles can be transient or reused for multiple parts of the turn around process, the methodology and model provided here is consistent and generates a predictable number of GSE vehicles required to turn an average aircraft around.

5.6.2.1 Tool.

As this model is based on a static analysis of the number of vehicles required to turn an aircraft, a simple tool was required. To simplify the process of building the model it has been constructed in Microsoft Excel to keep the entire process in an accessible format.

5.6.2.2Variables Assumed.

Based on the number of aircraft that are simultaneously turned around at an airport the number of vehicles required to turn those aircraft has been assumed based on the standard turn around procedures provided by Boeing and Airbus. The most important assumption for this model is that all of the aircraft on the ground are operating under the same minimum turn procedures; most airlines choose not to follow the minimum turn around procedures as defined in the manufacturer's airport planning manual,[12, 102] but using this as a baseline provides a consistent reference point that does not exist when attempting to replicate specific airline procedures.

The logic involved with this analysis includes the removal of baggage and cargo trains, galley service vehicles, and the potential cleaner service vehicles. The model also then considered a reduction in the service vehicles required assuming that water, power and air will all be provided through connections with the new terminal interface. The inclusion of services in the new system will also allow the removal of fuel trucks, and the need for pre-conditioned air to start jet aircraft on departure.

While this analysis is optimistic in its base assumptions it also provides a sense of the number of vehicles that could potentially become redundant if services were improved across the airport. To counteract the optimistic view of the number of vehicles that can be reduced, this model also assumes that for every ten aircraft there would also need to be a supplemental set of GSE equipment available to accommodate non-standard turns or provide redundancy should part of the proposed system become inoperable. This balance of optimistic and conservative figures provides a bit of resilience in the system and helps to validate the entire system concept as presented in this work.

5.6.2.3 Quality Control and Calibration.

This model has been produced mathematically looking at the total number of vehicles required to service simultaneous turn arounds, given the critical path analysis provided in the airport service manual.[12, 102] While this model is internally consistent with the Airport service manual, there has not been a rigorous peer review of the model itself though a comparison to a commercial model has been requested.

5.6.2.4 Results.

The results of the static analysis indicate a there is a growing reduction in the number of vehicles required for an apron area as the number of aircraft being serviced increases. This comes from the assumption that the system will need to account for a redundancy. A single turn still triggers the need for the redundancy, but this is not triggered again till the 11th simultaneous aircraft. This means there is little to no gain for small apron areas or terminals that handle only one or two aircraft at a time; its only as the number of aircraft grows that the true benefit are realized. The model as built is indicating that there is a benefit to implementing this system in large chunks rather than trying to build a single instance of the new system. These results are shown in a matrix that can be read by looking at the number of Code E aircraft being serviced (on the X axis) and the number of Code C aircraft being serviced (on the Y axis) at the same time. This table shows how many vehicles could potentially be taken off of the airside roadways given their typical simultaneous demand. For an airport servicing only Code E aircraft and with Up to 20 aircraft on the ground the model is indicating that up to 154 vehicles could be removed from the airfield. For a smaller airport that specializes in Code C aircraft with up to 30 aircraft on the ground up to 96 service vehicles could be removed from airside. An image of the resulting matric can be found below in Figure 12: Total Potential Reduction in GSE with Proposed System

- It is worth noting some of the vehicles quoted in these reductions are already being replaced by other elements of the system. GPUs for example are often being phased out as the power required can be provided to the aircraft by an APU on board or by a fixed power line often tied to the outside of the current jet bridge.

Optimistic Difference in GSE Required based on Simultaneous Turn Arounds

		Code E Aircraft																				
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Code C Aircraft	0	0	5	12	19	26	39	46	53	60	73	80	79	86	99	106	113	120	133	140	147	154
	1	-2	11	18	25	32	45	52	59	66	79	78	85	92	105	112	119	126	139	146	153	152
	2	1	14	21	28	35	48	55	62	69	74	81	88	95	108	115	122	129	142	149	148	155
	3	4	17	24	31	38	51	58	65	64	77	84	91	98	111	118	125	132	145	144	151	158
	4	10	23	30	37	44	57	64	63	70	83	90	97	104	117	124	131	138	143	150	157	164
	5	13	26	33	40	47	60	59	66	73	86	93	100	107	120	127	134	133	146	153	160	167
	6	16	29	36	43	50	55	62	69	76	89	96	103	110	123	130	129	136	149	156	163	170
	7	22	35	42	49	48	61	68	75	82	95	102	109	116	129	128	135	142	155	162	169	176
	8	25	38	45	44	51	64	71	78	85	98	105	112	119	124	131	138	145	158	165	172	179
	9	28	41	40	47	54	67	74	81	88	101	108	115	114	127	134	141	148	161	168	175	182
	10	34	39	46	53	60	73	80	87	94	107	114	113	120	133	140	147	154	167	174	181	188
	11	29	42	49	56	63	76	83	90	97	110	109	116	123	136	143	150	157	170	177	184	183
	12	32	45	52	59	66	79	86	93	100	105	112	119	126	139	146	153	160	173	180	179	186
	13	38	51	58	65	72	85	92	99	98	111	118	125	132	145	152	159	166	179	178	185	192
	14	41	54	61	68	75	88	95	94	101	114	121	128	135	148	155	162	169	174	181	188	195
	15	44	57	64	71	78	91	90	97	104	117	124	131	138	151	158	165	164	177	184	191	198
	16	50	63	70	77	84	89	96	103	110	123	130	137	144	157	164	163	170	183	190	197	204
	17	53	66	73	80	79	92	99	106	113	126	133	140	147	160	159	166	173	186	193	200	207
	18	56	69	76	75	82	95	102	109	116	129	136	143	150	155	162	169	176	189	196	203	210
	19	62	75	74	81	88	101	108	115	122	135	142	149	148	161	168	175	182	195	202	209	216
	20	65	70	77	84	91	104	111	118	125	138	145	144	151	164	171	178	185	198	205	212	219
	21	60	73	80	87	94	107	114	121	128	141	140	147	154	167	174	181	188	201	208	215	214
	22	66	79	86	93	100	113	120	127	134	139	146	153	160	173	180	187	194	207	214	213	220
	23	69	82	89	96	103	116	123	130	129	142	149	156	163	176	183	190	197	210	209	216	223
	24	72	85	92	99	106	119	126	125	132	145	152	159	166	179	186	193	200	205	212	219	226
	25	78	91	98	105	112	125	124	131	138	151	158	165	172	185	192	199	198	211	218	225	232
	26	81	94	101	108	115	120	127	134	141	154	161	168	175	188	195	194	201	214	221	228	235
	27	84	97	104	111	110	123	130	137	144	157	164	171	178	191	190	197	204	217	224	231	238
	28	90	103	110	109	116	129	136	143	150	163	170	177	184	189	196	203	210	223	230	237	244
	29	93	106	105	112	119	132	139	146	153	166	173	180	179	192	199	206	213	226	233	240	247
	30	96	101	108	115	122	135	142	149	156	169	176	175	182	195	202	209	216	229	236	243	250

Figure 12: Total Potential Reduction in GSE with Proposed System

5.6.3 Aircraft Throughput

The initial goal was to generate a new model that measured aircraft throughput of a generalized airport system by generating an assumed aircraft ground time. As this model began to develop with a randomized destination generator, the result began to quickly normalize rather than following a specific profile around time of the day or banked schedules. While this could potentially be a valid academic model the reality of airports and the reliance of airlines on their own internal practices to maintain schedules would quickly void any results of a generalized model. This model has therefore been abandoned in favor of focusing on generating more robust result for the passenger and GSE models.

5.7 Shortcoming of the Proposed System

Four shortcomings of the system presented in this work have been identified. While all four of these shortcomings can be overcome, they have fallen outside of the scope of work undertaken in this project and therefore remain shortcomings or potential future work.

5.7.1 Mechanical Engineering

This work is not addressed the specific mechanical engineering of the proposed system. While a rather detailed concept of operations and list of requirements has been formed along with a basic layout, the detail design and mechanical design of the proposed facility will need to be considered by an engineering and design team. The general concept has been considered to a level of detail that supports the concept of operation, the overall simplification of the airport, and supports the systems thinking of airport planners as they continue to build for an uncertain future. The concept has further been validated to test the benefits of the proposed system. These tests will help validate the concept design but an engineering team will still need to prepare designs for the mechanics of how the system will extend and retract.

5.7.2 Geometry

The proposed system is a theoretically sound concept but has not been tracked to test the geometry of the aircraft turn radius. While some aircraft can turn sharply not all aircraft are able to reliably turn away from a building to avoid contact between the wing-tip and the new terminal facility being proposed. As any potential contact between a wing tip and a building would cause the aircraft to be grounded, the proposed system will have to be more mobile in such a way as to prevent aircraft from making contact with the building.

5.7.3 Redundancy (lack there-of)

The proposed system is a single aggregated system that relies on a large number of elements working together to turn an aircraft. While not every element has to work perfectly there are some dependent systems like the passenger and cargo loading both requiring the mechanics to work to make contact with the aircraft. This shortcoming highlights one of the few advantages to the current disaggregated system, like the ones that are in place today, one element can fail but the rest of the systems can still perform all of their functions. As a series of systems that are not connected the current system is not as likely to face issues with breakdowns

5.7.4 Limited Flexibility

While more boarding space will be advantageous for getting more passengers on and off aircraft, the variability in aircraft size and sill height[6] will reduce the ability of the

[6] Sill Height refers to the height of an aircraft entry door's lower ledge. This is the height you would have to reach to enter an aircraft from the ground.

new system to be used across all aircraft groups. Jet bridges today can rise or drop to meet a variety of aircraft. The proposed new system will be not have as wide a rang of motion so will have to be tailored to a smaller range of aircraft.

5.8 Conclusions

The system proposed in the in work has been designed to be a compact and well-connected terminal interface that streamlines the passenger boarding process and simplifies access to other resources needed to turn around an aircraft. By looking at the history of the passenger boarding process, this work looks to build on the historic system and offer a new solution to fundamentally alter the aircraft turn around process. The proposed system builds on a number of the existing systems combining them into a unified system. This system has been developed into a concept design with requirements and proposed sub systems. The system concept has also been quantitatively simulated in a new NetLogo simulation that shows an improvement in the passenger boarding process cutting the expected total boarding time from approximately 20 minutes (1200 Seconds) to 11.5 minutes (690 Seconds). This model has been calibrated against the Airport planning Manuals for Both Boeing and Airbus but has not been validated independently of the manufacturer published average loading rates. The proposed system has also been used to develop a static calculation of the expected number of ground service equipment vehicles that could be reduced form the total fleet at any given airport. The new proposed system shows some clear benefits in the work presented and offers opportunities for further development of quantified assessment of the proposed new layout.

CHAPTER VI

SUMMARY OF THE SYSTEMS THINKING FRAMEWORK

6.1 Systems Thinking

This dissertation represents a significant body of work looking at one system and provides a snapshot of many thoughts on the apron area. Starting with an examination of historic changes in the apron area this work then looks at the state of the industry before offering insights into potential improvements and potential changes across the entire airport system. This chapter offers additional discussion, information and reference information on the systems engineering of the final proposed system while discussing some unexplored advantages of the system being proposed. This chapter also discusses how this new proposed system can be abstracted into a systemic framework that can be used to help uncover unexplored opportunities within systems and how taking a systems thinking approach can be an advantages when planning new systems. This section will also discuss some of the industry feedback provided on the conceptual design of the new proposed terminal interface system.

6.1.1 System Abstraction - the Design of a Framework

Element of the proposed system, several key steps were taken to help to define the system and its goals and requirements. A brief outline of the processes provided below as a base to a potential framework for rethinking the apron turnaround process as seen in most airports today. While this is not a complete framer it does provide an outline for systems thinking and rethinking of the key infrastructure projects as they are developed to service key infrastructure.

1. Definition of system boundaries: In looking at a new system it's important to define boundary of the current systems determining what can and cannot be included in the current system and how far reaching the new system can be.
2. Redefining the system: after defining the system boundaries, the next step is to define the new goals and boundaries of the purposed systems.
3. Defining inputs and outputs: as the system concept is developed the inputs and output need to be defined.
4. Bring in adjacent system requirements: when defining the system it is advantageous to consider what adjacent system could be brought into the new system concept. This provides a simplification and a more robust system that provides better functionality across the entire system.
5. Consider other implications of the system: final step is to look at what other system could be impacted by the implementation of the new system. But examining what other elements can be impacted hopefully conflicts

can be identified early and prevented as a system is in its inception phase rather than after it is built.

Goal of defining these major five steps in defining a new system, is to provide a baseline for system designers and planners to follow as they look to implement new systems and redefine existing infrastructure projects.

6.2 Industry Feedback

The conceptual system presented in this research has been shared with a variety of aviation industry professionals leading to some new direction of focus, and some creative feedback. While most of the feedback has been positive there were only three clear advantages identified and one major risk that was brought to my attention. Each of the clear points of feedback are described below.

6.2.1 Reduction of Vehicles

There is a clear advantage for safety and reduction in space needed around an aircraft if the system is able to reduce even just the baggage vehicles. As seen in the *** baggage dollies can have a huge impact on the airfield causing both congestion, incursions and damage to other equipment. If we can reduce the need for this space and the number of independent mobile objects the system would be of substantial benefit to the apron area.

6.2.2 Reduction of Emissions

By reducing the number of vehicles on the airfield and by containing the power provided to aircraft into the system, the proposed interface has significant potential to reduce the amount of emissions released associated with the turn around process. This could be quantified based on the number of vehicles reduced in the model presented but also has the ability to contribute toward an airports green targets to reduce their carbon footprint.

6.2.3 Simplification of Taxi Routes

If the geometry of the new proposed system can work out to prevent push backs, there will be significant reductions to the taxi times required. There would be potential traffic advantages that prevent not only delays but some of the most problematic intersection points at airports. This means that the taxiway alignment may be the most prevalent benefit for a lot of existing airports.

6.2.4 Too Optimistic

The one criticism I received when sharing this system was that the multi door boarding and parallel parking has already been tried and it required more concrete and was not seen as an efficient use of space. This was raised in relation to the concourses that exist in Geneva where four aircraft part broadside to a concourse so they can easily return to the taxiway. This system was not built in any other location and is not seen as the most efficient showing that there are some major drawbacks to the parallel parking of aircraft.

6.3 Thoughts on the Model

6.3.1 Biases

Though a model is not usually built with an intended bias, there is often a bias that appears or one that is inherent as the designer of the model usually has a specific viewpoint. As stated by George Box, “Since all models are wrong, the scientist must be alert to what is importantly wrong.”[104] By identifying some of the bias of this particular model the goal is to make an attempt to prevent “importantly wrong” elements within this model, and make the outputs more useful so the user understands some of the limitation. Though there was no intentional bias built into this model, it is no different than any other model so there are several potential biases that have made their way into the work. The following list is an attempt to capture some of the biases by category that may play a role in this model.

- Single gates: By simulating only a single gate this model is not necessarily showing the interactions of passenger across multiple flights. This means there are potentially more complex dynamics that are not captured in the work.
- Walls: to limit this model walls have been constructed to bound the passengers. In reality a terminal will have far more space including areas where passengers can exit accidently or leave the area leading to the potential for missed flights and more complex dynamic behavior depending on each individual passenger.
- F&B / Restrooms: This model is only looking at the passenger boarding area, so it does not consider food, beverage, restrooms or any sort shopping opportunities all

of which significantly complicate the movement of passengers through the space. While this was originally considered it became clear that the dynamics would not add significantly to the boarding process and would rather change the behavior prior to boarding.

- Arrival curves: Passenger entry into the terminal area frequently follows a normal distribution curve, this means that the dynamics of passenger interaction get more complicated closer to flight time. While adding a entry curve was considered, the focus of this study being the boarding meant that the entry into the terminal area could be ignored for this study.

6.3.2 Ground Service Equipment

Ground Service Equipment or GSE is a large category of equipment, mostly vehicles, that service aircraft on the ground. There are a number of sub-categories of GSE but each piece of equipment generally serves a single purpose supporting the general process of turning aircraft around. The number of types of vehicles required to turn an aircraft is therefore not all that flexible. The number of vehicles that are needed across the entire system however can be dramatically changed by specific operations at an airport. The specific operational variables that impact the number of service vehicles are briefly described below:

- Schedule overlap – the more aircraft on the ground at a time the more GSE needed
- Layout of the terminal – terminal facilities that allow common use of GSE by reducing transit time are more efficient in the number of GSE vehicles required

- Size of aircraft – Larger aircraft require more GSE
- Types of Service – full VS low cost the more services offered on board the more GSE is needed to prepare for that service.
- Number of Gates – the more gates the more GSE is generally required to support the simultaneous operations.

Each of these items are specific operational variables that can be airline, airport or even concourse specific. Some of these variables can be condensed to help simplify the system, others cannot.

In addition to generalized variables that impact the number of GSE Vehicles, one of the other factors that can heavily impact the total number of vehicles needed is the governance structure and ground service agreements in place at the airport. The ground service agreements determine which party is responsible for specific elements of the aircraft turn around process. In some locations airlines with sufficient infrastructure take responsibility for their entire turn around process. If multiple airlines operate however, there is often a third party that operates all of the GSE to effectively utilize all of the equipment across the entire airport. The overlap of airlines and GSE operators allows the single operator to reduce the number of vehicles required across the entire airport. In many environments however competition requires multiple GSE operators. Competition and efficiency often therefore conflict and lead to different trends

6.3.2.1. Electric GSE.

As efficiency emerges as one of the most desirables trends globally, GSE service providers are following the trends and producing all electric vehicles for use at airports. Electric service vehicles allow operators to reduce their emissions footprint by switching over to electric equipment. To maintain operations with electric GSE equipment, service providers also need more vehicles to replace those that are out of service because they must return to a charging station. By having to charge frequently electric GSE increases not only the number of vehicles required, but the space needed for charging infrastructure.

While the concept of electric GSE is good in theory, the implementation has a way to come before all electric equipment is a viable replacement for gas and diesel-based fuel equipment.

6.3.2.2 Smart GSE.

As technology improves the use of intelligent solutions to accomplish normal tasks become more common. Through automation new solution are becoming available for commercial use in many different sectors including airports. From simple automation of passenger processed to automation in the bag room, technological solutions are becoming the norm across the aviation industry.

Automated GSE is a valuable solution that some airports have already begun implementing. Solutions such as automated baggage carts that can traverse the apron to an aircraft are already being trialed.

Smart GSE carry more risk however because they need to be more aware of not only other traffic but the aircraft and other moving infrastructure as well. While it is possible to overcome the limited situational awareness of the autonomous vehicles, there are still gaps in the current situational awareness which means that the mistakes these vehicles make can be exponentially expensive.

6.3.3 Weather

6.3.3.1 Snow and Ice Extreme Temperatures.

Much of aviation takes place in areas that experience some seasonality, there is some need therefore, to consider both cold and hot weather operations. During these extreme weather operations, the manual operation of much of the ground service equipment can make the apron an unforgiving working environment. The proposed system looks to alleviate some of the manual operations and thus lessen some of the discomfort of the extreme weather operations. While there will still be manual tasks that must take place in the open air, by bringing services closer to the aircraft much of the transportation and manual processing of equipment, cargo, fuel and the aircraft itself can be limited.

6.3.3.2 Deicing Operations.

Though deicing operations are not common everywhere there are some regions that have to de-ice aircraft frequently. In these regions there are a variety of methods for setting up deicing facilities. Some facilities are centralized, others are terminal specific, while still others are airline specific operations that take place at specific gates. While the proposed system does not alleviate the need for deicing it does offer more opportunity for creative solutions to the full deicing process or even just the recapture of more of the glycol used in deicing. While this is not one of the main advantages of the proposed system it is a significant opportunity for further development of the proposed system.

6.3.3.3 Lightning.

In the aviation environment lightning is one of the most disruptive weather events. While lightning is not a significant concern to those within an aircraft or those within the terminal building, lighting almost always brings a stop to the ground servicing of the aircraft. While weather proofing of all of the ground services was not one of the original goals in designing this system, the ability to both cover and ground the aircraft to prevent most of the danger in the apron opens up the possibility that this system could reduce lightning related shutdowns.

6.3.4 Environment Consideration

The biggest, unexpected advantage of the proposed system is that potential environmental implications of reducing the number of GSE vehicles burning petrol based fuels around the airfield. According to the model presented there is an opportunity to pull a significant number of vehicles off of the airfield by offering an alternative solution to the servicing of aircraft. While this has not been explored in this work there has been interest expressed in examining the system as a carbon offsetting measure as airports continue to plan to meet their carbon reduction targets.

6.4 Concluding Thoughts on this System Engineering Framework

Over the course of the past two years, as this work has been developing and maturing, the literature and the construction of the system itself have let several insights. First, though an airport is currently a complex socio-technical system of systems, there is no need for the systems to remain independent, and there is in fact benefits to simplifying the unique systems into a singular system. Next it is clear that as the aviation industry has reached a relative level of maturity around the globe. As such, the systems that support aviation have begun to stagnate and are therefore stuck in the current status quo. This equilibrium is regularly reinforced and means that the industry resists large scale change, but this also means that the accommodation of a new change will require a sift in the entire system. The final key conclusion from this work is, by offering a dynamic change to the way airports go about the process of embracing new technologies and procedures, systems engineering has the potential to greatly benefit not only airports but the entire aviation industry across the globe.

CHAPTER VII

CONCLUSION

The work presented in this document represents the culmination of a doctorial level study into the operations and systems of the apron area at an airport. While this dissertation is not exhaustive, and does not present all the work undertaken in the pursuit of this doctoral degree, this work does show a clear contiguous body of work that contributes to the way projects are proposed and systematically planned at airports. This work also provides clear direction for planners and engineers who are looking to implement novel systems for passenger and cargo boarding at an airport. While I do not anticipate seeing the concepts presented in this work, in the near future, it is possible that elements presented within this work could help trigger new thoughts that contribute to the next generation of airports.

7.1 A Review of Key Research Findings

7.1.1 Historic Review of Pan Am

Research Question: Can we use Data Science to analyze changes in a historic airline; and can we generate graphics like Minard's visualization of Napoleon's march?

Hypothesis: Examining Pan American World Airways through data science, will provide new insights into the history of the airline, as well as generate a snapshot of an aviation icon.

Results: The work conducted under the historic review was published and offers a novel way of looking at history through a data science lens. It did provide new insights and a series of snapshots of the history of Pan Am. The work was well received at the AIAA Sci-Tech forum and offered a good foundation for the study of systematic changes within the apron area.

7.1.2 Review of the Current Risks Facing Aviation

Research Question: How do we define system risks and changes? Do these changes differ based on the system in question?

Hypothesis: Systems face three interrelated categories of change that must coexist in order for a change to propagate. The presence of all three categories of change leads to sustainable evolution of a system.

Results: The technical review of the current risks facing aviation helped identify some of the advantages of system thinking and opened the study of how to simplify the turnaround process. This work also helped build up the argument for fundamentally rethinking how some of the current airports are operated and designed.

7.1.3 Building a New System for Turning Aircraft

Research Question: Can the apron area be simplified and integrated into a single streamlined system to better serve aircraft and airline stakeholders?

Hypothesis: A simplified system will face emcee hurdles before it is implemented but can offer efficiency and force planner to think wholistically about the system impacts of partial interventions.

Results: The final system presented offers not only a novel concept for turning aircraft but offers insight into how airports need to think about the future expansion of facilities in order to future proof the infrastructure for some of the changes that the industry is likely to face.

7.2 Contributions

This work has been made up three major elements, the examination of historic changes, the assessment of current risks facing the industry and the proposal of the new terminal interface system. By examining the past and present, this work is meant to help build up the case for the implementation of systems engineering practices within the aviation environment. By further offering a proposed new system this work is meant to offer a systematic process for planning new systems within the apron and across the entire industry. It is further hoped that by engineering a novel system, the approach used will offer insight to planners and future investors as they look to design new concepts for the next generation of airports.

By bringing a systematic approach to the aviation industry there is a significant benefit to be gained by following the design process that this project and framework follow. If only one sunk cost project can be prevented by encouraging planner to think systematically, this work will demonstrate value across the entire aviation industry. The prevention of sunk cost project will hopefully encourage the implementation of a systematic approach. The new approach offers potential financial and time saving for airports and ultimately the owners which in many cases (at least in the US) is the local tax payers. This method of developing new innovative infrastructure that simplifies the systems will help prevent many of the current bottlenecks from continuing to be a problem in future airports.

7.3 Lessons Learned

The process of building this dissertation began in 2013, so has been a largely evolutionary process. The original topic and direction has long since been abandoned in favor of other avenues of study. I also took almost 5 year away from the academic study of airports to work as a consultant for airports. As the recent Covid-19 pandemic led to my layoff, I choose to refocus on academic pursuits and return to my academic study of the apron area. This brought my attention back to my series of published works, and brought back the review of the holes within aviation systems.

Over the past seven years I have interacted with a variety of professionals that have somewhat differing opinions on the design of airports. Having worked within the aviation industry I have a greater appreciation of the differing governance structures and how the governance and local opinions can shape the direction of changes and planning at airports. Learning how to deal with different types of airports was the most valuable lesson learned and helped me to not only redefine some of my own opinions but also helped direct me to where I can actually contribute to my industry. It was knowing where I wanted to contribute that lead me toward actually constructing the model and the chapters presented in this work. The next lesson was more of a reminder, that "all models are wrong" and that I therefore need to consider how much time I want to spend perfecting some of the more menial elements of a model. In addition to the lessons about governance, personalities, and modeling I feel that it is valuable to point out that some of the lessons, or at least the most helpful lessons learned, have been outside of the process of constructing this dissertation. Over the course of writing it has been valuable to take breaks, understand my own limits and understand when to stop.

7.4 Next Steps

This work, as stated, is not complete, this document rather provides a portfolio of three published/publishable chapters that show a clear contribution to how planners, designers and engineers approach the design and construction of an airport.

7.4.1 Immediate Next Steps

The immediate next steps for this work is to take the model presented in CHAPTER V to it natural conclusion by submitting the work to the Journal of Air Transportation Management, while also presenting the work more widely to industry professionals.

The step after that is to work with some industry professionals to provide an understanding of the need for systems thinking so that some of the principals of systems engineering can be incorporated into planning and design of future airport.

7.4.2 Potential Future Work

In addition to submitting this work for publication there are several potential future studies that can be undertaken. First would be a detailed study of the system itself to generate a mechanical and geometric drawing that detail how the physical system would be constructed and would then meet the aircraft. The second potential study is a further validation of the benefits to passenger boarding. While the simulation presented is both internally consistent and consistent with the figures provided by the manufactures, there has not been any further validation of the model itself to see if it accurately represents passenger boarding. The third potential study would be a detailed examination of the carbon emission reduction from implementing the proposed unified system. This would have to be build around several assumption on ground fuel burn but has thepotential to help benefit airports looking to reduce carbon emissions over the next several years. The final potential study to undertake would be based around the financial development of the proposed system. The goal of that study would be to assess the benefit of reducing the number of vehicles required on the airfield as compared to the cost of building and maintaining the new proposed system. The idea would be to expand beyond the standard rate of return and benefit cost analysis but would be a comparison of financial benefits over the entire lifecycle of the project. This is not an exhaustive list on directions for future study but is rather a list of potential additional elements that could be explored.

REFERENCES

[1] S. A. M. Dupeyrat, H. Hesselink, S. Loth, A. Remiro, P. Schmollgruber, and C. W. R. Verbeek, "Evaluation of operations on an airport with a circular runway," presented at the 29th Congress of the International Council of the Aeronautical Sciences (ICAS 2014), St. Petersbourg, Russia, October 22, 2014, 2014. [Online]. Available: https://www.researchgate.net/publication/281418696_Evaluation_of_operations_on_an_airport_with_a_circular_runway/citations#fullTextFileContent.

[2] A. K. Wing, "Taking a systemic Modeling approach to the Apron area at Major metropolitan airports," Masters of Engineering, School of Systems and Enterprises, Stevens Institute of Technology, Hoboken, New Jersey, 2015.

[3] A. Graham, T. a. F. Group, Ed. *Managing Airports: An international Perspective*, Fifth ed. New York, NY: Routledge, 2018, p. 428. Elsevier.

[4] S. Baldwin, "Why US Airports Are So Bad," M. Sigaios, Ed., ed. United States: CNBC, 2019, p. 12:22.

[5] A. T. W. Seth B. Young, L. Poplawski, Ed. *Airport Planning and Management*, Seventh ed. New York: McGraw-Hill Education, 2019, p. 442.

[6] *Federal Airport Act*, t. Congress 377, 1946.

[7] R. Doganis, "The impact of liberalization on European airline strategies and operations," *Journal of Air Transport Management*, vol. 1, no. 1, pp. 15-25, 1994, doi: 10.1016/0969-6997(94)90027-2.

[8] T. K. Y. Cheung, C. W. H. Wong, and A. Zhang, "The evolution of aviation network: Global airport connectivity index 2006–2016," *Transportation Research Part E: Logistics and Transportation Review*, vol. 133, p. 101826, 2020, doi: 10.1016/j.tre.2019.101826.

[9] K. O'Connor, "The historical foundations of the Asia Pacific air service network," *Journal of Transport Geography*, vol. 81, p. 102528, 2019, doi: 10.1016/j.jtrangeo.2019.102528.

[10] A. O. Richard de Neufville, L. S. Hager, Ed. *Airport Systems: Planning, Design and Management*, Second ed. New York: McGraw-Hill Education, 2013, p. 782.

[11] B. Jeremic, "Investment in infrastructure and customer experience vital for airport industry," ed. Denver, 2020.

[12] B. C. Airplanes, "787 Airplane Characteristics for Airport Planning," March 2018 2018. [Online]. Available: https://www.boeing.com/resources/boeingdotcom/commercial/airports/acaps/787.pdf

[13] G. Öttl, P. Böck, N. Werpup, and M. Schwarze, "Derivation of representative air traffic peaks as standard input for airport related simulation," *Journal of Air Transport Management*, vol. 28, pp. 31-39, 2013, doi: 10.1016/j.jairtraman.2012.12.008.

[14] I. A. T. A. (IATA), "Airport Development Reference Manual (ADRM)," 2019. [Online]. Available: https://www.iata.org/en/publications/store/airport-development-reference-manual/.

[15] *AC-150/5360 - 13 Planning and Design Guidlines for Airports and Terminal Facilities*, U. S. D. f. Tranportation, April 22, 1988 1988.

[16] A. SAS, "A380 Aircraft Characteristics Airport and Maintenance Planning," France, November 2020 2020. [Online]. Available: https://www.airbus.com/aircraft/support-services/airport-operations-and-technical-data/aircraft-characteristics.html

[17] M. Jones. "Hydrant (Commercial Ramp) vs. Tanker Fuel (GA Ramp): What You Need to Know." Universal Weather & Aviation, Inc. https://www.universalweather.com/blog/hydrant-commercial-ramp-vs-tanker-fuel-ga-ramp-what-you-need-to-know/ (accessed 3/10/2021, 2021).

[18] B. C. Airplanes, "737 MAX Airplane Characteristics for Airport Planning," February 2021 2021. [Online]. Available: https://www.boeing.com/resources/boeingdotcom/commercial/airports/acaps/737MAX_RevF.pdf

[19] A. SAS, "A320 Aircraft Characteristics Airport and Maintenance Planning," France, December 2020 2020. [Online]. Available: https://www.airbus.com/aircraft/support-services/airport-operations-and-technical-data/aircraft-characteristics.html

[20] W. B. Rouse and N. Serban, "Understanding change in complex socio-technical systems," *Inf. Knowl. Syst. Manag.*, vol. 10, pp. 25-49, 2011.

[21] D. Gillen, "The evolution of airport ownership and governance," *Journal of Air Transport Management*, vol. 17, no. 1, pp. 3-13, 2011, doi: 10.1016/j.jairtraman.2010.10.003.

[22] S. Craig, J. Airola, and M. Tipu, "General Purpose or Special District Governance? Technical Efficiency versus Rent Dissipation in Airport Finances," *Public Finance Review*, vol. 40, pp. 712-735, 11/01 2012, doi: 10.1177/1091142112448415.

[23] (2005). *The Effect of Institution Form on Airport Governance Efficieny*.

[24] D. Gillen and A. Lall, "Competitive advantage of low-cost carriers: some implications for airports," *Journal of Air Transport Management*, vol. 10, no. 1, pp. 41-50, 2004, doi: 10.1016/j.jairtraman.2003.10.009.

[25] D. Gillen and A. Lall, "Developing measures of airport productivity and performance: an application of data envelopment analysis," *Transportation Research Part E: Logistics and Transportation Review*, vol. 33, no. 4, pp. 261-273, 1997, doi: 10.1016/s1366-5545(97)00028-8.

[26] A. K. Wing and R. Cloutier, "The Historic Pan Am Fleet: A Data Science Review of the History of Pan American World Airways' Fleet and its Changes Over

Time," presented at the AIAA SCITECH 2022 Forum, San Diego, CA, 29 Dec 2021, 2022. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2022-2066.

[27] A. Georges Assaf and D. Gillen, "Measuring the joint impact of governance form and economic regulation on airport efficiency," *European Journal of Operational Research*, vol. 220, no. 1, pp. 187-198, 2012, doi: 10.1016/j.ejor.2012.01.038.

[28] T. H. Oum, J. Yan, and C. Yu, "Ownership forms matter for airport efficiency: A stochastic frontier investigation of worldwide airports," *Journal of Urban Economics*, vol. 64, no. 2, pp. 422-435, 2008, doi: 10.1016/j.jue.2008.03.001.

[29] T. H. Z. Oum, Anming; Zhang, Yimin, "Alternative Forms of Economic Regulation and their Efficiency Implications for Airports," *Journal of Transport Economics and Policy*, vol. 38, no. May 2004, 2, pp. 217-246, 2004. [Online]. Available: http://docserver.ingentaconnect.com/deliver/connect/lse/00225258/v38n2/s3.pdf?expires=1613107857&id=0000&titleid=1311&checksum=1C64A59D9881F9FEAAB80207D90692EB.

[30] *AIrport Governace and Accountability*, C. A. Council, 2022. [Online]. Available: https://canadasairports.ca/about-canadas-airports/airport-governance-and-accountability/

[31] S. Y. Kim, "Institutional arrangements and airport solar PV," *Energy Policy*, vol. 143, p. 111536, 2020, doi: 10.1016/j.enpol.2020.111536.

[32] E. L. Trist, *The evolution of socio-technical systems*. Ontario Quality of Working Life Centre Toronto, 1981.

[33] W. M. Fox, "Sociotechnical system principles and guidelines: past and present," *The Journal of applied behavioral science*, vol. 31, no. 1, pp. 91-105, 1995.

[34] G. Baxter and I. Sommerville, "Socio-technical systems: From design methods to systems engineering," *Interacting with Computers*, vol. 23, no. 1, pp. 4-17, 2011, doi: 10.1016/j.intcom.2010.07.003.

[35] M. H. Judith Dahmann, Bud Lawson,Heidi Davidz, Alan Faisandier, "Socio-Technical Features of Systems of Systems," in *The Systems Engineering Body of Knowledge* vol. 2.5, October 15, 2021 ed: SEBoK, 2021.

[36] E. Palmer, "Socio-technical Systems," in *The Systems Engineering Body of Knowledge* vol. 2.5, October 15, 2021 ed: SEBoK, 2021.

[37] E. N. Corlett, "The investigation and evaluation of work and workplaces," *Ergonomics*, vol. 31, no. 5, pp. 727-734, 1988/05/01 1988, doi: 10.1080/00140138808966716.

[38] M. Sony and S. Naik, "Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model," *Technology in Society*, vol. 61, p. 101248, 2020, doi: 10.1016/j.techsoc.2020.101248.

[39] K. Mustapha, H. McHeick, and S. Mellouli, "Modeling and Simulation Agent-based of Natural Disaster Complex Systems," *Procedia Computer Science*, vol. 21, pp. 148-155, 2013/01/01/ 2013, doi: https://doi.org/10.1016/j.procs.2013.09.021.

[40] C. W. Clegg, "Sociotechnical principles for system design," *Applied Ergonomics*, vol. 31, no. 5, pp. 463-477, 2000/10/02/ 2000, doi: https://doi.org/10.1016/S0003-6870(00)00009-0.

[41] W. Lin, "The politics of flying: aeromobile frictions in a mobile city," *Journal of Transport Geography,* vol. 38, pp. 92-99, 2014, doi: 10.1016/j.jtrangeo.2014.06.002.
[42] F. O. Flemisch *et al.*, "Human System Integration at System Limits and System Failure of Cooperatively Interacting Automobiles: Concept and First Results," *IFAC-PapersOnLine,* vol. 52, no. 8, pp. 93-98, 2019/01/01/ 2019, doi: https://doi.org/10.1016/j.ifacol.2019.08.054.
[43] B. Whitworth, "A brief introduction to sociotechnical systems," in *Encyclopedia of Information Science and Technology, Second Edition*: IGI Global, 2009, pp. 394-400.
[44] M. W. Maier, "Architecting Principles forSystems-of-Systems," *Systems Engineering,* vol. 1, pp. 267-284, 1998.
[45] A. W. Righi, P. Wachs, and T. A. Saurin, "Characterizing complexity in socio-technical systems: a case study of a SAMU Medical Regulation Center," *Work,* vol. 41, no. Supplement 1, pp. 1811-1817, 2012.
[46] K.-H. Liu, S.-L. Hwang, M.-H. Hsieh, S.-F. Max Liang, and C.-F. Chuang, "Systematic layout planning in human–system interface: An evaluation of alarm displays with spatial proximity for accidents diagnosis of advanced boiling water reactor," *International Journal of Industrial Ergonomics,* vol. 51, pp. 30-42, 2016/02/01/ 2016, doi: https://doi.org/10.1016/j.ergon.2014.12.014.
[47] N. Gil, M. Miozzo, and S. Massini, "The innovation potential of new infrastructure development: An empirical study of Heathrow airport's T5 project," *Research Policy,* vol. 41, no. 2, pp. 452-466, 2012/03/01/ 2012, doi: https://doi.org/10.1016/j.respol.2011.10.011.
[48] P. Carayon, "Human factors of complex sociotechnical systems," *Applied Ergonomics,* vol. 37, no. 4, pp. 525-535, 2006, doi: 10.1016/j.apergo.2006.04.011.
[49] O. Lordan and J. M. Sallan, "Core and critical cities of global region airport networks," *Physica A: Statistical Mechanics and its Applications,* vol. 513, pp. 724-733, 2019, doi: 10.1016/j.physa.2018.08.123.
[50] O. Lordan, J. M. Sallan, P. Simo, and D. Gonzalez-Prieto, "Robustness of the air transport network," *Transportation Research Part E: Logistics and Transportation Review,* vol. 68, pp. 155-163, 2014, doi: 10.1016/j.tre.2014.05.011.
[51] A. Cherns, "`The Principles of Sociotechnical Design," *Human Relations,* vol. 29, 8, pp. 783-792, 1976.
[52] D. Helbing, Ed. *Social Self-Organization: Agent-Based Simulations and Experiments to Study Emergent Social Behavior* (Understanding Complex Systems. New York: Springer, 2012, p. 343.
[53] C. J. Foster, K. L. Plant, and N. A. Stanton, "Adaptation as a source of safety in complex socio-technical systems: A literature review and model development," *Safety Science,* vol. 118, pp. 617-631, 2019, doi: 10.1016/j.ssci.2019.05.035.
[54] G. Spinardi, "Up in the air: Barriers to greener air traffic control and infrastructure lock-in in a complex socio-technical system. ," *Energy Research & Social Science,* vol. 6, pp. 41-49, 2015, doi: 10.1016/j.erss.2014.11.006.

[55] Y. Wang, J. Zhan, X. Xu, L. Li, P. Chen, and M. Hansen, "Measuring the resilience of an airport network," *Chinese Journal of Aeronautics*, vol. 32, no. 12, pp. 2694-2705, 2019/12/01/ 2019, doi: https://doi.org/10.1016/j.cja.2019.08.023.

[56] A. Wong, S. Tan, K. R. Chandramouleeswaran, and H. T. Tran, "Data-driven analysis of resilience in airline networks," *Transportation Research Part E: Logistics and Transportation Review*, vol. 143, p. 102068, 2020/11/01/ 2020, doi: https://doi.org/10.1016/j.tre.2020.102068.

[57] F. W. Geels, "Co-evolutionary and multi-level dynamics in transitions: The transformation of aviation systems and the shift from propeller to turbojet (1930–1970)," *Technovation*, vol. 26, no. 9, pp. 999-1016, 2006, doi: 10.1016/j.technovation.2005.08.010.

[58] F. R. van der Linden, "Government, Business, and Technology: U.S. Airliner Development, 1927–2012," *World Neurosurgery*, vol. 78, no. 3, pp. 206-213, 2012/09/01/ 2012, doi: https://doi.org/10.1016/j.wneu.2012.06.040.

[59] B. Zou, N. Kafle, Y.-T. Chang, and K. Park, "US airport financial reform and its implications for airport efficiency: An exploratory investigation," *Journal of Air Transport Management*, vol. 47, pp. 66-78, 2015, doi: 10.1016/j.jairtraman.2015.05.002.

[60] S. E. Creeger, "Airline Deregulation and Airport Regulation," *The Yale Law Journal*, vol. 93, no. 2, pp. 319-339, 1983.

[61] P. Forsyth, "Airport Policy in Australia and New Zealand: Privatisation, Light Handed Regulation and Performance " in *Fundacion Rafael del Pino*, Madrid, September 18-19, 2006 2006. [Online]. Available: https://www.researchgate.net/profile/Peter-Forsyth-2/publication/228670208_Airport_Policy_in_Australia_and_New_Zealand_Privatisation_Light_Handed_Regulation_and_Performance/links/00b7d527a8d4c9a928000000/Airport-Policy-in-Australia-and-New-Zealand-Privatisation-Light-Handed-Regulation-and-Performance.pdf.

[62] A. R. Goetz and T. M. Vowles, "The good, the bad, and the ugly: 30 years of US airline deregulation," *Journal of Transport Geography*, vol. 17, no. 4, pp. 251-263, 2009, doi: 10.1016/j.jtrangeo.2009.02.012.

[63] E. D. George Woods, "The Millennial Traveller — Implications for Airports," vol. XIX, no. 3, p. 4. [Online]. Available: https://www.lek.com/sites/default/files/insights/pdf-attachments/1903_The_Millennial_Traveller_Executive_Insights.pdf

[64] CASA. "Electronic Flight Bag." Australian Government: Civil Aviation Safety Authority https://www.casa.gov.au/aircraft/aircraft-safety/electronic-flight-bag (accessed 4/30/2021, 2021).

[65] T. H. Schatz, "ACRP Report 79: Evaluating Airfield Capacity," Nationsl Academies of Sciences, Engineering, and Medicine, Washington, D.C., 1935-9802, 2012. [Online]. Available: http://nap.edu/22674

[66] W. M. Gautman Gupta, Yoon Jung, "Incorperating Active Runway Crossings in Airport Departure Scheduling," *AIAA*

[67] D. R. Polsby, "Airport Pricing of Aircraft Takeoff and Landing Slots: An Ecconomic Critique of Federal Regulatory Policy " *California Law Review* vol. 89, no. 3, pp. 779-816, 2001.
[68] A. Zhang and Y. Zhang, "Airport capacity and congestion pricing with both aeronautical and commercial operations," *Transportation Research Part B: Methodological,* vol. 44, no. 3, pp. 404-413, 2010, doi: 10.1016/j.trb.2009.09.001.
[69] Y. J. Hamas Balakrishnan, "A Framework for coordinated Surface operations Planning At Dallas For Worth," *AIAA*, 2007
[70] T. h. Yoon Jung, Justin Montoya, Gautam Gupta, Waqar Malik, Leonard Tobias, Hua Wang, "Performance Evaluation of surface movement Dallas-Fort Worth," *USA/Europe Air Traffic Managment Reasearch and Development Seminar* vol. Nine, 2011.
[71] S. R. Mehndiratta and M. Kiefer, "Impact of slot controls with a market-based allocation mechanism at San Francisco International Airport," *Transportation Research Part A: Policy and Practice,* vol. 37, no. 7, pp. 555-578, 2003, doi: 10.1016/s0965-8564(02)00055-1.
[72] P. Swaroop, B. Zou, M. O. Ball, and M. Hansen, "Do more US airports need slot controls? A welfare based approach to determine slot levels," *Transportation Research Part B: Methodological,* vol. 46, no. 9, pp. 1239-1259, 2012, doi: 10.1016/j.trb.2012.03.002.
[73] Y. Jiang, J. Lu, T. Feng, and Z. Yang, "Determinants of wave-system structures of network airlines at hub airports," *Journal of Air Transport Management,* vol. 88, p. 101871, 2020, doi: 10.1016/j.jairtraman.2020.101871.
[74] B. Mirković and V. Tošić, "Apron capacity at hub airports-the impact of wave-system structure," *Journal of Advanced Transportation,* vol. 50, no. 7, pp. 1489-1505, 2016, doi: 10.1002/atr.1412.
[75] "First US Passenger Airliners." BirthofAviation.org. birthofaviation.org/first-us-airliners/ (accessed 5/30/2021, 2021).
[76] E. Mazareanu. *Number of air carriers in the United States from 1995 to 2020,* Statista. [Online]. Available: statista.com/statistics/183428/number-of-us-air-carrirts-since-1995/
[77] R. Gandt, *Skygods: The Fall of Pan Am*. Ebook: Smashwords Edition, 2012.
[78] L. J. Hoffman, *Pan American World Airways: Images of Modern America*. Charlston, South Carolina: Arcadia Publishing, 2015.
[79] J. K. James Patrick Baldwin, Leslie Giles, *Pan American World Airways: Aviation History in the Words of its People*. Saint Augstine Florida Bluewater press, 2011.
[80] R. Daley, *Juan Trippe and his Pan Am Empire An American Saga*, First ed. New York: Random House Inc, 1980.
[81] J. Sutter, *747: Creating the Worlds first Jumbo Jet and Other Adventures from a Life in Aviation* (Smithsonian Books). Collins Publishers, 2007.
[82] austrailianaviation.com.au. (2019) The Joyce Choice: Qantas's Project Sunrise Evaluation. *Australian Aviation*. Available: https://australianaviation.com.au/2019/06/the-joyce-choice-qantass-project-sunrise-evaluation/

[83] austrailianaviation.com.au. (2017, August 25th, 2017) Qantas Seeks Holy Grail of Nonstop Sydney to London, New York Flights by 2022. *Austrailain Aviation*. Available: https://australianaviation.com.au/2017/08/qantas-seeks-holy-grail-of-nonstop-sydney-to-london-new-york-flights-by-2022/
[84] R. E. G. Davis, *Pan Am an Airline and its Aircraft*. Crown, 1987.
[85] R. P. Hallion, "World War I: an air war of consequence," *Endeavour,* vol. 38, no. 2, pp. 77-90, 2014/06/01/ 2014, doi: https://doi.org/10.1016/j.endeavour.2014.05.003.
[86] J. H. H. Mark Cotta Vaz, *Pam Am at War: How the airlines secrestly helped America Fight World War II*. New York: Skyhorse Publishing.
[87] B. Conard, *Pan Am: An Aviation Legend*. Woodford Press, 1999.
[88] B. C. Airplanes, "747 Airplane Characteristics Airport Planning," May 1984 2011.
[89] D. W. Smith, D. G. Kilpatrick, S. A. Falsetti, and C. L. Best, "Postterrorism services for victims and surviving family members: Lessons from Pan Am 103," *Cognitive and Behavioral Practice,* vol. 9, no. 4, pp. 280-286, 2002, doi: 10.1016/s1077-7229(02)80021-9.
[90] A. Ash. (2020, Feb 19th 2020) The Rise And Fall of Pan Am. *Business Insider Australia* [Interview]. Available: https://www.businessinsider.com.au/how-pan-am-went-from-pioneering-air-travel-to-bankruptcy-2020-2?r=US&IR=T
[91] J. Steele. *Names of Pan Am Clippers 1934-1991 by manufactrer and Model*.
[92] R. D. Arnold and J. P. Wade, "A Definition of Systems Thinking: A Systems Approach," *Procedia Computer Science,* vol. 44, pp. 669-678, 2015, doi: 10.1016/j.procs.2015.03.050.
[93] S. Dožić, M. Kalić, and O. Babić, "Heuristic Approach to the Airline Schedule Disturbances Problem: Single Fleet Case," *Procedia - Social and Behavioral Sciences,* vol. 54, pp. 1232-1241, 2012/10/04/ 2012, doi: https://doi.org/10.1016/j.sbspro.2012.09.837.
[94] M. W. Maier, "Architecting principles for systems-of-systems," *Systems engineering,* vol. 1, no. 4, pp. 267-284, 1998, doi: 10.1002/(SICI)1520-6858(1998)1:4%3C267::AID-SYS3%3E3.0.CO2-D.
[95] A. Vieno, "'Airport People' in Transformation: Vertical Disintegration and the Reconfiguration of Occupational Belonging in Terminal Work at Helsinki-Vantaa International Airport," *Sociological Research Online,* vol. 26, no. 1, pp. 108-124, 2021, doi: 10.1177/1360780420912271.
[96] K. L. P. Craig J. Foster, Neville A. Stanton, "A very temporary operating instruction: Uncovering emergence and adaptation in air traffic control," *Reliability Engineering and System Safety,* vol. 208, 107386, 2021, doi: doi:10.1016/j.ress.2020.107386.
[97] J. Xu *et al.*, "Human performance measures for the evaluation of process control human-system interfaces in high-fidelity simulations," *Applied Ergonomics,* vol. 73, pp. 151-165, 2018/11/01/ 2018, doi: https://doi.org/10.1016/j.apergo.2018.06.008.
[98] C. P. Company, "Aviation Fuel Technical Review," San Ramon, 2007.

[99] J. Bailey, "Could the "Flying-V" Fuselage be the Future of Aviation?," *Simply Flying*, June 4, 2019. [Online]. Available: https://simpleflying.com/flying-v-aircraft/
[100] D. b. Eitan Bachmat, Luba Sapir, Steven Skiena, Natan Stolyarov, "Analysis of Airplane Boarding via space-time geometry and random matrix theory," *Physics Society*, 2005.
[101] H. Van Landeghem and A. Beuselinck, "Reducing passenger boarding time in airplanes: A simulation based approach," *European Journal of Operational Research*, vol. 142, no. 2, pp. 294-308, 2002, doi: 10.1016/s0377-2217(01)00294-6.
[102] B. C. Airplanes, "737 Airplane Characteristics for Airport Planning," October 2021 2021. [Online]. Available: https://www.boeing.com/resources/boeingdotcom/commercial/airports/acaps/737NG_REV%20C.pdf
[103] A. SAS, "A350 Aircraft Characteristics Airport and Maintenance Planning," France, May 2020 2020. [Online]. Available: https://www.airbus.com/aircraft/support-services/airport-operations-and-technical-data/aircraft-characteristics.html
[104] G. E. P. Box, "Science and Statistics," *Journal of the American Statistcal Association*, vol. 71, 356, pp. 791-799, December 1976 1976. [Online]. Available: https://www-sop.inria.fr/members/Ian.Jermyn/philosophy/writings/Boxonmaths.pdf.

APPENDIX

Appendix A: NetLogo Code

The simulation model presented as a portion of CHAPTER V was built in the Open source NetLogo Tool to provide a validation of the benefits of the new passenger boarding system. This section provide both versions of the code with limited commentary.

<u>Image of Existing Boarding Process Simulation</u>

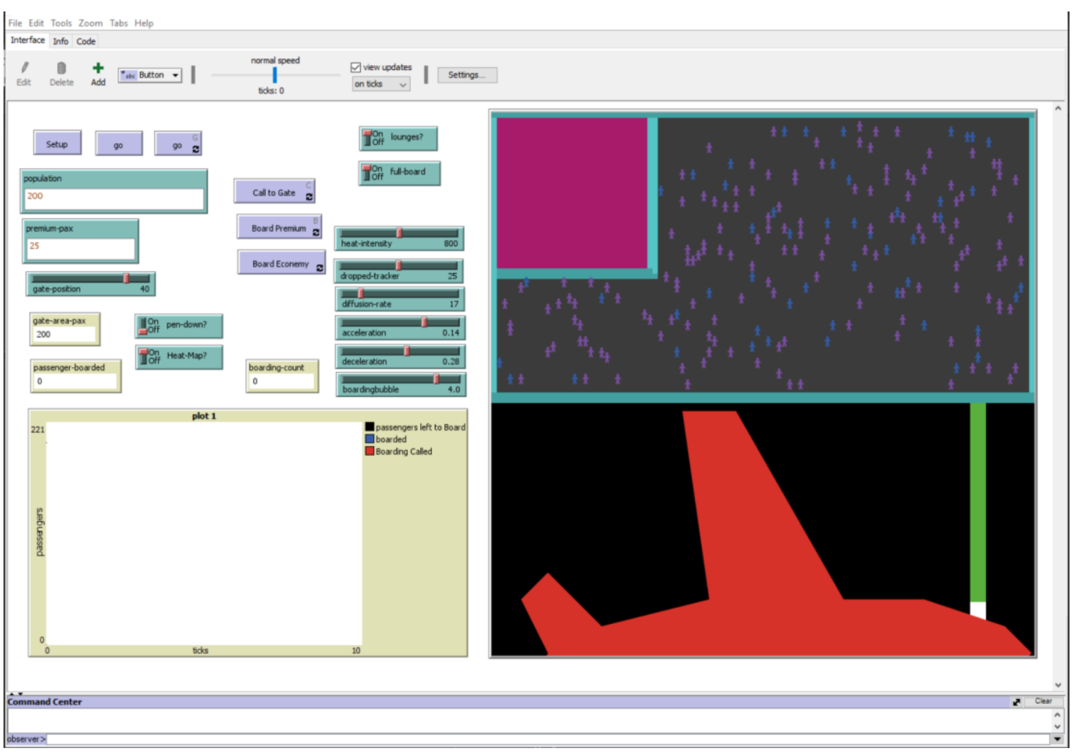

Figure 13. Simulation of Existing Boarding Process

Code Representing the Existing Boarding Process

```
globals [
 terminal-zone
 gates
  jetbridge
  is-jetbridge?
  gate-point
  gate-x
  gate-y
  gate-pointa
  gate-positiona
  gate-position-a
  premium-dep?
  normal-dep?
  ecq
  fseq
  ecqq
  prq
  fspq
  prqq
  vwall
  hwall
  seats
  l-vwall
  l-hwall
  h-wallp?
  v-wallp?
  lounge?
  boarding-pax
  boarding-count
  goint
  gtgint
  seatplane

]

turtles-own[
  prepax
  maxwalksp
  minwalksp
  walksp
```

```
  at-gate?
]
followprems-own [
in-lounge?
]

patches-own [
chemical
is-terminal?
]

breed [passengers passenger]; used as a first variable for passengers and for testing new
functions
breed [fstprems fstprem]
breed [fstecons fstecon]
breed [followprems followprem]
breed [followecons followecon]
breed [acfts acft]

;;;;;;;;;;;;;;;;;;;;;;;
;;; Setup procedures ;;;
;;;;;;;;;;;;;;;;;;;;;;;

to setup
  clear-all
  setup-patches
  aircraft ;; gernerates aircraft for passengers to board
  populate ;; Creates population of passengers
  reset-ticks
  set boarding-pax 0
  set boarding-count 0
  set gtgint false
end

to populate
 if premium-pax > 0 [
    create-fstprems 1
  [ set size 2         ;; easier to see
    set color blue     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    setxy gate-position 5 ;; set each passenger to a random location above the zero line -
this is an easy way to demarkate the terminal
    set heading 180
    set walksp 1 + random-float 1.5
    set maxwalksp 3
```

```
    set minwalksp 0
    set premium-dep? true
    set normal-dep? False
    set at-gate? true
    if pen-down? = true [pen-down]
    ]
  create-followprems ((population * (premium-pax / 100)) - 1) ; sets premium passengers
to the percentage identified in the box on the user interface
  [ set size 2         ;; easier to see
    set color blue     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    disperse ;; set each passenger to a random location above the zero line - this is an easy
way to demarkate the terminal
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set premium-dep? true
    set normal-dep? False
    set at-gate? False
    if pen-down? = true [pen-down]
    ]
  ]
  if premium-pax < 100 [
    create-fstecons 1
  [ set size 2         ;; easier to see
    set color violet     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    setxy gate-position 10 ;; set each passenger to a random location above the zero line -
this is an easy way to demarkate the terminal
    separate-pax; would normally not have this here but elected to keep it as passenger in
econnemy would likely get out of the way or would be pushed out of the eay of premium
passengers
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set heading 180
    set premium-dep? true
    set normal-dep? False
    set at-gate? true
    if pen-down? = true [pen-down]
  ]
 create-followecons ((population * (1 - (premium-pax / 100))) - 1)
  [ set size 2         ;; easier to see
    set color violet     ;; blue = departure passenger
    set shape "person" ;; sets the shape of passenger to "person"
```

```
    ;setxy random-pxcor random 49 ;; set each passenger to a random location above the
zero line - this is an easy way to demarkate the terminal
    ;  if pcolor = cyan       ; if it's on the wall...
    disperse        ; sets positions not on walls
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set premium-dep? False
    set normal-dep? true
    set at-gate? False
    if pen-down? = true [pen-down]
  ]
  ]
  sequencepax
end

to sequencepax
  if premium-pax > 0 [ sequencepaxp ]
  if premium-pax < 100 [ sequencepaxe ]
end

; These functions generate a list of passengers in order of proximity to the gate split
between premium and econemy passengers
; the second set then pulls that seed passenger and appends it to the begining of the list so
every one must follow th seed passengers

to sequencepaxe
set ecq sort-by [ [a b] -> [ distancexy gate-position 0 ] of a < [ distancexy gate-position 0
] of b ] followecons
set fseq one-of fstecons
set ecqq sentence fseq ecq
  econq
end

to sequencepaxp
set prq sort-by [ [a b] -> [ distancexy 25 0 ] of a < [ distancexy 25 0 ] of b ] followprems
set fspq one-of fstprems
set prqq sentence fspq prq
  premq
end


; These two functions set the previous or precedeing passenger on the list to the
predisesor (Prepax variable)
    ; position gives position number in list
```

```
    ; item gives item in a position
    ; by combining both of these fucntions it is possible to set each prepax in any order given we are refferencing the list.
    ; this function is also only iterating the number of times that there are passengers

to premq
   let n 1
  while [n < (population * (premium-pax / 100))] [
  ask ( item n prqq) [
   set prepax item ((position (item n prqq) prqq) - 1) prqq
  ]
    set n n + 1
  ]
end

to econq
   let c 1
  while [c < (population * (1 - (premium-pax / 100)))] [
  ask ( item c ecqq) [
   set prepax item ((position (item c ecqq) ecqq) - 1) ecqq
  ]
    set c c + 1
  ]
end

to aircraft ;; Builds a single aircraft centered and adjacent to the terminal. This isn't acctully doing anything but it is a nice visual
  create-acfts 1
  [
    set size 100
    set color red
    set shape "airplane"
    set heading 90
    setxy 0 -50
    set at-gate? true
  ]
end

;;;;;;;;;;;;;;;;;;
;;Build patches ;;
;;;;;;;;;;;;;;;;;;

to setup-patches
  build-terminal
  place-jetbridge
```

```
  build-lounge
  draw-wall ; has to be last in order to prevent passengers from wandering down the
bridge before boarding
end

to build-terminal
  set terminal-zone patches with [
    (pycor > -2 )
  ]
  ask terminal-zone [
  set pcolor 2 ; was white but wanted the heat mapping to go to white so passengers
wouldn't die when it reached full saturation
  set is-terminal? true
   set v-wallp? False
   set h-wallp? False
   set lounge? False
  ]
end

to draw-wall
  set vwall patches with [ ((pxcor = 50) and (pycor > -2)) or ((pxcor = -50) and (pycor > -
2))]
  ask vwall [
    set pcolor cyan
    set v-wallp? true
    set is-terminal? false
  ]
    set hwall patches with [(pycor = -2) or (pycor = -3) or (pycor = 50)]
  ask hwall [
    set pcolor 84
    set h-wallp? true
    set is-terminal? false
  ]
end

;This function simply puts the gate on top of the wall so that passengers can walk on it
effectively opening the bridge to passengers
to place-jetbridge
  set gate-positiona (gate-position + 1)
  set gate-position-a (gate-position - 1)
  set gate-pointa list gate-position gate-positiona ; list command is only accepting 2 values
at a time
  set gate-point insert-item 2 gate-pointa gate-position-a ;third value is then appended into
the list giving us ta three patch wide jetbridge
  set gate-x gate-position
```

```
  set gate-y 2 ; was set to 0 but passengers we wandering outside of the terminal by
adjusting to 2 it shifts passengers slightly away from the terminal face as the congregate
in the gate area
  set jetbridge patches with [
    member? pycor [-2 -3 -4 -5 -6 -7 -8 -9 -10 -11 -12 -13 -14 -15 -16 -17 -18 -19 -20 -21 -
22 -23 -24 -25 -26 -27 -28 -29 -30 -31 -32 -33 -34 -35 -36 -37 -38 -39 -40] and
    member? pxcor gate-point ; calling the list allowed me to shift the gate based on the
slider
  ]
  ask jetbridge [
    set is-jetbridge? True
    set pcolor green
    set is-terminal? false
  ]
  set seatplane patches with [
    member? pycor [-41 -42 -43 -44] and
    member? pxcor gate-point]
  ask seatplane [
  set pcolor white
  ]
end

to build-lounge
  if lounges? = true
  [set seats patches with [((pycor > 20) and (pxcor < -20))]
  ask seats [
    set pcolor magenta
      set lounge? true
      set is-terminal? false
  ]
  set l-vwall patches with [ ((pxcor = -20) and (pycor > 19)) or ((pxcor = -21) and (pycor
> 19))]
  ask l-vwall [
    set pcolor cyan
    set v-wallp? true
    set is-terminal? false
  ]
      set l-hwall patches with [ ((pxcor < -19) and (pycor = 20)) or ((pxcor < -20) and
(pycor = 21)) ]
  ask l-hwall [
    set pcolor 84
    set h-wallp? true
    set is-terminal? false
  ]
  ]
```

```
end

;;;;;;;;;;;;;;;;
;;Go Procedures;;
;;;;;;;;;;;;;;;;
to go
    ifelse goint = true [stop]
  [mingle
    if lounges? = true [go-to-lounge]];[flock-gate]
end

to mingle
  ask followecons [
   bounce2
   ;testwall
   ;move-speeda
   movestep
   right random 22
   left random 22
  ]
  tick
end

to go-to-lounge
ask followprems [
  ifelse xcor > -21 or ycor < 21
  [facexy -23 23
      move-speeda]
      ;separate-paxa]
    [bounce2
   move-speeda
   ;separate-paxa
   right random 20
   left random 20
   set in-lounge? true]
     ]
  tick
end

to flock-gate
end

to move-to-gate
    set goint true
  if (all? followprems [xcor <= (gate-x + 15) and
```

```
    xcor >= (gate-x - 15) and
    ycor <= 20] and all? followecons [xcor <= (gate-x + 15) and
    xcor >= (gate-x - 15) and
    ycor <= 20])
   [ stop ]
  if gtgint = true [stop]
  callprem
  callecon
end

to callprem
   if all? followprems [xcor <= (gate-x + 15) and
    xcor >= (gate-x - 15) and
    ycor <= 20]
    [stop]
    ask followprems [
    ifelse ((in-lounge? = true and at-gate? = false) or ((ycor > 21) and (xcor < 35))) [(set
heading 90)
        move-speeda
        gate-bounce
      if xcor > (-20) [set in-lounge? False]]
    [ ifelse ( xcor > (gate-x + 15) or
    xcor < (gate-x - 15) or
      ycor > 20 ) [
        facexy gate-x gate-y
  move-speeda
  gate-bounce
    ] [set at-gate? true
      separate-paxa]
    ]
    ] ;[ set at-gate? True] ; sets passengers within area as ready - tested with set color red

  tick
end

to callecon
   if all? followecons [xcor <= (gate-x + 15) and
    xcor >= (gate-x - 15) and
    ycor <= 20]
    [stop]
   ask followecons [
  if xcor > (gate-x + 15) or ; ajusted from if else
    xcor < (gate-x - 15) or
      ycor > 20
   [ facexy gate-x gate-y
```

```
  move-speeda
  gate-bounce
  separate-paxa] ;[ set at-gate? True ] ; sets passengers within area as ready - tested with
set color red
  ]
  tick
end

to premium-boarding
  place-jetbridge
  set boarding-pax population
  set gtgint true
  ifelse full-board = true [
   if all? followprems [ycor <= -20]
   [ board-econ ]
 if all? followecons [ycor < -41]
   [ stop ]
  ]
  [ if all? followprems [ycor < -41]
  [ stop ]
  ]
  board-prem
end

to board-prem ;; closest passenger to the gate takes fisrt step toward gate
  ask fstprems [
    if pycor = 5 [sequencepaxp]
    ;;;; Error in line above potential ;;;;
    ifelse pcolor = green [ fd 0.75]
    [fd 1.5]
 ifelse pcolor = white
   [die]
    [ set chemical chemical + dropped-tracker ]
  ]
  ask followprems [ ; generates a folow command for passengers to follow the closest
passenger to the gate
   ifelse pcolor = green  [set heading 180 move-speeda][
      face prepax; turtle (who - 1)
      gate-bounce
      que-speed
    ]
 ifelse pcolor = white
   [die]
    [ set chemical chemical + dropped-tracker ]
  ]
```

```
  build-heat-map
  set boarding-count boarding-count + 1
  tick
end

to board-econ
  place-jetbridge ; has to be recalled here to open the jet bridge otherwise passengers will
not walk down the bridge
  set boarding-pax population
  if all? followecons [ycor < -41]
   [ stop ]
  ask fstecons [
    if pycor = 10 [sequencepaxe]
    ;;;; Error in line above potential ;;;;
    ifelse pcolor = green [ fd 1.5]
    [fd 2]
    ifelse pcolor = white
   [die]
    [ set chemical chemical + dropped-tracker ] ;; drop some chemical
  ]
   ask followecons [ ; generates a folow command for passengers to follow the closest
passenger to the gate
   ifelse pcolor = green  [set heading 180 move-speeda][
      face  prepax;turtle (who - 1)
      ;;;turtles still dieing
      gate-bounce
      que-speed
    ]
    ifelse pcolor = white
   [die]
    [ set chemical chemical + dropped-tracker ]
  ]
  build-heat-map
  set boarding-count boarding-count + 1
  tick
end

;;;;;;;;;;;;;;;;;;;;;
;;Reporting Commands;;
;;;;;;;;;;;;;;;;;;;;;

to-report gate-area-pax
  ;if at-gate? [
  report (count turtles - 1);[if at-gate?]
  ;]
```

```
end

to-report passenger-boarded
  report population + 1 - count turtles
end

to-report boarding?
  report boarding-pax
end

to build-heat-map
  if Heat-Map? = true [
    diffuse chemical (diffusion-rate / 100)
  ask terminal-zone [
     if  (is-terminal? = true) [ ; is-terminal? was a global variable which caused issues in
this function but as a patch variable this now work
        set pcolor scale-color red chemical 0.1 heat-intensity ];]
    ]
  ]
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;Extra Procedures Used Throughout;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to separate-pax ; this procedure is a turtle only procedure and had to be included in the
creation of passengers wihtin the setup. It prevents passengers from being generated on
the same patch and moves them closer to the gate if they overlap.
  if any? other turtles-here [ ; tests if another turtle is on the same patch
    facexy gate-x gate-y ; faces gate
    fd 2 ; jumps two squares to move away from the passenger that it was on top of.
    set heading random 360 ; resets turtle to a random heading
    separate-pax
  ]
end

to disperse
 setxy random-pxcor random 49 ;; set each passenger to a random location above the zero
line but below the wall - this is an easy way to demarkate the terminal
  ifelse (pcolor = cyan or pcolor = 84 or pcolor = magenta)      ; if ond of the passengers is
places on the boundary wall it resets its position
[ disperse]
  [separate-pax
  ]
end
```

```
to separate-paxa ; this procedure is a follow on from above but is not specifying a
heading as it was producing errors
  if any? other turtles-here [
    set heading (270 - random 180)
    fd 1
    set color green
    separate-paxa
  ]
end

to separate-paxb ; this procedure is a follow on from above but it rotates from its given
heading and includes the bounce
  if any? other turtles-here [
    rt 45
    bounce2
    fd 1
  ]
end

to movestep ; this is a movement fuction after direction and speed are set.
  ifelse (patch-ahead walksp = nobody) [ rt 180 fd walksp]
  [ifelse ([pcolor] of patch-ahead walksp = cyan or [pcolor] of patch-ahead walksp = 84 or
[pcolor] of patch-ahead walksp = black or [pcolor] of patch-ahead walksp = magenta or
[pcolor] of patch-ahead walksp = green) ; "or patch-ahead walksp = nobody) " Cant be
the same as the other options
  [set color red
    reconsider]
  [fd walksp]
  ]
end

to reconsider
    ; check: hitting a right or left wall?
    if ([pcolor] of patch-ahead walksp = cyan or [pcolor] of patch-ahead 1 = cyan) ; or
[pcolor] of patch-ahead 2 = cyan); Cyan is an 85 and is now the top and bottom wall,
    ; if so, reflect heading around x axis
  [ set heading (- heading) fd walksp ] ;movestep]
  ; check: hitting top or bottom wall?
    if ([pcolor] of patch-ahead walksp = 84 or [pcolor] of patch-ahead 1 = 84) ; or [pcolor]
of patch-ahead 2 = 84); 84 is now side walls
    ; if so, reflect heading around x axis
  [ set heading (180 - heading) fd walksp] ; movestep]
end
```

```
to bounce2;; turtle procedure bounce but with color instead of limits
  if ( patch-ahead 1 = nobody or patch-ahead walksp = nobody or abs [pxcor] of patch-
ahead 1 >= 50 or abs [pxcor] of patch-ahead walksp >= 50) [ facexy gate-x gate-y]; if
tutrles hit the edge of the map they turn 180 and continue moving
    ; check: hitting a colored wall?
    if ([pcolor] of patch-ahead 1 = cyan or [pcolor] of patch-ahead walksp = cyan) ; Cyan
is an 85, 84 now on side walls
    ; if so, reflect heading around x axis
    [ set heading (- heading) ]
  ; check: hitting top or bottom wall?
    if ([pcolor] of patch-ahead 1 = 84 or [pcolor] of patch-ahead walksp = 84) ; Cyan is an
85 84 now on side walls
    ; if so, reflect heading around x axis
    [ set heading (180 - heading) ]
end

to gate-bounce ;
  ; check: hitting any wall or if it would be off the wall of the terminal?
  if ([pcolor] of patch-ahead walksp = cyan or [pcolor] of patch-ahead walksp = 84 or
[pcolor] of patch-ahead walksp = black)
    ; if so, reflect heading around x axis
    [ facexy gate-x gate-y ]
end

to testwall
  if patch-ahead walksp = nobody [ rt 180 ] ; if tutrles hit the edge of the map they turn
180 and continue moving
  ; check: hitting left or right wall?
  if (abs [pxcor] of patch-ahead walksp >= 50);
    ; if so, reflect heading around x axis
    [ set heading (- heading) ]
  ; check: hitting top or bottom wall?
  if ([pycor] of patch-ahead walksp >= max-pycor or [pycor] of patch-ahead walksp <= -
2)
    ; if so, reflect heading around y axis
    [ set heading (180 - heading) ]
end

to move-speeda
  let personalbubble ifelse-value (boardingbubble < 2.5) [2][boardingbubble] ; deals with
the width of the boarding bridge preventing passengers from walking around previous
passengers. This is just adding mannors that may not be there in real life but should be
here in the model.
  let paxad one-of turtles in-cone personalbubble  180
  ifelse any? other turtles in-cone personalbubble 180
```

```
    [ ifelse any? fstprems in-cone personalbubble  180 [set walksp (1.5 - deceleration)][
      set walksp [ walksp ] of paxad - deceleration
]];set color red]] ; commented out to test "testwall" function
      [ speed-up-pax
];set color black] ;; otherwise, speed up
    ;; don't slow down below speed minimum or speed up beyond speed limit
    if walksp < minwalksp [ set walksp minwalksp ]
    if walksp > maxwalksp [ set walksp maxwalksp ]
    fd walksp
end

to que-speed
  ifelse (distance prepax) <= boardingbubble
      [ set walksp [ walksp ] of prepax - deceleration ]
      [ speed-up-pax ] ;; otherwise, speed up
    ;; don't slow down below speed minimum or speed up beyond speed limit
    if walksp < minwalksp [ set walksp minwalksp ]
    if walksp > maxwalksp [ set walksp maxwalksp ]
    fd walksp
end

to slow-down-pax [ pax-ahead ] ;; turtle procedure
  ;; slow down so the passengers are walking more slowly than the passenger in front of
them
  set walksp [ walksp ] of pax-ahead - deceleration
end

to speed-up-pax ;; turtle procedure
  set walksp walksp + acceleration
end

;; Other helpful reference materials outside of manual
; https://stackoverflow.com/questions/42350384/netlogo-list-in-list-iterations-with-
counter
; https://ccl.northwestern.edu/netlogo/bind/primitive/in-cone.html
```

Image of New Boarding Process Simulation

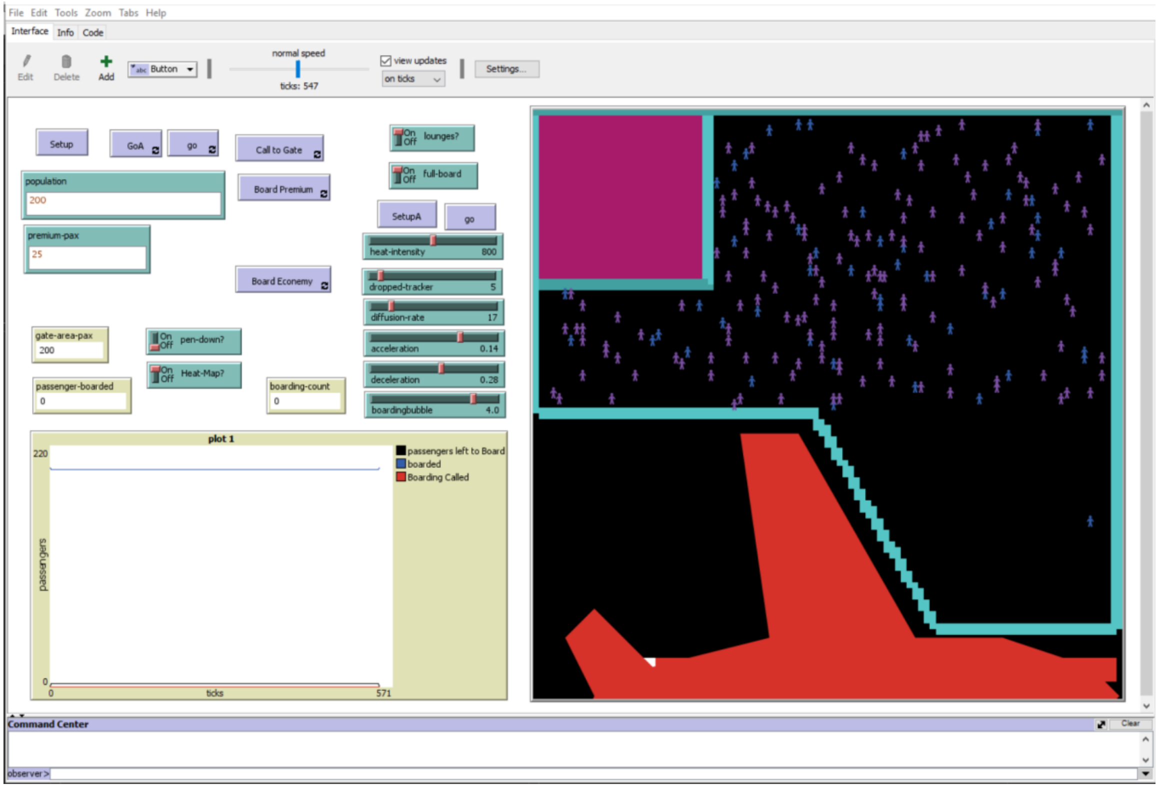

Figure 14. Simulation of Proposed Boarding Process

Code Representing the New Boarding Process

```
globals [
 terminal-zone
 gates
  jetbridge
  is-jetbridge?
  gate-point
  gate-x
  gate-y
  gate-pointa
  gate-positiona
  gate-position-a
  premium-dep?
  normal-dep?
  ecq
```

```
  fseq
  ecqq
  prq
  fspq
  prqq
  vwall
  hwall
  seats
  l-vwall
  l-hwall
  h-wallp?
  v-wallp?
  lounge?
  boarding-pax
  boarding-count
  gtgint
  asile
  endzone
  goint
]

turtles-own[
  prepax
  maxwalksp
  minwalksp
  walksp
  at-gate?
]
followprems-own [
in-lounge?
  flockmates
]

patches-own [
chemical
is-terminal?
]

breed [passengers passenger]; used as a first variable for passengers and for testing new
functions
breed [fstprems fstprem]
breed [fstecons fstecon]
breed [followprems followprem]
breed [followecons followecon]
breed [acfts acft]
```

```
breed [ants ant]
breed [antzs antz]

;;;;;;;;;;;;;;;;;;;;;;;
;;; Setup procedures ;;;
;;;;;;;;;;;;;;;;;;;;;;;

to setup
  clear-all
  setup-patches
  aircraft ;; gernerates aircraft for passengers to board
  ;populate ;; Creates population of passengers
  reset-ticks
  set boarding-pax 0
  set boarding-count 0
  set gtgint false
  setupA
  goa
end

to setupa
  set-default-shape turtles "airplane"
  create-ants 1
    [ set color red ]
  ask ants
    [ setxy -50 -2
      set heading 90
      set size 6
      set pen-size 16
      set color cyan
];pen-down ]                         ;; the leader also leaves a trail
  reset-ticks
    create-antzs 1
    [ set color red ]                      ;; leader ant is red and start with a random heading
  ask antzs
    [ setxy -50 -1                   ;; start the ants out at -1the nest
      set heading 90
      set size 6
      set pen-size 16
      set color cyan
];pen-down ]                         ;; the leader also leaves a trail
  reset-ticks
end

to goa ;; This function draws the new shape of the wall
```

```
  if all? ants [xcor >= 50] and all? antzs [xcor >= 50]
    [ populate stop ]
  ask ants [
    ifelse xcor > -3 and xcor < 19
    [ set heading 150
 fd 0.2
    set pcolor cyan]
    [ ifelse xcor > 48 [set heading 0
      ifelse ycor < 49 [fd 0.5 set pcolor cyan][die]
      ]
      [set heading 90
        fd 0.5
    set pcolor cyan]]
  ]

  ask antzs [
    ifelse xcor > -3 and xcor < 19
    [ set heading 150
 fd 0.2
    set pcolor cyan]
    [ ifelse xcor > 49 [set heading 0
      ifelse ycor < 49 [fd 0.5 set pcolor cyan][die]
      ]
      [set heading 90
        fd 0.5
    set pcolor cyan]]
  ]
  tick
end

to populate
 if premium-pax > 0 [
    create-fstprems 1
  [ set size 2         ;; easier to see
    set color blue     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    setxy 45 -20 ;; set Location fo the first passenger to a fixed location near the boarding
area
    set heading 180
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set premium-dep? true
    set normal-dep? False
    set at-gate? true
```

```
    if pen-down? = true [pen-down]
    ]
  create-followprems ((population * (premium-pax / 100)) - 1) ; sets premium passengers
to the percentage identified in the box on the user interface
  [ set size 2        ;; easier to see
    set color blue     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    disperse ;; set each passenger to a random location above the zero line - this is an easy
way to demarkate the terminal
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set premium-dep? true
    set normal-dep? False
    set at-gate? False
    if pen-down? = true [pen-down]
    ]
  ]
  if premium-pax < 100 [
    create-fstecons 1
  [ set size 2        ;; easier to see
    set color violet     ;; blue = departure premium passenger
    set shape "person" ;; sets the shape of passenger to "person"
    setxy 40 10 ;; set each passenger to a random location above the zero line - this is an
easy way to demarkate the terminal
    separate-pax; would normally not have this here but elected to keep it as passenger in
econnemy would likely get out of the way or would be pushed out of the eay of premium
passengers
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set heading 180
    set premium-dep? true
    set normal-dep? False
    set at-gate? true
    if pen-down? = true [pen-down]
  ]
 create-followecons ((population * (1 - (premium-pax / 100))) - 1)
  [ set size 2        ;; easier to see
    set color violet     ;; blue = departure passenger
    set shape "person" ;; sets the shape of passenger to "person"
    ;setxy random-pxcor random 49 ;; set each passenger to a random location above the
zero line - this is an easy way to demarkate the terminal
    ;  if pcolor = cyan       ; if it's on the wall...
    disperse        ; sets positions not on walls
```

```
    set walksp 1 + random-float 1.5
    set maxwalksp 3
    set minwalksp 0
    set premium-dep? False
    set normal-dep? true
    set at-gate? False
    if pen-down? = true [pen-down]
  ]
  ]
  sequencepax
end

to sequencepax
  if premium-pax > 0 [ sequencepaxp ]
  if premium-pax < 100 [ sequencepaxe ]
end

; These functions generate a list of passengers in order of proximity to the gate split
between premium and econemy passengers
; the second set then pulls that seed passenger and appends it to the begining of the list so
every one must follow th seed passengers

to sequencepaxe
set ecq sort-by [ [a b] -> [ distancexy 40 -37 ] of a < [ distancexy 40 -37 ] of b ]
followecons
set fseq one-of fstecons
set ecqq sentence fseq ecq
  econq
end

to sequencepaxp
set prq sort-by [ [a b] -> [ distancexy 40 -37 ] of a < [ distancexy 40 -37 ] of b ]
followprems
set fspq one-of fstprems
set prqq sentence fspq prq
  premq
end


; These two functions set the previous or precedeing passenger on the list to the
predisesor (Prepax variable)
    ; position gives position number in list
    ; item gives item in a position
    ; by combining both of these fucntions it is possible to set each prepax in any order
given we are refferencing the list.
```

```
  ; this function is also only iterating the number of times that there are passengers

to premq
   let n 1
  while [n < (population * (premium-pax / 100))] [
  ask ( item n prqq) [
   set prepax item ((position (item n prqq) prqq) - 1) prqq
  ]
    set n n + 1
  ]
end

to econq
   let c 1
  while [c < (population * (1 - (premium-pax / 100)))] [
  ask ( item c ecqq) [
   set prepax item ((position (item c ecqq) ecqq) - 1) ecqq
  ]
    set c c + 1
  ]
end

to aircraft ;; Builds a single aircraft centered and adjacent to the terminal. This isn't
acctully doing anything but it is a nice visual
  create-acfts 1
  [
    set size 100
    set color red
    set shape "airplane"
    set heading 90
    setxy 0 -50
    set at-gate? true
   die
  ]
    set asile patches with [((pycor = -45) and (pxcor < 50) and (pxcor > -30)) or ((pycor = -
46) and (pxcor < 50) and (pxcor > -30)) or ((pycor = -47) and (pxcor < 50) and (pxcor > -
30)) or ((pycor = -44) and (pxcor < 50) and (pxcor > -30))]
  ask asile [
    set pcolor red
  ]
  set endzone patches with [((pycor >= -47) and (pycor <= -44) and (pxcor <= -30) and
(pxcor >= -33))]
    ask endzone [
      set pcolor white
    ]
```

```
  set gate-x 45
end

;;;;;;;;;;;;;;;;;
;;Build patches ;;
;;;;;;;;;;;;;;;;;

to setup-patches
  build-terminal
  build-lounge
  draw-wall ; has to be last in order to prevent passengers from wandering down the
bridge before boarding
end

to build-terminal
  set terminal-zone patches with [
    (pycor > -2 ) ;or (pxcor > 10) and (pycor > -30)
  ]
  ask terminal-zone [
  ;set pcolor 2 ; was white but wanted the heat mapping to go to white so passengers
wouldn't die when it reached full saturation
  set is-terminal? true
   set v-wallp? False
   set h-wallp? False
   set lounge? False
  ]
end

to draw-wall
  set vwall patches with [  ((pxcor = -50) and (pycor > -2)) or ((pxcor = 50) and (pycor > -
2)) ]
  ask vwall [
    set pcolor cyan
    set v-wallp? true
    set is-terminal? false
  ]
  set hwall patches with [ (pycor = 50) ]
  ask hwall [
    set pcolor 84
    set h-wallp? true
    set is-terminal? false
  ]
end
```

```
;This function simply puts the gate on top of the wall so that passengers can walk on it
effectively opening the bridge to passengers
to place-jetbridge
  set jetbridge patches with [ ((pxcor > 20) and (pxcor < 50) and (pycor < -17) and (pycor
> -45))]
  ask jetbridge [
    set is-jetbridge? True
    set pcolor green
    set is-terminal? false
  ]
end

to build-lounge
  if lounges? = true
  [set seats patches with [((pycor > 20) and (pxcor < -20))]
  ask seats [
    set pcolor magenta
      set lounge? true
      set is-terminal? false
  ]
  set l-vwall patches with [ ((pxcor = -20) and (pycor > 19)) or ((pxcor = -21) and (pycor
> 19))]
  ask l-vwall [
    set pcolor cyan
    set v-wallp? true
    set is-terminal? false
  ]
      set l-hwall patches with [ ((pxcor < -19) and (pycor = 20)) or ((pxcor < -20) and
(pycor = 21)) ]
  ask l-hwall [
    set pcolor 84
    set h-wallp? true
    set is-terminal? false
  ]
  ]
end


;;;;;;;;;;;;;;;;;
;;Go Procedures;;
;;;;;;;;;;;;;;;;;
to go
  ifelse goint = true [stop]
  [ mingle
    ifelse lounges? = true [go-to-lounge][flock-toward-gate]];[flock-gate]
```

```
end

to mingle
  ask followecons [
    ifelse ycor < -6
    [bounce2
      fd 0.1
      right random 22
      left random 22]
    [bounce2
      fd walksp ;movestep
      right random 22
      left random 22
  ]]
  tick
end

to flock-toward-gate
  ask followprems [
      set flockmates other followprems in-radius 8
  ;if any? flockmates
    ;[ set nearest-neighbor min-one-of flockmates [distance myself]
  ]
end

to go-to-lounge
ask followprems [
  ifelse xcor > -21 or ycor < 21
  [facexy -23 23
      move-speeda]
      ;separate-paxa]
    [bounce2
   move-speeda
   ;separate-paxa
   right random 20
   left random 20
   set in-lounge? true]
     ]
  tick
end

to move-to-gate
  set goint true
  if (all? followprems [xcor <= (gate-x + 15) and
    xcor >= (gate-x - 15) and
```

```
    ycor <= 20] and all? followecons [xcor <= (gate-x + 15) and
    xcor >= (gate-x - 15) and
    ycor <= 20])
   [ stop ]
  if gtgint = true [stop]
  callprem
  callecon
end

to callprem
   if all? followprems [xcor <= (20)  and
    ycor <= 20]
    [stop]
    ask followprems [
    ifelse ((in-lounge? = true and at-gate? = false) or ((ycor > 21) and (xcor < 35))) [(set
heading 90)
        move-speeda
        gate-bounce
      if xcor > (-20) [set in-lounge? False]]
    [ ifelse ( xcor > (48) or
    xcor < (20) or
      ycor > 10 ) [
        facexy 35 -20
  move-speeda
  gate-bounce
    ] [set at-gate? true
      separate-paxa]
    ]
    ] ;[ set at-gate? True] ; sets passengers within area as ready - tested with set color red

  tick
end

to callecon
   if all? followecons [xcor <= (48) and
    xcor >= (10) and
    ycor <= 20]
    [stop]
   ask followecons [
  if xcor > (48) or ; ajusted from if else
    xcor < (10) or
      ycor > 20
   [ facexy 35 -5
  move-speeda
  gate-bounce
```

```
  separate-paxa] ;[ set at-gate? True ] ; sets passengers within area as ready - tested with
set color red
  ]
  tick
end

to premium-boarding
  place-jetbridge
  set boarding-pax population
  set gtgint true
  ifelse full-board = true [
   if all? followprems [ycor <= -20]
   [ board-econ ]
 if all? followecons [ycor < -41]
   [ stop ]
  ]
  [ if all? followprems [ycor < -41]
  [ stop ]
  ]
  board-prem
end

to board-prem ;; closest passenger to the gate takes fisrt step toward gate
  ask fstprems [
    if pycor = 5 [sequencepaxp]
    ;;;; Error in line above potential ;;;;
    ifelse pcolor = green [ fd 1.5]
     [ifelse pcolor = red [
      set heading 270
      fd 1.5]
      [fd 2]]
 ifelse pcolor = white
    [die]
    [ set chemical chemical + dropped-tracker ]
  ]
  ask followprems [ ; generates a folow command for passengers to follow the closest
passenger to the gate
   ifelse pcolor = green  [set heading 180 move-speeda]
    [ifelse pcolor = red [set heading 270 fd 1.5][
      face  prepax;turtle (who - 1)
      ;;;turtles still dieing
      gate-bounce
      que-speed
    ]]
 ifelse pcolor = white
```

```
    [die]
    [ set chemical chemical + dropped-tracker ]
  ]
  build-heat-map
  set boarding-count boarding-count + 1
  tick
end

to board-econ
  place-jetbridge ; has to be recalled here to open the jet bridge otherwise passengers will
not walk down the bridge
  set boarding-pax population
  if all? followecons [ycor < -41]
   [ stop ]
  ask fstecons [
    if pycor = 10 [sequencepaxe]
    ;;;; Error in line above potential ;;;;
    ifelse pcolor = green [ fd 1.5]
    [ifelse pcolor = red [
      set heading 270
      fd 1.5]
      [fd 2]]
    ifelse pcolor = white
    [die]
    [ set chemical chemical + dropped-tracker ] ;; drop some chemical
  ]
   ask followecons [ ; generates a folow command for passengers to follow the closest
passenger to the gate
   ifelse pcolor = green  [set heading 180 move-speeda]
    [ifelse pcolor = red [set heading 270 fd 1.5][
      face  prepax;turtle (who - 1)
      ;;;turtles still dieing
      gate-bounce
      que-speed
    ]]
    ifelse pcolor = white
    [die]
    [ set chemical chemical + dropped-tracker ]
  ]
  build-heat-map
  set boarding-count boarding-count + 1
  tick
end

;;;;;;;;;;;;;;;;;;;;
```

```
;;Reporting Commands;;
;;;;;;;;;;;;;;;;;;;;;

to-report gate-area-pax
  ;if at-gate? [
  report (count turtles - 1);[if at-gate?]
  ;]
end

to-report passenger-boarded
  report population + 1 - count turtles
end

to-report boarding?
  report boarding-pax
end

to build-heat-map
  if Heat-Map? = true [
    diffuse chemical (diffusion-rate / 100)
  ask terminal-zone [
     if  (is-terminal? = true) [ ; is-terminal? was a global variable which caused issues in
this function but as a patch variable this now work
        set pcolor scale-color red chemical 0.1 heat-intensity ];]
    ]
  ]
end

;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;
;;Extra Procedures Used Throughout;;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;

to separate-pax ; this procedure is a turtle only procedure and had to be included in the
creation of passengers wihtin the setup. It prevents passengers from being generated on
the same patch and moves them closer to the gate if they overlap.
  if any? other turtles-here [ ; tests if another turtle is on the same patch
    facexy gate-x gate-y ; faces gate
    fd 2 ; jumps two squares to move away from the passenger that it was on top of.
    set heading random 360 ; resets turtle to a random heading
    separate-pax
  ]
end

to disperse
```

```
 setxy random-pxcor random 49 ;; set each passenger to a random location above the zero
line but below the wall - this is an easy way to demarkate the terminal
  ifelse (abs([pxcor]) of patch-ahead walksp > 47 or pcolor = cyan or pcolor = 84 or
pcolor = magenta)      ; if ond of the passengers is places on the boundary wall it resets its
position
[ disperse]
  [separate-pax
  ]
end

to separate-paxa ; this procedure is a follow on from above but is not specifying a
heading as it was producing errors
  if any? other turtles-here [
    set heading (270 - random 180)
    fd 1
    set color green
    separate-paxa
  ]
end

to separate-paxb ; this procedure is a follow on from above but it rotates from its given
heading and includes the bounce
  if any? other turtles-here [
    rt 45
    bounce2
    fd 1
  ]
end

to movestep ; this is a movement fuction after direction and speed are set.
  ifelse (patch-ahead walksp = nobody) [ rt 180 ]
  [
    ; check: hitting a right or left wall?
    if (abs([pxcor]) of patch-ahead walksp > 47 or [pcolor] of patch-ahead walksp = cyan
or [pcolor] of patch-ahead 1 = cyan) ; Cyan is an 85 and is now the top and bottom wall,
    ; if so, reflect heading around x axis
  [ set heading (- heading) ]
  ; check: hitting top or bottom wall?
  if ((([pycor] of patch-ahead walksp < -2) and ([pxcor] of patch-ahead walksp < 30)) or
[pcolor] of patch-ahead walksp = 84 or [pcolor] of patch-ahead 1 = 84) ; 84 is now side
walls
    ; if so, reflect heading around x axis
    [ set heading (180 - heading) ] ]
  fd walksp
end
```

```
to bounce2;; turtle procedure bounce but with color instead of limits
  ifelse ( patch-ahead 1 = nobody or patch-ahead walksp = nobody or abs [pxcor] of
patch-ahead 1 > 47 or abs [pxcor] of patch-ahead walksp > 47) [ facexy 0 10 fd walksp];
if tutrles hit the edge of the map they turn 180 and continue moving
    ; check: hitting a colored wall?
    [ ifelse ((heading > 120) and (heading < 240))
       [if ([pcolor] of patch-ahead 1 = cyan or [pcolor] of patch-ahead walksp = cyan) ;
Cyan is an 85 84 now on side walls
    [ set heading (180 - heading) ]]
  [
    if (abs([pxcor]) of patch-ahead walksp > 47 or [pcolor] of patch-ahead 1 = cyan or
[pcolor] of patch-ahead walksp = cyan) ; Cyan is an 85, 84 now on side walls
    ; if so, reflect heading around x axis
    [ set heading (- heading) ]
  ; check: hitting top or bottom wall?
    if ((([pycor] of patch-ahead walksp < -2) and ([pxcor] of patch-ahead walksp < 30)) or
[pcolor] of patch-ahead 1 = 84 or [pcolor] of patch-ahead walksp = 84) ; Cyan is an 85 84
now on side walls
    ; if so, reflect heading around x axis
      [ set heading (180 - heading) ]
  ]
]
end

to gate-bounce ;
  ; check: hitting any wall or if it would be off the wall of the terminal?
  if (abs([pxcor]) of patch-ahead walksp > 47 or [pcolor] of patch-ahead walksp = cyan or
[pcolor] of patch-ahead walksp = 84 or [pcolor] of patch-ahead walksp = black)
    ; if so, reflect heading around x axis
    [ facexy 35 -20 ]
end

to testwall
  if patch-ahead walksp = nobody [ rt 180 ] ; if tutrles hit the edge of the map they turn
180 and continue moving
  ; check: hitting left or right wall?
  if (abs [pxcor] of patch-ahead walksp >= 50);
    ; if so, reflect heading around x axis
    [ set heading (- heading) ]
  ; check: hitting top or bottom wall?
  if ([pycor] of patch-ahead walksp >= max-pycor or [pycor] of patch-ahead walksp <= -
2)
    ; if so, reflect heading around y axis
    [ set heading (180 - heading) ]
```

```
end

to move-speeda
  let personalbubble ifelse-value (boardingbubble < 2.5) [2][boardingbubble] ; deals with
the width of the boarding bridge preventing passengers from walking around previous
passengers. This is just adding mannors that may not be there in real life but should be
here in the model.
  let paxad one-of turtles in-cone personalbubble  180
  ifelse any? other turtles in-cone personalbubble 90
    [ ifelse any? fstprems in-cone personalbubble  180 [set walksp (1.5 - deceleration)][
      set walksp [ walksp ] of paxad - deceleration
]];set color red]] ; commented out to test "testwall" function
      [ speed-up-pax
];set color black] ;; otherwise, speed up
    ;; don't slow down below speed minimum or speed up beyond speed limit
    if walksp < minwalksp [ set walksp minwalksp ]
    if walksp > maxwalksp [ set walksp maxwalksp ]
    fd walksp
end

to que-speed
  ifelse (distance prepax) <= boardingbubble
      [ set walksp [ walksp ] of prepax - deceleration ]
      [ speed-up-pax ] ;; otherwise, speed up
    ;; don't slow down below speed minimum or speed up beyond speed limit
    if walksp < minwalksp [ set walksp minwalksp ]
    if walksp > maxwalksp [ set walksp maxwalksp ]
    fd walksp
end

to slow-down-pax [ pax-ahead ] ;; turtle procedure
  ;; slow down so the passengers are walking more slowly than the passenger in front of
them
  set walksp [ walksp ] of pax-ahead - deceleration
end

to speed-up-pax ;; turtle procedure
  set walksp walksp + acceleration
end

;; Other helpful reference materials outside of manual
; https://stackoverflow.com/questions/42350384/netlogo-list-in-list-iterations-with-
counter
; https://ccl.northwestern.edu/netlogo/bind/primitive/in-cone.html
```

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Publications:

A. K. Wing, R. J. Cloutier, and W. N. Felder, "Airport Ramp Area Support System An Approach for the Analysis of the Aviation System of Systems," presented at the CESUN, Hoboken New Jersey, 2014.

A. K. Wing and R. Cloutier, "The Historic Pan Am Fleet: A Data Science Review of the History of Pan American World Airways' Fleet and its Changes Over Time," presented at the AIAA SCITECH 2022 Forum, San Diego, CA, 29 Dec 2021, 2022. [Online]. Available: https://arc.aiaa.org/doi/10.2514/6.2022-2066.

A. K. Wing, W. N. Felder, and R. J. Cloutier, "Modeling a Ramp Area Support System," in *15th AIAA Aviation Technology, Integration, and Operations Conference*, 2015.

M. A. K. Wing, R. J. Cloutier, and W. N. Felder, "Ramp Area Support System: Limitations of Modeling Approach to an Airport Apron Area," *Procedia Computer Science,* vol. 44, pp. 354-362, 2015, doi: 10.1016/j.procs.2015.03.068.

A. K. Wing, "Taking a systemic Modeling approach to the Apron area at Major metropolitan airports," Masters of Engineering, School of Systems and Enterprises, Stevens Institute of Technology, Hoboken, New Jersey, 2015.