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Air Transportation Pandemic Control - A Stochastic Nonlinear Complex Adaptive System

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Abstract: Due to the unprecedented impact of COVID-19, airlines and airports have suffered major losses in revenue and trust from passengers. The FAA has published the "Runway to Recovery" as a guideline for the response to COVID-19 but has not set standards for how they should be implemented. A Decision Support System (DSS) has been designed to provide a cost-benefit analysis of defense measures against infectious disease. The DSS follows a Swiss cheese model of statistically independent defensive layers, such as temperature scans and social distancing, to mitigate the risk of infection by reducing the chance of a single layer failure. The DSS conducts a simulation which has the capability to vary a range of parameters which affect the disease and the defensive measures. By allowing the flexibility to modify these parameters, the DSS provides the capability to serve as a framework not only for COVID-19, but also for future diseases.

Keywords: FAA, Decision Support System, Airlines, Airport, Air Transportation, COVID-19, Infectious Disease

1. Introduction

COVID-19 has had an unprecedented impact on the air transportation industry. Passenger throughput has decreased by up to 63% compared to 2019, measured by TSA (Airlines For America, 2020). Airlines have struggled to adapt in the wake of large losses in revenue. Five airlines in the United States and more than ten additional airlines around the world have been forced to cease or restructure operations. Airlines for America estimates that passenger volumes are unlikely to return to 2019 level until 2023-2024 (Airlines For America, 2020).

2. Context Analysis

2.1 Current Situation

Airports and airlines around the US are implementing a range of different measures, some more than others. One of the main issues with the current system is a lack of standardization in defensive measures. Other than face covering requirements, there is no standardized regulation for pre-flight requirements, symptom screening (attestation, temperature scans), social distancing enforcement, disinfecting requirements, boarding methods, contact tracing, transportation capacity limits, or baggage claim operations (Josephs, 2020).

2.2 DSS Objectives

This DSS provides a methodology to perform a cost-benefit analysis on different combinations of defensive layers that may be applied to the air transportation system (domestic operations). It provides three example design alternatives which can be applied as standardized policies for airlines, airport authorities, and TSA. The alternatives are as follows: low-safety/low-cost, medium-safety/medium-cost, and high-safety/high-cost. Each alternative is compared against the base case (the air transportation system without any defensive measures, pre-COVID-19). Although this paper presents three predetermined combinations of design alternatives, the DSS provides the framework for measuring the cost and benefit of any combination of defensive layers.

3. Stakeholder Analysis

3.1 Primary Stakeholders

The primary stakeholders of the DSS are the FAA/DOT, the airlines and Airlines for America, the airport authorities, and the TSA. Safety guidelines are provided from the public health sector to the FAA, who provide safety mitigation strategies to the DSS. The DSS then performs an analysis of the given strategies to create recommendations that the stakeholders of the air transportation system can follow based on weight towards safety or cost. Goals of the FAA and governmental branches are to support the system through safety regulations and/or funding. Goals for the airlines, airport authority, and TSA are to maximize throughput and ensure safety. Goals for the passengers, workforce, businesses and organizations are safety and/or providing services.

3.2 Tensions

We have identified three main tensions among the stakeholders: revenue/cost, safety, and data collection. The cost the DSS imposes on the air transportation system comes from restructuring and new recurring costs to incorporate the defensive layers. The difficulty comes from generating the revenue for the airports and airlines to stay in business while passenger throughput has dropped due to safety concerns. Safety is a major factor in the reduced passenger throughput due to travel bans, restrictions, and the fear of contracting the disease. Lifting social distancing restrictions 12 weeks into an epidemic would cost 500,000 additional lives (Kahn, 2020). Data collection is outside of the scope of the DSS but plays a major role in infectious disease mitigation.

4. Problem and Need Statement

In the wake of the COVID-19 pandemic, the air transportation industry has suffered immensely. The FAA has published a set of recommendations for the industry but has not given any regulations/standards to follow for a path to recovery.

A standardized method for providing a cost-benefit analysis of defensive measures against disease is needed for the air transportation industry. A set of design alternatives have been created to give a matrix of options for the industry to apply based on their needs, with cost and utility modeled to give a realistic expectation of the solution they follow for COVID-19 recovery. This system focuses on design changes that will implement measures to regain passenger trust and promote a safer air transportation environment in the future.

5. Concept of Operations

5.1 System Scope

As shown below in Figure 1, the scope of the DSS considers a door-to-door representation of the air transportation system from the viewpoint of a passenger. The passenger will proceed from their origin point to the airport via personal or public transportation. Within each airport, a TSA checkpoint must be visited with optional stops of concessions/restaurants and inter-airport transportation. Layover flights are represented by a loop between departure and arrival airports (arrival becomes the new departure airport). The passenger then exits the arrival airport, with similar stops to the arrival airport. Upon leaving the arrival airport, they proceed to their destination via personal or public transportation.

5.2 Defensive Layers

The defensive layering methodology follows the Swiss-cheese model by implementing statistically independent layers to reduce the probability of a single layer failure. The DSS considers two different forms of defensive measures: prevention measures and response/mitigation measures. Prevention measures describe methods to prevent healthy individuals from contracting the disease. This includes PPE, air filtration, staggered boarding, social distancing, disinfecting, hand sanitizer, shielding, and a baggage claim queueing system (discussed later). Response/mitigation measures are methods to minimize the impact of contagious individuals in the system. This includes health attestations (health check), temperature scanning, and negative test results.

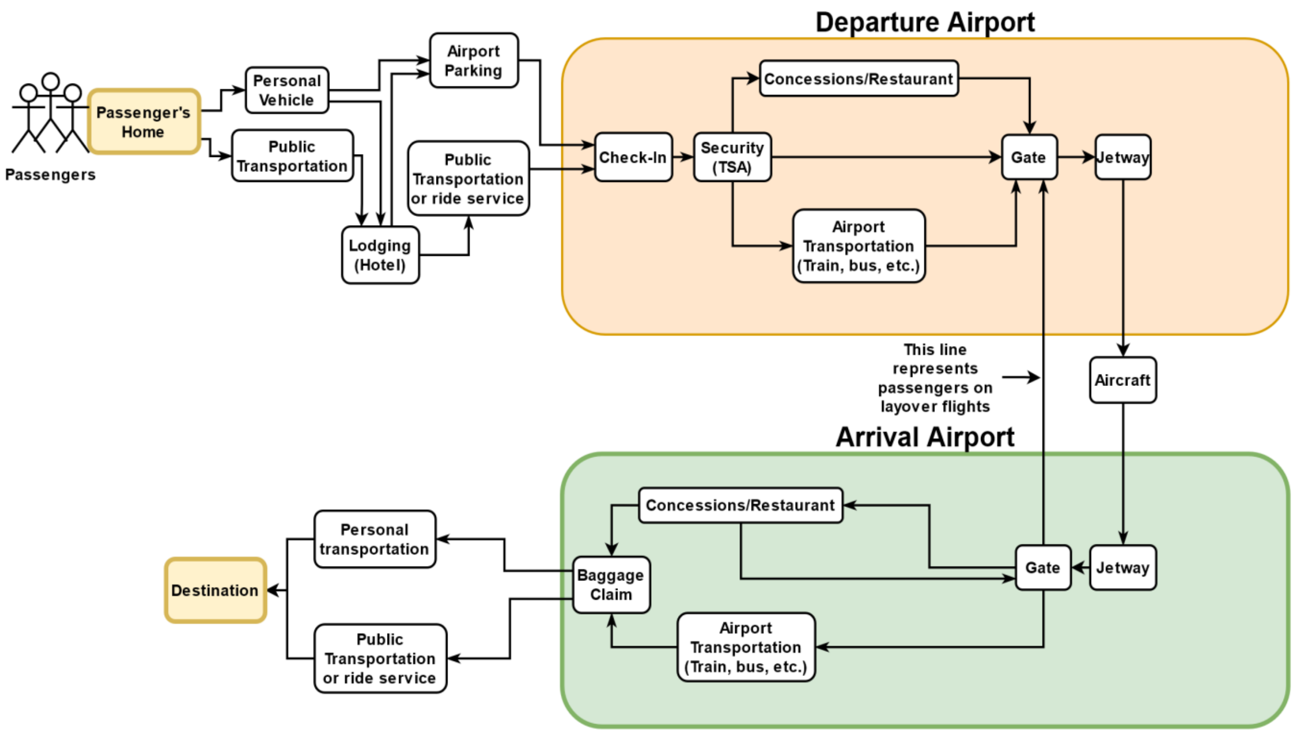

Figure 1. System Scope Diagram

6. Mission Requirements

MR.1: The system shall have a 50% chance or greater of detecting contagious individuals who encounter mitigation measures.

MR.2: An individual who goes through the system will have a 10^{-4} chance of becoming infected.

MR.3: The system shall maintain a throughput ≥ 50% of peak passenger throughput for a given airport while maintaining the target level of safety (the highest number of passengers recorded in a day for a given year).

7. Design Alternatives

7.1 Base Case

Washington Dulles Airport is the use case for the following design alternatives. The base case models the air transportation system without the use of any defensive measures in place in a pre-pandemic scenario. High passenger throughput and a low level of safety are observed when contagious individuals are introduced into the system. This case is used to measure the impact when defensive layers are implemented for each of the design alternatives. The probability of infection used for COVID-19 in the base case is set to 70% in the simulation model, which is defined as "the chance of being exposed to airborne viral particles when within the infection radius of a contagious individual". The base case builds the foundation for the simulation analysis, showcasing the highest level of risk.

7.2 Defensive Layer Cases

The following design alternatives involve three different combinations of defensive layers: a low safety case, a medium safety case, and a high safety case. The low safety case prioritizes lowering costs by implementing a minimal number of defensive layers. These layers include the use of PPE, hand sanitizer, HEPA filters, and account for a lower rate of compliance with social distancing.

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The medium safety case prioritizes a mid-level of safety by implementing more defensive layers than the low safety case. These layers include what is used in the low safety case but adds disinfecting of areas, a single temperature scan, staggered boarding of aircraft, and account for a higher rate of compliance with social distancing.

The high safety case prioritizes the highest level of safety by implementing the use of a large number of defensive layers at the expense of a high cost. These layers include what is used in the medium safety case but adds in a requirement of negative test results, a health attestation (health check), onsite testing, capacity limits on transportation, additional temperature scans, shielding, and a revamped baggage claim queueing system.

8. Simulation

8.1 Simulation Design

The DSS simulation is a stochastic agent-based model, built using the NetLogo modeling environment, which represents the different areas passengers will visit, including check-in, restrooms, elevators, escalators, TSA, shuttles, concessions, gate, and baggage claim. The model creates individual agents which have specific behaviors to represent passengers. The agents are introduced into the simulation at an arrival rate based on Washington Dulles Airport historical flight data from the Bureau of Transportation Statistics. The initial population consists of healthy agents and contagious agents. The contagious have the capability to infect the healthy, either through airborne transmission or from surface contamination. Attributes of the disease can be controlled through the simulation, such as the radius in which a contagious individual may spread the disease, the chance of contracting the disease via airborne transmission, the chance of contracting the disease from surface contact, the prevalence rate of the disease in the airport population (how many contagious individuals are present), and the amount of viral load a healthy individual can tolerate before being considered infected.

8.2 Assumptions

Due to time constraints and limited computational resources, model assumptions are considered to best reflect reality within the simulation. General assumptions include basic simulation behavior, how data is transferred from one area to the next, how probability and spread of infection are implemented, and the limitations involved in simulating a complex system. Asymptomatic cases are not easily traceable in reality but are applied to the simulation by introducing a higher prevalence rate of the contagious population.

A main assumption for the general simulation behavior is that newly infected individuals are not yet contagious within the timespan of the model, thus they cannot infect other individuals. We assume the chance of becoming infected is based on the time spent near someone who is contagious and the amount of viral particles the contagious individual is able to spread within that time. Due to surface transmission being much lower, we have chosen $1.4 * 10^{-3}$ to represent the highest possible risk of infection (Pitol, 2021).

Other general assumptions are that the simulation resolution factors in time and distance. The NetLogo time unit, called a ‘tick’, accounts for one second within a 24-hour clock. Distance is accounted for in a similar manner, where a single unit of space in NetLogo, called a ‘patch’, is considered equivalent to 3 feet.

One of the main challenges of this model is that each area is an independent model, i.e. the areas do not all run continuously in one large model of an airport. However, it is desirable to have a connection between the areas in order to observe the trends of infections as passengers progress through the system. To capture this behavior without a way to directly transfer the exact population of healthy, newly infected, and contagious individuals between areas, we have created a data transfer method. The process of transferring the data involves several steps, which are described in detail in the full report. The general idea is to capture the mean populations of an area and their standard deviation between runs. It should also be noted that each simulation area represents a fraction of the total airport. For example, check-in represents only 1 out of the 60 total airline check-in areas available at Dulles.

9. Results and Analysis

9.1 Results Summary

The data collected from the simulation resulted in 48 design outcomes, which were based on three different design alternatives (low/med/high), with input parameters of throughput (25%, 50%, 75%, or 100%), prevalence rate (1% or 5%), and mask type (surgical or cloth). Outcomes are then measured against 2 base case outcomes, both at 100% throughput, one for each prevalence rate and not considering any mask protection or social distancing.

The base case found that nearly 50% of the total airport population would become infected by the end of the simulation. The primary risk areas were the gate during the boarding process and TSA. In the base case, the risk of becoming infected in the gate was 34.5% and in TSA 6.5%. When the low safety case universally applied cloth masks, the risk dropped to 10.6% for gate and 1.2% for TSA. With universal application of surgical masks, this dropped even further to 1.35% for gate and < 0.001% for TSA. As more defense layers were applied in the medium and high cases, these rates dropped even more. The highest risk of infection in the medium case was < 0.15%, and in high case < 0.05%.

The primary risk areas were found to be places that had queues with potential for high delays. These formed risks because they created situations where it was more difficult for passengers to keep physical distance, and there was more time spent near other passengers. Check-in, shuttle, baggage claim and aircraft were found to be secondary risk areas, which had a lower risk when compared to gate and TSA. The secondary risk areas were also more easily mitigated when defense layers were applied. The highest risk of these secondary areas (base case) was check-in at 1.9% risk of becoming infected.

9.2 Utility Function

The utility function (1) is composed of the single dimensional value functions for throughput and safety (2), which have a negative relationship. As the number of passengers increases, the chance of becoming infected grows. The base weight for throughput and safety are 35% and 65%, respectively.

$$U(\text{Alternative}) = w_t * v_t(x_t) + w_s * v_s(x_s) \quad (1)$$
$$v_t(x_t) = (x - 0) / (70000-0) \quad \text{and} \quad v_s(x_s) = 1 - e^{-P(x)/0.5} \quad (2)$$

The threshold for the target level of safety, at 10^{-4}, had 8 outcomes that satisfied MR.2, all from the high safety case. 10 other outcomes were within +0.06% coming from all safety cases. The threshold for the target level of detection for contagious passengers, set to greater than 50%, was satisfied by the high safety outcomes for MR.1.

9.3 Ranking

The best values for each safety level are ranked based on the lowest chance of getting infected and highest utility score, Table 1. The table is split from top to bottom by prevalence rate and left to right by inputs (orange header) and outputs (blue header). The values in bright green indicate the mission requirement being met and light red where they have failed.

Table 1. Utility Function Ranking Results

Ranking	Safety Level	Throughput	Masks Type	Prevalence Rate	Chance of Getting Infected	Contagious Removed	Utility	Cost (Millions)
1	High	100%	Surgical	1%	0.00%	87%	0.90	$17.9
2	Base	100%	No Mask	1%	9.44%	0%	0.89	$0
3	Medium	50%	Surgical	1%	0.03%	27%	0.73	$17.3
4	Low	25%	Surgical	1%	0.04%	0%	0.65	$16.9
1	High	100%	Surgical	5%	0.01%	84%	0.90	$17.9
2	Low	100%	Surgical	5%	1.92%	0%	0.90	$16.9
3	Base	100%	No Mask	5%	52.12%	0%	0.74	$0
4	Medium	50%	Surgical	5%	0.06%	31%	0.73	$17.3

9.4 Sensitivity Analysis

There are tradeoffs between the medium and low safety cases in contrast to the base case. When swinging the weight on safety to 45%, the medium case starts to have higher utility than the base case as the weight increases. When swinging the weight on safety to 85%, the low case starts to have a higher utility than the base case as the weight increases. At the base weight of 65% for safety, the medium and high case show higher utility than the base case.

9.5 Cost-Curve Analysis

The net present value, NPV, factors in the initial costs of the defensive layers and the annual recurring costs at a 3% monthly interest rate. The layers include costs for: PPE vending machines, employee PPE, social distancing markers, acrylic barriers, temperature scans, disinfecting, hand sanitizer, and the baggage claim queue system. The annual NPV for each design is shown in table 1.

At low prevalence (1%), there are 2 outcomes to consider: the high and medium safety cases with utilities of 0.73 and 0.90, annual costs (millions) of $17.9 and $17.3, and throughput of 100% and 50%, respectively.

At high prevalence (5%), the same outcomes can be considered from the low prevalence but now the low safety case comes in at a higher utility than medium with a utility of 0.90, annual cost (millions) of $16.9, and throughput of 100% with a difference of 1.86% for chance of infection.

9.6 Recommendation

Through our analysis, we recommend the high safety level design. Outcomes at this safety level most often met the target level of safety and the requirements for handling all levels of throughput while offering the highest detection of contagious passengers when compared to the other designs. There is a difference of 0.17 in utility and $600,000 of cost in contrast to the medium safety design. When considering the design choice, it is important for the stakeholder to assess safety and throughput as a multifactorial decision. Safety reflects the changes in prevalence rate due to demographics or the timeframe of the disease/outbreak, characteristics of the disease and epidemiology, as well as the type of masks passengers will wear as conducted in our simulation. Throughput is based on what the simulation can handle versus the allowable limit of passengers decided by the stakeholder. This is an ethical decision between choosing a robust system, with a low risk of infection at a high cost, or a cost-effective system, with a higher risk of infection at reduced costs.

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