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Analysis of Infectious Diseases Screening Systems for Transatlantic Air Passengers

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ANALYSIS OF INFECTIOUS DISEASES SCREENING SYSTEMS FOR TRANSATLANTIC AIR PASSENGERS

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ANALYSIS OF INFECTIOUS DISEASES SCREENING SYSTEMS FOR TRANSATLANTIC AIR PASSENGERS

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THESIS

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Declaration

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Abstract

Since transportation systems, especially air transportation, have the potential to spread infectious diseases (e.g. Ebola, SARS) quickly across large geographical area through its users, passenger health screening systems installed at the airports can help to slow down the international spread.

This thesis identifies and tests health screening system designs using discrete event simulation. The three objectives are: (1) to provide the necessary background regarding the diseases and screening technologies, (2) to create models of an air transportation network in a simulation software, and (3) to conduct simulation experiments, analyze and interpret the results including the formulation of recommendations for decision makers.

In the first part of the thesis, several infectious diseases are described, as well as the health screening methods and procedures. In the second part, four simulation models are developed. In the third part, the experimental results are presented and, based on them, several recommendations are provided.

The research showed that from the global perspective, exit screening in the affected countries is the most important measure in order to slow down the spread of an infectious disease. Adding another screenings (entry screening) at the receiving airports did not bring much improvement. From the perspective of the local design, a screening station should consist of four to six questionnaire evaluation stations and one non-contact infrared thermometer.

Keywords: pandemic disease, health screening, air transportation, airport, simulation

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Chapter 1: Introduction

We live in a globalized world where the time distances are shorter than ever before thanks to advanced transportation systems and technologies. Speaking of intercontinental journeys, air transportation plays the key role. What it took several weeks in the last century, now takes only several hours. People and organizations profit from the benefits of faster business exchange and travel every day.

However, as usual, besides the positives, there are also negatives. One of them is the fast spread of diseases. A disease which would remain only a local matter can be spread literally all over the world in a few days through the transportation network. This is not only a theoretical possibility. The world experienced several health threads during the last decades which began as a local outbreak.

This thesis deals with the question on how the spread of a dangerous infectious disease in an air transportation network can be slowed down. In other words, the main goal is to identify the optimum health screening system design by means of simulation experiment.

1.1 Thesis Objectives

This thesis has three objectives. The first one is to provide the necessary background information, namely to describe several diseases which became pandemic in the recent past and to review the equipment, methods, and procedures which are used at the airports to detect the diseases.

The second one is to create models of an air transportation network in a simulation software of which results should answer the question on what the optimum health screening system design is under certain assumptions and from different perspectives.

The third objective is to describe and analyze the simulation experiments' outputs, and based on them provide recommendations on the health screening system design for decision makers.

1.2 Thesis Outline

Chapter 1 is an introduction to the problem. It introduces the thesis objectives and outline.

Chapter 2 provides a review of several infectious diseases which spread into more than one continent in the last decades.

Chapter 3 focuses on the health screening devices and procedures. It also includes examples of the preventive measures from practice.

Chapter 4 describes the different scenarios used for the simulation including the models of an air transportation network, their parameters, and the simulation software itself.

Chapter 5 presents and analyzes the results obtained from the simulations and also compares the results of different scenarios.

Chapter 6 provides recommendations on the deployment and design of passengers' health screening stations.

Chapter 7 concludes the research presented in the thesis, summarizes its contributions and limitations, and suggests possible future research in this field.

Chapter 2: Review of Recent Pandemic and Epidemic Diseases

According to the World Health Organization (WHO) and its Department of Pandemic and Epidemic Diseases, there are many types of diseases which can widely spread: airborne diseases (such as influenza or respiratory syndromes), vector-borne diseases (yellow fever, Zika), water-borne diseases (cholera), rodent-borne (plague), hemorrhagic fevers (Ebola) and others (WHO 2016). This chapter describes four of them which were pandemic in the last decades and pose a risk even to developed countries.

2.1 Avian Influenza

Avian Influenza (AI), often called as “bird flu” or “avian flu”, is an infectious viral disease occurring mostly among birds and poultry. However, some of the AI viruses can also adapt to humans and can be transmitted from one person to another. There are two main subtypes of the virus which can infect humans: A(H5N1) and A(H7N9).

The A(H5N1) virus subtype is more dangerous than A(H7N9) because of its high pathogenicity. The first case of A(H5N1) human infection was reported in 1997 in Hong Kong, followed by another outbreak happened in 2003 and 2004. Since then, hundreds of human cases in Asia, Africa, and North America have been found. About one-half of all the cases have resulted in death. The most affected countries were Egypt, Indonesia, and Vietnam (WHO 2016). The map with all affected countries is presented below. Human-to-human transmission was registered only rarely.

The A(H7N9) virus subtype is low pathogenic and therefore relatively less dangerous. The first human cases were reported in China in 2013 and only one case outside of China has been detected ever since. The number of cases is like the A(H5N1) virus, but the death rate is lower. Human-to-human transmission occurred but also very rarely.

Both the AI subtypes (and also other viruses) are still circulating among poultry in different parts of the world, thus posing a potential danger to the human population. There is also a possibility that the viruses become more transferable among humans.

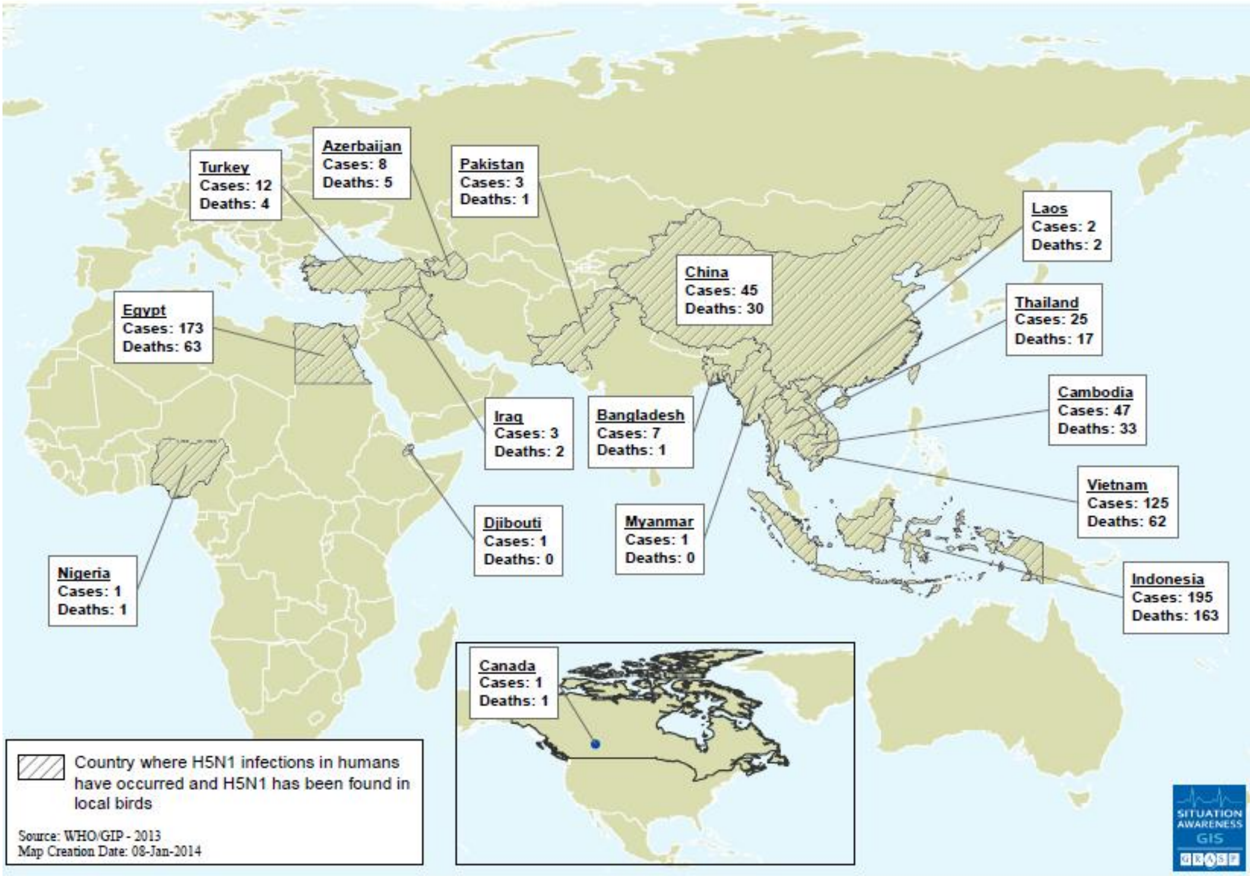

Figure 2.1: Avian Influenza (A(H5N1)) Outbreak (CDC 2014)

Transmission of AI viruses from birds to humans is done through direct contact with an infected animal, e.g. by touching the animal or contaminated surface and then touching person's mouth, nose or eyes, or simply by breathing the air containing the virus. Human-to-human transmission was reported only in case of long, close contact with a person with weakened immunity. The transmission has never become sustainable (ongoing) in a community.

The incubation period for AI is usually longer than for classic seasonal flu: it ranges from 2 to 8 days. WHO recommends potential patients be monitored for 7 days. The first symptoms are the same as for the normal flu: high fever (usually above 38°C), cough, sore throat, muscle aches, but also diarrhea, vomiting, and bleeding from the nose and gums. Later, shortness of

breath, difficulty breathing, pneumonia, acute respiratory distress, viral pneumonia, or respiratory failure may occur (CDC 2016).

Avian influenza cannot be diagnosed only by the symptoms themselves, laboratory testing is needed – using a swab from the nose or throat (CDC 2016).

2.2 Ebola

Ebola Virus Disease (EVD), also known as Ebola hemorrhagic fever, is a viral hemorrhagic fever caused by ebolaviruses, which is dangerous for humans and other primates (monkeys, gorillas, and chimpanzees). It can be transmitted from wild animal to human and also among the human population.

Ebola was first discovered in 1976 in Central Africa and since then, several outbreaks in Africa have been reported. The largest outbreak occurred in western Africa in 2014. The most affected countries are Guinea, Liberia, and Sierra Leone, single cases were detected in Nigeria, Senegal, Mali, Spain, and the U.S. (see the map below). The western Africa outbreak has been called a "Public Health Emergency of International Concern" by WHO.

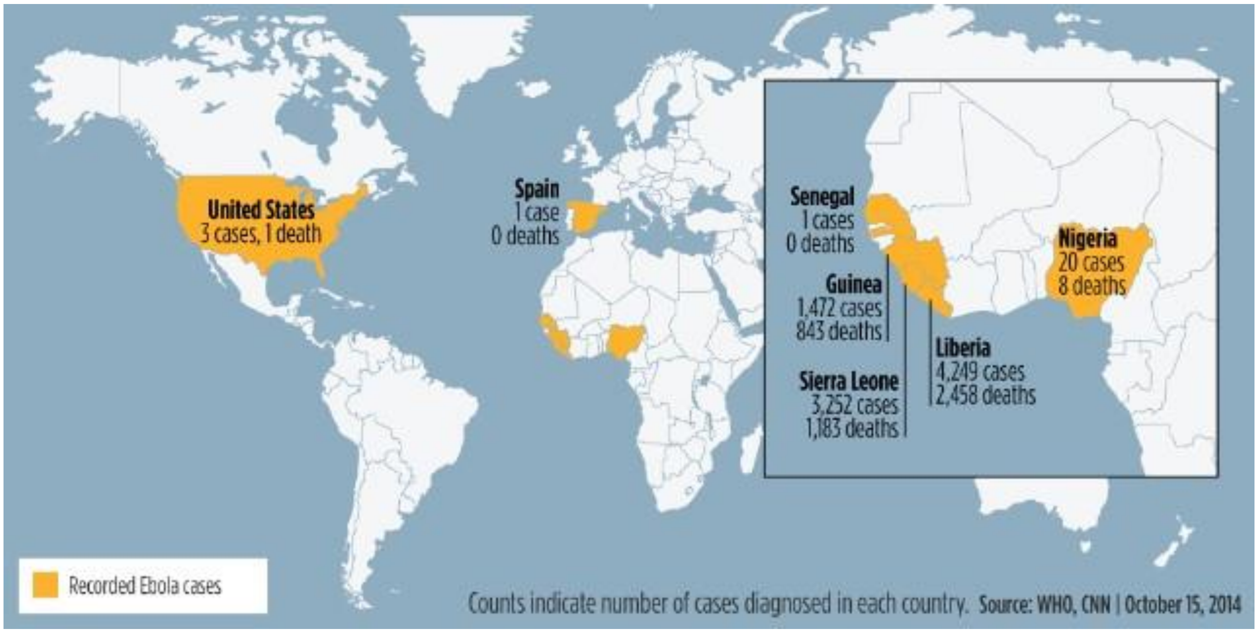

Figure 2.2: Ebola Outbreak in western Africa (CNN 2014)

A person can get infected with Ebola through close contact with bodily fluids of infected animals (chimpanzees, gorillas, fruit bats, monkeys, forest antelopes), but also through direct contact with infected people (human-to-human transmission). That includes a contact through broken skin or mucous membranes with bodily fluids or organs of an infected person or with surfaces and materials contaminated with these fluids. Sexual transmission is also possible, even from a person who has recovered from Ebola. Ebola does not spread through the air or by water.

The Ebola's incubation period lasts 2 to 21 days; the average is 8 to 10 days. The first symptoms include: fever (usually higher than 38.3°C (Hoenen et al. 2006)), fatigue, muscle pain, headache, and sore throat, subsequent signs are vomiting, diarrhea, rash, symptoms of impaired kidney and liver function, and occasionally both internal and external bleeding (WHO 2016).

Because the symptoms are common for a variety of diseases, laboratory tests (blood tests) are necessary to confirm the diagnosis of a suspected case.

2.3 MERS AND SARS

Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS) are both viral respiratory diseases caused by coronaviruses (MERS-CoV and SARS-CoV).

SARS was first detected in 2002 in Asia and there was a global outbreak the following year. The illness spread from Asia to Europe and Americas with more than 8,000 people infected. However, since 2004 there has not been any reported new case (CDC 2013). The most affected countries/territories in the 2003 outbreak were China, Hong Kong, Taiwan, Canada, and Singapore. See all the affected countries/territories on the map below.

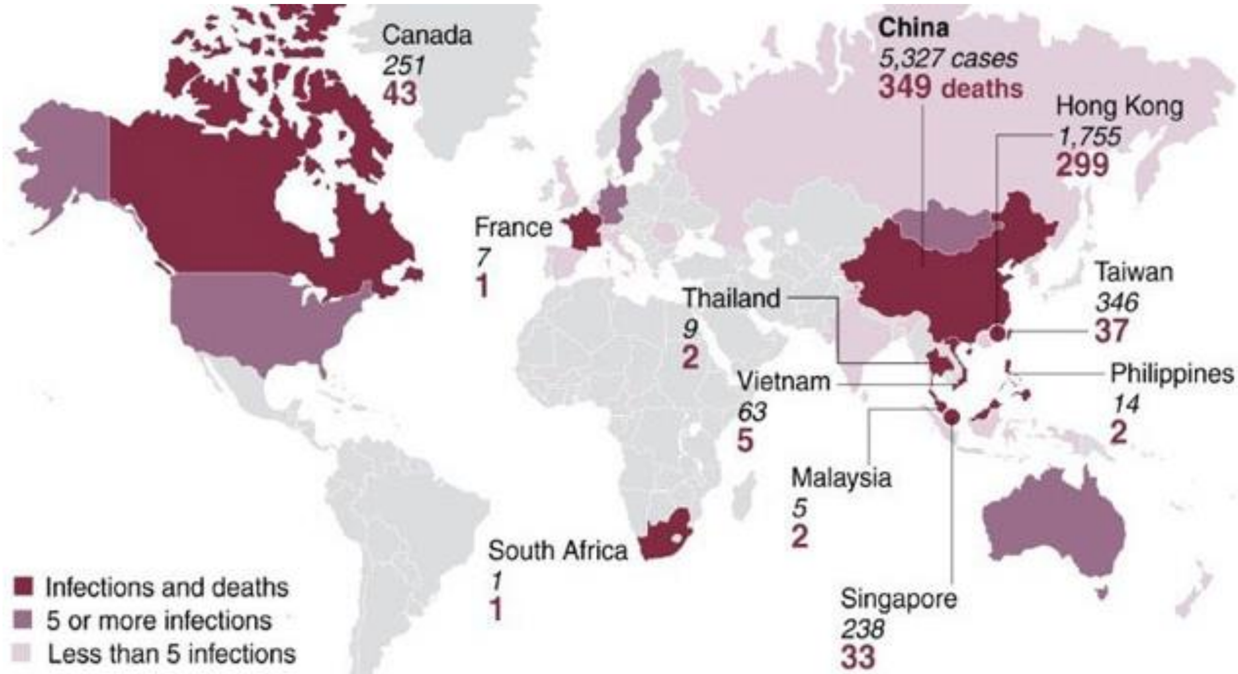

Figure 2.3: SARS Outbreak (TheNewsTribe 2003)

On the other hand, MERS is a more current issue. The first case was reported in 2012 in Saudi Arabia and since then the disease has spread to 27 countries in the Middle East, Africa, Asia and North America (WHO 2016). Most of the cases have happened in Saudi Arabia (> 85 %). The largest outbreak outside the Middle East has been in the Republic of Korea. See the following map for all the affected countries.

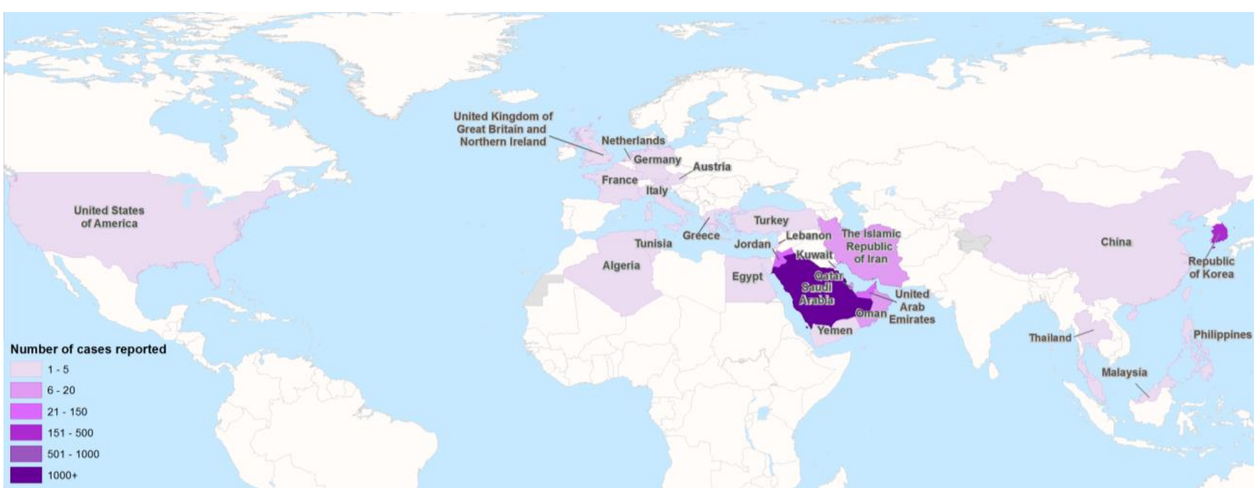

Figure 2.4: MERS Outbreak (WHO 2016)

SARS is spread by a close contact with an infected person. Such a contact includes living with or caring for an ill person, direct contact with his/her bodily fluids (especially with droplets produced when infected person coughs or sneezes), kissing or hugging, or talking with the person from fewer than 3 feet. MERS is spread in similar ways but less easily.

MERS is also transmitted to humans from animals. It is thought that the main animal reservoir of the virus are camels. However, the exact way of transmission has not been fully understood yet.

The incubation period of SARS is 2 to 7 days but it can be a few days longer. In the case of MERS, it is mostly 5 or 6 days. However, in some cases, it can be up to 14 days. After the incubation period, in both cases, the patient usually has high fever (more than 38°C), headache, diarrhea, feeling of discomfort, and body aches. Later, a dry cough and pneumonia may develop.

Again, laboratory tests are needed to set the diagnosis (using respiratory specimens, blood or stool).

2.4 Zika

Zika virus disease (ZVD), also known as "Zika fever" or simply "Zika", is caused by a mosquito-borne virus. The illness itself is not very dangerous. The patient's condition usually does not require a hospitalization and death caused by Zika is very rare. However, Zika virus can cause microcephaly and Guillain-Barré syndrome if a mother was infected during her pregnancy.

Zika was discovered in 1947 in Central-Eastern Africa in monkeys and in 1952 in humans in the same region. Since then, cases of ZVD have been reported in Africa, Americas, Asia, and Oceania. The first major outbreak occurred in Oceania in 2007, the most recent outbreak has taken place in the Americas with many countries and territories affected (mainly Brazil and Puerto Rico, see the Figure 2.5).

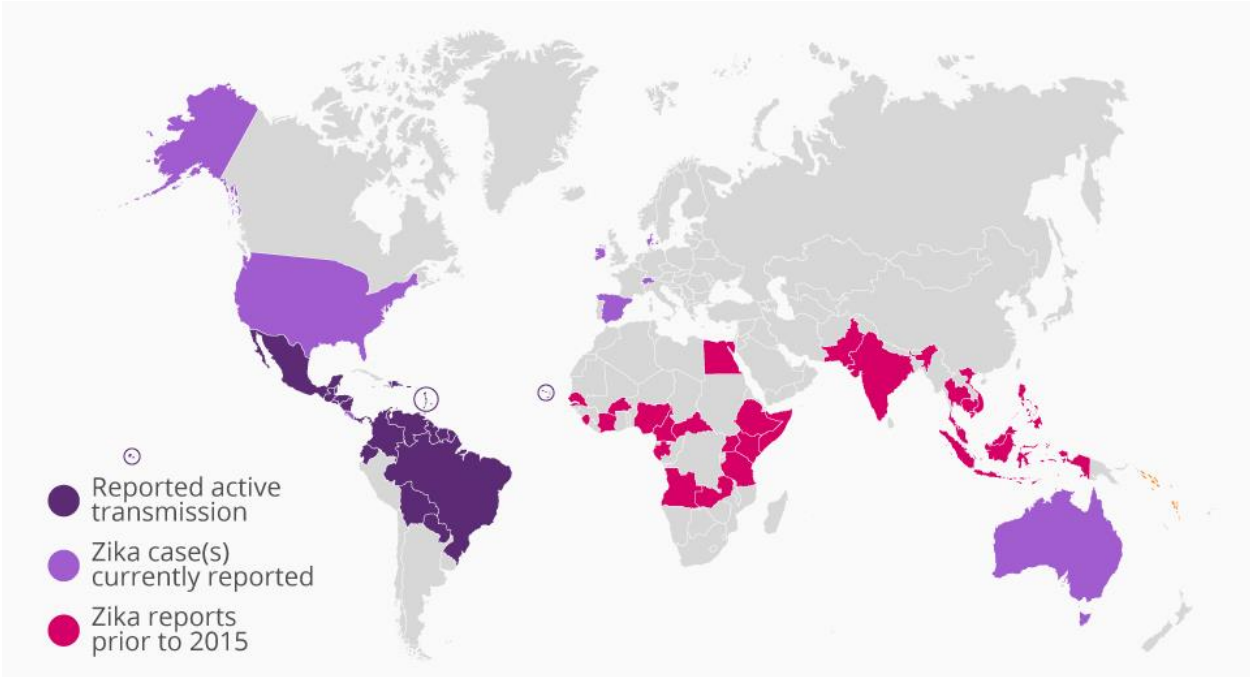

Figure 2.5: Zika Outbreak (Statista 2016)

There are several possibilities of the Zika virus' transmission. The primary way is through the bite of an infected mosquito. The other ways are human-to-human transmission: from a pregnant mother to her fetus, sexual transmission, or through blood transfusion.

After a few days of the incubation period (the exact duration is not clear but is most likely between 3 and 12 days), the following symptoms can emerge: fever, rash, joint pain, conjunctivitis (red eyes), muscle pain, headache. Nevertheless, most of the infected people remain asymptomatic (WHO 2016).

The symptoms are similar to other infections such as dengue fever and therefore, also in this case, laboratory tests of blood or urine are required for the diagnosis of the symptoms.

2.5 Summary

The above mentioned diseases have their specific characteristics. Some common characteristics can be observed, like fever or relatively non-probable human-to-human transmission.

The following table summarizes the most important information from this chapter.

Table 2.1: Key Indicators of Selected Diseases

Disease	Avian Influenza	Ebola	MERS and SARS	Zika
Incubation period	2 – 8 days	2 – 21 days	2 – 7 days	3 – 12 days
Early symptoms	Fever (> 38°C), cough, sore throat, muscle aches	Fever (> 38.3°C), fatigue, muscle pain, headache, sore throat	Fever (> 38°C), headache, body aches, dry cough, diarrhea	Mild fever, rash, joint pain, red eyes, muscle pain, headache
Human-to-human transmission	Rare; long, close contact, weakened immunity	Direct contact with bodily fluids	Close contact, droplets in the air	Pregnant mother to her fetus, sexual, blood transfusion
No of cases worldwide (cumulative)	A(H5N1): 854 (WHO 2016)	2014 – 2016: 28,652 (CDC 2016)	MERS: 1,800 SARS: 8,096 (WHO 2016)	2015 – 2016, Americas: 119,530 (WHO 2016)
Death rate	A(H5N1): 53 % (WHO 2016)	40 % (CDC 2016)	MERS: 36 % SARS: 10 % (WHO 2016)	0 % (WHO 2016)

Chapter 3: Health Screening Methods and Procedures in Air Transportation

The health and airport authorities have several options on how to screen and detect passengers suspected of having a communicable disease to slow down the spread of the pandemic (if not to stop the spread completely).

There is no standard guideline for health screening at airports (Gaber et al. 2009). This means that the measures to implement health screening of air travelers lie within the local authority. Nevertheless, WHO issued a legally binding document for all its members (almost all states in the world) called International Health Regulations (IHR) in 2005 which sets some basic principles regarding the prevention of an international spread of diseases. One of the main principles is to react to possible public health threat adequately and with as little impact on international travel and trade as possible (WHO 2005). There is also an instrument called "Public Health Emergency of International Concern" which is announced by WHO in case a local outbreak can become a global threat, which binds the affected countries to conduct an exit screening at airports.

There are also some guidelines issued by the International Civil Aviation Organization (ICAO), International Air Transport Association (IATA), Airports Council International (ACI), and other organizations providing certain recommendations for airports or airlines, e.g. "Guidelines For States Concerning The Management Of Communicable Disease Posing A Serious Public Health Risk" (ICAO) or the "Medical Manual" (IATA 2017).

This chapter summarizes the currently known and used means and procedures in health screening of air travelers.

3.1 HEALTH SCREENING METHODS

3.1.1 Visual Inspection

Probably the least sophisticated form of screening is the visual observation of passengers by non-medical personnel. This method uses the current aviation industry employees and

therefore it can be easily implemented and requires no additional costs. Only short training needs to be provided to the airport and airlines personnel who are in direct contact with passengers (most typically check-in agents and cabin crew, or security officers).

They are tasked to notice travelers with visible symptoms of a specific disease such as cough, sneezing, sweat caused by fever, or even more serious ones. They can hand the suspicious passenger over to further medical examination.

On the other hand, detection of ill travelers is not part of their job description and only symptomatic passengers can be detected this way.

3.1.2 Questionnaires and Passenger Locator Forms

Another tool of passenger health screening are questionnaires, passenger locator forms (or cards), or another form of mandatory self-reporting documents. There are three main purposes of such a questionnaire: (i) to ascertain if there was any travel in or near an affected area (an area with a significant incidence of disease) or any possible contact with a carrier of the disease (e. g. poultry, mosquitos); (ii) to detect a symptomatic passenger; and (iii) to be able to contact the passenger in his/her destination if necessary.

The survey may be conducted in different phases of a journey, e.g. before the travel (during check-in or before boarding the aircraft) or during the travel (on board the aircraft) and it may be repeated at different times of the same journey if circumstances require so.

The importance of self-reported information is mainly given by the fact that many travelers may not have symptoms before and during their journeys or they can remain asymptomatic completely.

This method, of course, has its disadvantages. Probably the biggest one is the unwillingness of travelers to provide any kind of information which could lead to delay or even cancellation of the travel. Gostic et al. (2015) assume that a maximum of 25% of potentially infected passengers fills in the form truthfully. The other disadvantage can be insufficient intelligibility of the questionnaire including missing language versions. In some cases, it also can

be difficult for the authorities to know what to ask for (e.g. in the case of MERS-CoV the way of transmission from animals to humans is not quite clear so one does not know if a contact with camels can pose a threat or not). Processing of the data fast enough (e.g. before the plane lands) may be challenging.

3.1.3 Thermal Scanning

The contribution of body temperature scanning in the process of detecting infected passengers is still not clear. Various studies have contradictory conclusions (Shu et al. 2005; Priest et al. 2011). As can be seen from Table 2.1, the common symptom of the majority of the infectious diseases is fever and therefore, thermal scanning methods shall not be ruled out.

The average body temperature of a healthy individual lies in the interval from 97.7°F (36.5°C) to 98.6°F (37.5°C), while fever is a temperature above the normal range.

There are two basic groups of thermal scanning tools: contact and non-contact, which are represented by following devices used at the airports: Non-Contact Infrared (forehead) Thermometers (NCIT), Non-Contact Infrared Thermal Cameras (NCITC; also called thermographic camera or thermal imaging camera), and ear (tympanic) infrared thermometers. Infrared thermometers calculate the temperature based on the thermal radiation emitted by the object and its emissivity. Individual instruments are described in more details below.

Since fever is only one of the symptoms, which in many cases may not be present in a patient, or the fever may not have started yet, the detection of infectious diseases by the use of thermometers is considerably limited. Also, other factors can reduce its effectiveness even more. Without speaking of a device’s accuracy and human errors, these factors can be: using antipyretics (medicine reducing the fever) before scanning, and ambient conditions (temperature and humidity). Furthermore, a person considered as febrile may be in fact sunburnt, or he or she just came in a hurry, with heavy luggage etc.

Thermal scanning can be placed in various parts of the airport or even on board the aircraft. In most of the airports that have implemented this type of device for screening, the measurement stations are located before immigration counters in the arrival hall.

3.1.3.1 Non-Contact Infrared Thermometers

Non-contact infrared thermometers are the typical devices used for airport screening (Gostic et al. 2015). Measurement using NCIT requires a worker who holds the device between 1.2 to 6 inches (3 to 15 cm) from the body, usually pointed to the middle of passenger's forehead (see the figure below). Only an easy training for the screening staff is needed and no complicated calibration of the device is required (CDC 2014).

Figure 3.1: Non-Contact Infrared Thermometer (BBC 2014)

The accuracy of NCIT can be up to ±1.0°C (Fluke 2016) and the detection rate of febrile patients (sensitivity) varies from 80% to 99% (CDC 2014).

The advantages of NCIT include no direct contact (however the passengers are relatively close to the operator), sufficient accuracy, easy handling, no need of frequent recalibration of the device, and low initial costs. On the other hand, the screening process is relatively slow and therefore, more devices are needed to scan large numbers of travelers.

3.1.3.2 Non-Contact Infrared Thermal Cameras

Non-Contact Infrared Thermal Cameras collect thermal images in the form of a two-dimensional digital picture using the same principle as NCIT. The camera can record one or several passengers simultaneously from a larger distance (see the figure below). To ensure a proper function of the camera, a trained staff should prepare the camera for the measurement. The rules to follow are: no hot objects are allowed in in the field of view, the camera should run at least 30 minutes before the measurement, calibration using an ear thermometer should be done (FLIR Systems n. d.). NCITC are not approved as medical equipment and therefore they have to be used together with some approved thermometer to confirm or rejects the measurement results (CDC 2014).

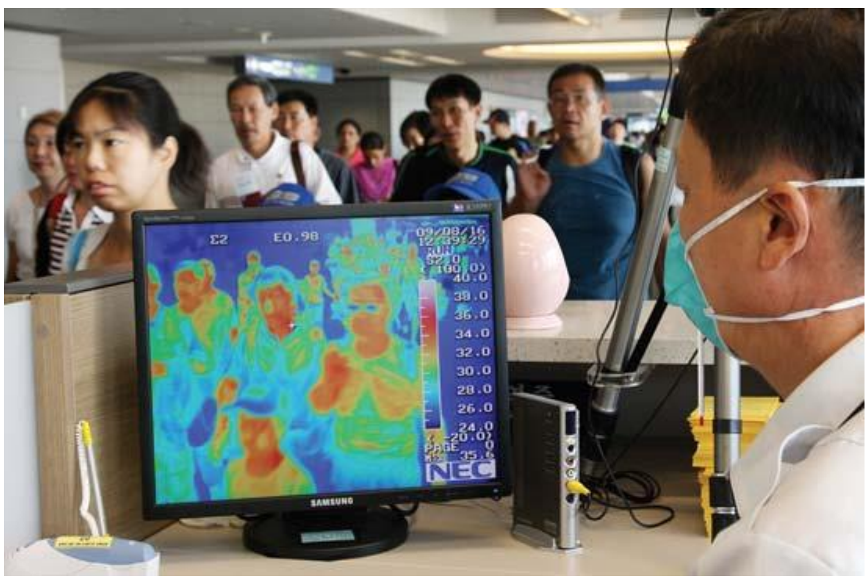

Figure 3.2: Non-Contact Infrared Thermal Camera (Quartz Media 2015)

The temperature readings accuracy of NCITC is ±2.0°C. Nevertheless, the accuracy is not crucial in this application. Some manufacturers provide their cameras with software which constantly calculates a moving average from the last 10 scanned passengers' temperature and marks only those whose temperature exceeds a given deviation. Automatic alarm reduces the workload of operating personnel (FLIR Systems n. d.). According to Nguyen et al. (2010), the sensitivity varies from 80 to 91% (it would be probably lower in real conditions).

The major advantages of NCITC are high capacity of screening and absolutely no contact with the passengers. On the other hand, the precision is lower, frequent calibration is needed, initial costs are the highest, and secondary measurement is necessary to confirm the suspected case.

3.1.3.3 Ear Infrared Thermometers

Ear infrared (IR) thermometers are usually used for a secondary measurement. It is the only contact device which is in use in thermal scanning at airports. The scanning technology is the same as at the non-contact instruments. However, in this case, the thermometer is placed in the ear. Thus, the temperature is measured at the eardrum and surroundings which is an area of the human body which should well reflect the actual core body temperature (Braun 2016), instead of the skin temperature measured by non-contact tools.

Their biggest advantage of ear infrared thermometers is their accuracy. Tympanic infrared thermometers are similarly accurate as rectal thermometers (Amoateng-Adjepong et al. 1999), the latter is commonly considered as the most accurate. They are also easy to use and give result relatively quickly. Their acquisition costs are not high; they are similar or cheaper than forehead thermometers.

An obvious disadvantage of ear infrared thermometers is a need for changing or disinfecting the probe of the device in order to prevent cross-contamination. Furthermore, the measured result may be affected by the presence of impurities or inflammation in the ear.

3.1.4 Medical Examination

In the case of detecting a passenger with an elevated temperature by a primary non-contact detection tool (which may need to be confirmed by secondary contact measurement) or detecting a potentially infected person based on the questionnaires, the passenger should undergo a medical examination. This is the first time in the process of screening when medical personnel is needed to decide whether the traveler can continue his or her journey or not.

In this case, a physician examines the suspected passenger based on the nature of the pandemic disease and if there are any doubts about the passenger's health, further travel is prevented and the patient is sent for further examination, e.g. samples for laboratory testing should be taken.

3.1.5 Summary of Detection Methods

There are several methods on how to screen and detect passengers who potentially became infected by a dangerous infectious disease. These methods range from the least sophisticated one (visual inspection) up to the medical examination and laboratory testing. Since it is not possible to provide medical examination to all the passengers, questionnaires and thermal scanning are the most commonly used tools in practice. It is clear that these instruments cannot detect all the infected individuals because they have considerable limitations.

The main features of each method (device) are summarized in the table below.

Table 3.1: Comparison of Different Methods of Health Screening

Method	Advantages	Disadvantages	Costs	Sensitivity
Visual Inspection	Easy to implement	Not a separate tool	None	n/a
Questionnaires	Able to detect non-febrile passengers	Limited willing-ness to self-report	Low	≤ 25 %
NCIT	No direct contact, easy to use	Slowness => more personnel needed	Moderate (low on equipment, high on personnel)	80 – 99%
NCITC	No direct contact, high throughput	Calibration needed, lower precision	High initial, low operational	80 – 91% or less
Ear IR Thermometers	High precision	Direct contact	Low	> 90%
Medical Examination	Qualified judgement	Slowness	High (personnel, testing)	n/a

3.2 Health Screening Procedures

As stated before in this chapter, there is no standardized health screening procedure (a sequence of health screening methods) for air transportation passengers. An example of such a procedure is represented in the flow chart below. This example can be applied to both departing and arriving passengers. Not all the screening methods/devices from the previous section of this chapter must be present. In addition, the order of screening may vary (e.g. in the case of arrival screening, the questionnaire is probably distributed on board the aircraft, i.e. before reaching the destination airport). Visual inspection is not present in the diagram since it is not a separate tool itself but a part of other on-going activities.

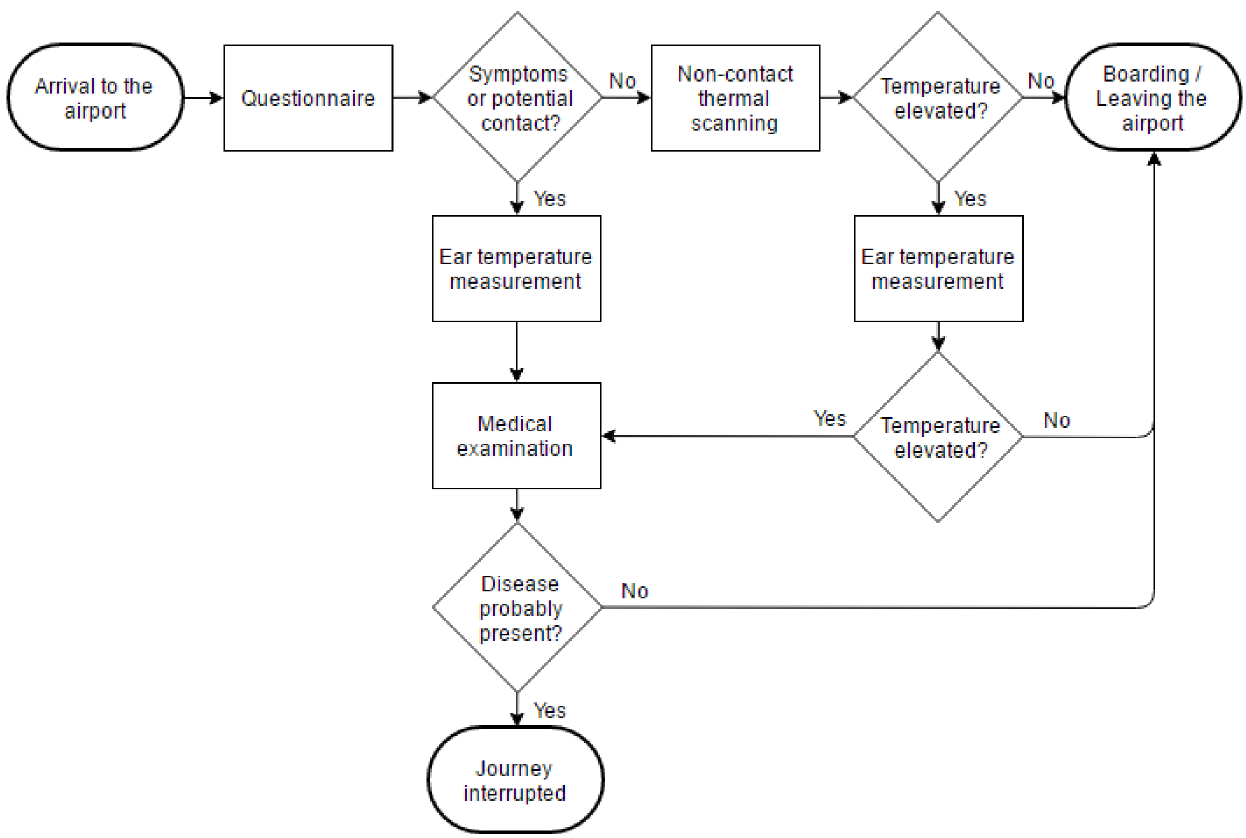

Figure 3.3: Example of Health Scanning Procedure

3.2.1 Examples from Practice

The most affected countries by the outbreak of Ebola virus (Guinea, Liberia, Sierra Leone) have established an exit screening procedure according to WHO recommendations. The

screening procedure consisted of a questionnaire and a temperature measurement, following by medical examination in case of any doubt about a passenger's health.

On the other side of the Atlantic Ocean, in the United States (U.S.), the Centers for Disease Control and Prevention (CDC) and U.S. Customs and Border Protection (CBP) introduced an enhanced entry screening procedure at five international airports which were estimated to handle 94% passengers arriving from the Ebola-affected countries. The enhanced screening procedure included questionnaire (symptoms, potential exposure risk, contact), non-contact temperature measurement and visual observation by CBP officers. If any of the methods identify a possible presence of the disease, the passenger is sent to CDC public health officers situated at the airport for further examination (Brown et al. 2014).

In the Republic of Korea, arriving passengers from quarantinable countries (determined by the Korean Minister of Health and Welfare) were scanned by NCITC and must submit a health questionnaire. The temperature of those with some self-reported symptoms or with elevated temperature was measured once again using an ear infrared thermometer. Travelers with a temperature above 37.8°C must undergo a medical examination. Laboratory testing was conducted on final suspected cases (Cho and Yoon 2014).

A very similar procedure was being used in Taiwan to prevent the spreading of SARS in 2003 and 2004. During the SARS pandemic, the temperature of both incoming and outgoing passengers was measured. The measurement was taken by NCITC with a secondary check by ear infrared thermometer (if the primary temperature screening found an elevated temperature). In addition, each passenger had to fill in a "SARS Survey Form". The procedure has been used to screen dengue fever as well since 2003 (Shu et al. 2005).

3.2.2 The Frankfurt Model

In respond to SARS and other pandemics of the last decades and non-existing standards for health screening, Gaber et al. (2009) proposed a framework for the whole screening procedure, called "The Frankfurt Model", based on the experience in pandemic management at

the Frankfurt International Airport in Germany. The model suggests both exit and entry screening.

3.2.2.1 Exit Screening

According to the IHR (WHO 2005), exit screening must be established in the affected country. Gaber et al. (2009) proposed the screening to be limited to international flights. First of all, the passenger tickets are (pre)checked at the terminal entrance and only passengers with a valid ticket can enter the terminal. “Meeters” and “greeters” are not allowed to walk in, so that the exposure of people within the terminal is reduced.

The passengers proceed immediately to health screening where they either obtain an official stamp which enables them to continue to the check-in or security counter or their journey is interrupted. The proper screening method should be selected considering the characteristics of the disease. The advantage of this procedure is that passengers do not check in their baggage before they are cleared to continue.

3.2.2.2 Entry Screening

Entry screening measures are applicable only to flights arriving from the affected areas. First of all, all passengers have to fill in mandatory passenger cards. This can be done in a paper form on board the aircraft or electronically before the travel begins.

Secondly, the health screening measures should be done on board the aircraft after landing but before the passengers leave the cabin to make the identification of possible infected passengers easier. (There are records of passengers’ seating, however, some passengers may change their seat during the flight so they would become unfindable.) Gaber et al. (2009) suggest using NCIT or ear infrared thermometers to detect febrile passengers.

If there is a passenger suspected of having the pandemic disease (either as a result of temperature measurement, crew observation or self-reporting), he or she is labeled by red color and is transferred properly to the nearest medical facility. Close contacts, which are family members, other co-travelers, passengers sitting within a range of 6 ft., and crew members who

served the specific section of the cabin, are labeled by yellow color and are transferred by designated airport bus to medical examination at the airport. The further procedure depends on the characteristics of the disease. Other passengers are labeled by green color which means that they can continue their journeys and obtain paper information about the disease.

The following flow chart illustrates the Frankfurt Model. Some details can vary per the specific disease.

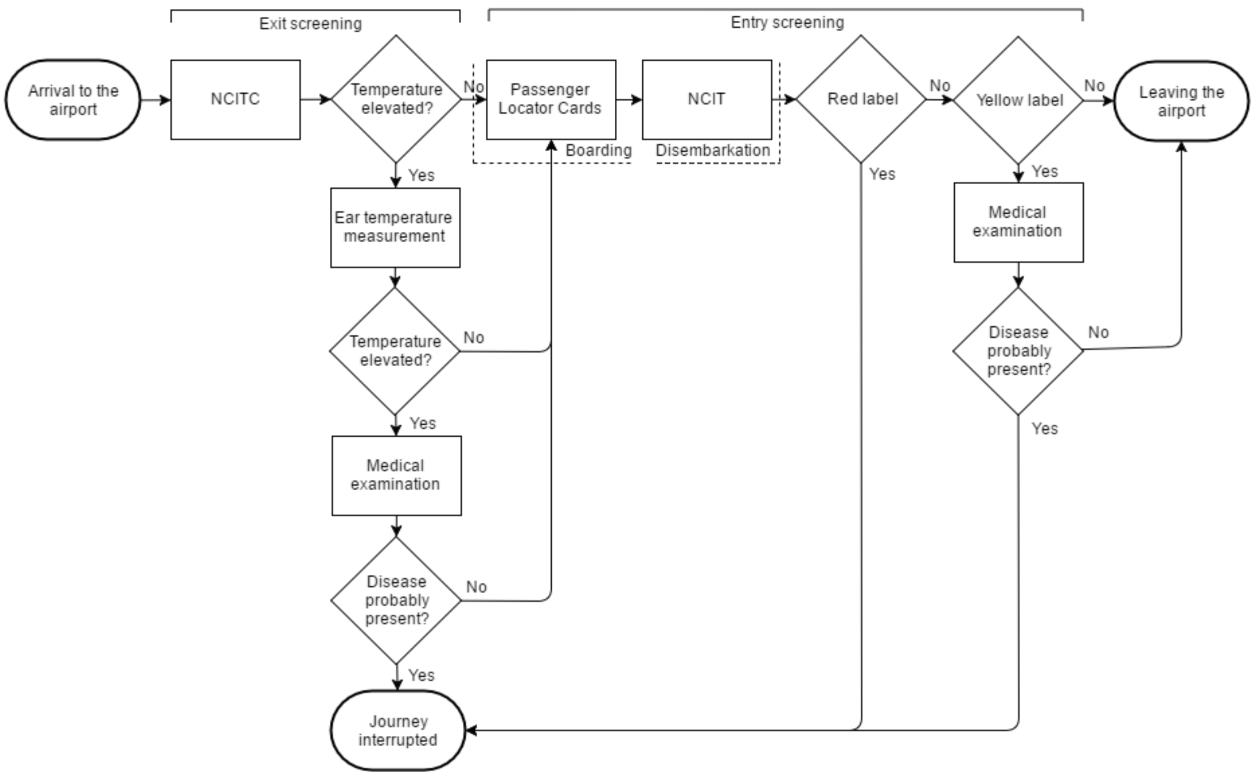

Figure 3.4: The Frankfurt Model

3.2.3 Summary of Procedures

Although there is no standard procedure internationally, most of the countries rely on a combination of self-reporting questionnaire and non-contact thermal scanning, followed by ear temperature measurement and medical examination. Exit screening shall be installed in affected countries as the primary protection while entry screening may be established in ports of entry receiving flights from affected countries as a secondary detection measure. This practice is taken into consideration by the Frankfurt Model.

Chapter 4: Simulation Settings

Based on the recent outbreak of Ebola and relating to the fact that this thesis is a part of the Transatlantic Dual Master's Degree Program, the following outbreak episode was assumed: An outbreak of an infectious disease similar to Ebola is being observed in western Africa (specifically in Guinea, Liberia, and Sierra Leone). The subject of inquiry will be flights from this region to the U.S. and Europe including the passengers from western Africa who transfer in Europe on their way to the U.S.

4.1 Simulation Scenarios

The simulation has five scenarios. Four of them represent global interpretations of the screening procedures. The scenarios are differentiated by the presence of an exit and entry screening at each continent/region (western Africa, Europe, and U.S.). The aim is to determine which scenario is the most effective in terms of detecting passengers with the dangerous infectious disease. The fifth scenario represents microscopic operations of a "screening station" which should help to design the number of screening devices (and personnel) needed at a specific airport.

Due to limited resources, the simulation models do not include manual observation and any secondary inspection in case a suspected passenger was detected. If this happens, the passenger's journey in the systems ends as "interrupted".

4.1.1 Global Scenarios

4.1.1.1 Scenario 0: Do Nothing

Scenario 0 is the do-nothing scenario where no screening at all is conducted. In other words, all the passengers are allowed to travel and to reach their destination as the following flowchart shows. This may represent a situation at the very beginning of the disease's outbreak. Note that the direct line in Figure 4.1 between a western African and an American airport does not mean a direct flight but any flight which does not involve a transit stop at a European airport.

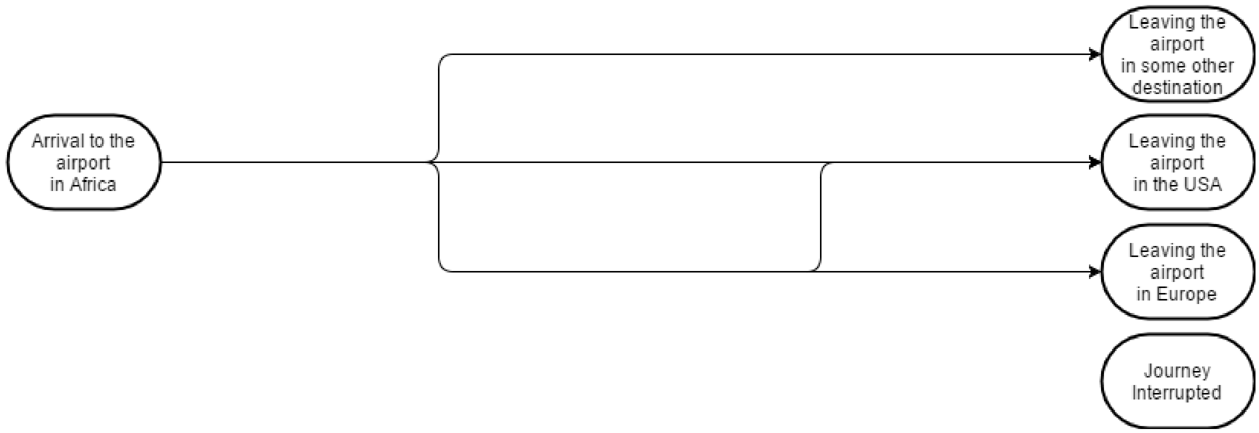

Figure 4.1: Scenario 0 Flowchart

4.1.1.2 Scenario 1: Exit Screening

Scenario 1 is based on the common practice during the early stage of the 2013-2016 Ebola outbreak. In this case, WHO has already activated the Public Health Emergency of International Concern (PHEIC). This means exit screenings at the airports in affected western African countries are required. The screenings are conducted using a questionnaire about symptoms, potential exposure risk, and destination of the journey, and using infrared non-contact thermometers to scan passengers' temperature. In this scenario, there is no entry screening in other countries.

The deployment of screening measures in the second scenario is illustrated by the flowchart below.

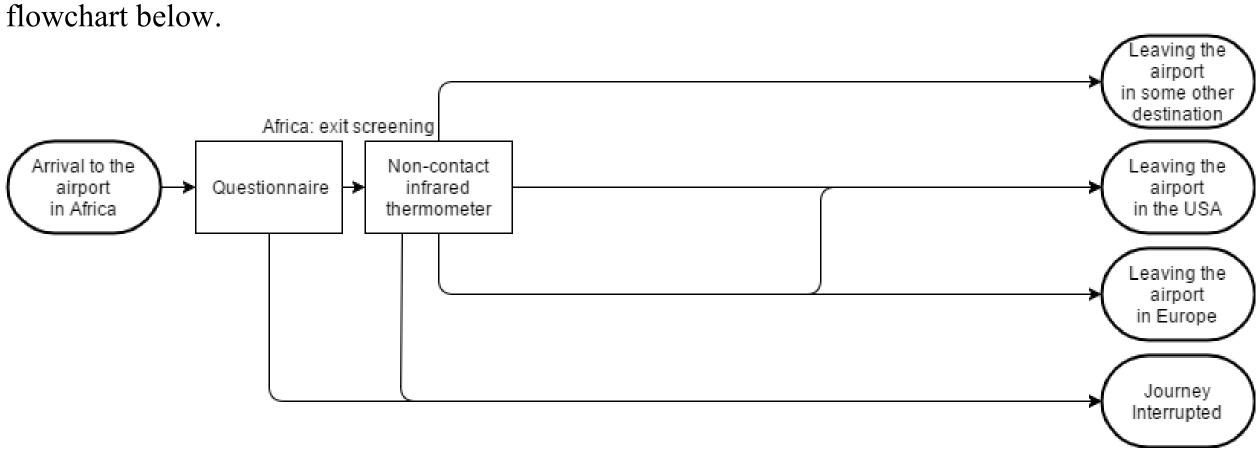

Figure 4.2: Scenario 1 Flowchart

4.1.1.3 Scenario 2: Exit-Entry Screening

Scenario 2 represents another common practice but in a subsequent phase of the outbreak when the U.S. decided to introduce entry screening with the same screening measures as in western Africa (Brown et al. 2014). The "screening team" also observes the passengers for symptoms, however, this is not modeled.

There is no screening at the European airports. European countries reacted to the Ebola threat differently. Most of the countries decided not to conduct any entry screening following the statement of the European Commission which stated that there was no need to check the incoming passengers from western Africa (Croft and Guarascio 2014). Such a situation is modeled in this scenario.

Nevertheless, France and the United Kingdom (U.K.) introduced entry screening at Paris' Charles de Gaulle airport and London's Heathrow and Gatwick airports respectively. In France, the screening team used non-contact thermometers before passengers arriving from Guinea left the air bridge to enter the terminal. In the U.K., the authority distributed a questionnaire to passengers from Liberia, Sierra Leone, and Guinea and medical staff checked some travelers' body temperature and observed the symptoms.

Scenario 2 is represented by the flowchart below.

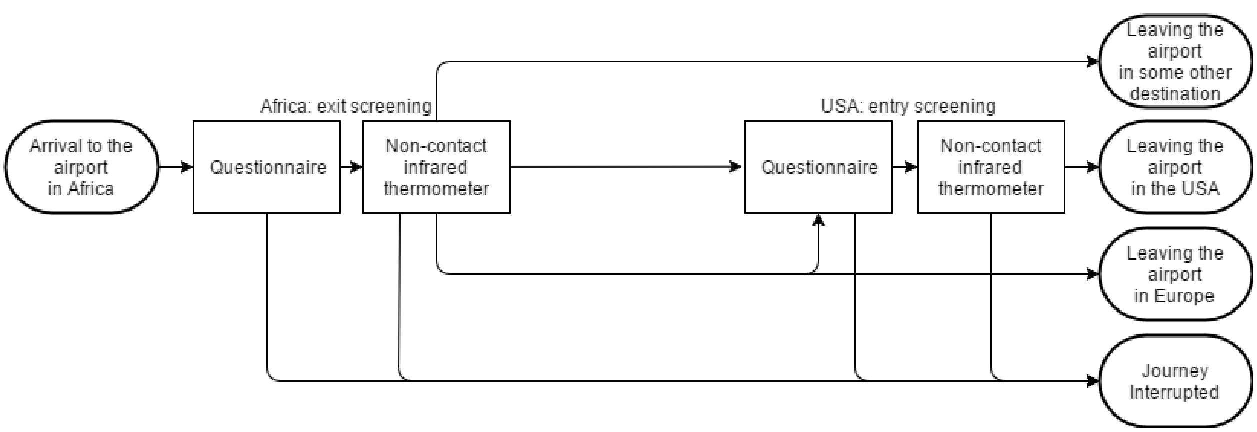

Figure 4.3: Scenario 2 Flowchart

4.1.1.4 Scenario 3: Exit-Entry-Entry Screening

Scenario 3 is hypothetical. It adds an entry screening at the European site to Scenario 2. The author decided to use the same screening measures as in western Africa and the U.S. for the European screening procedure. The flowchart of this scenario can be seen below.

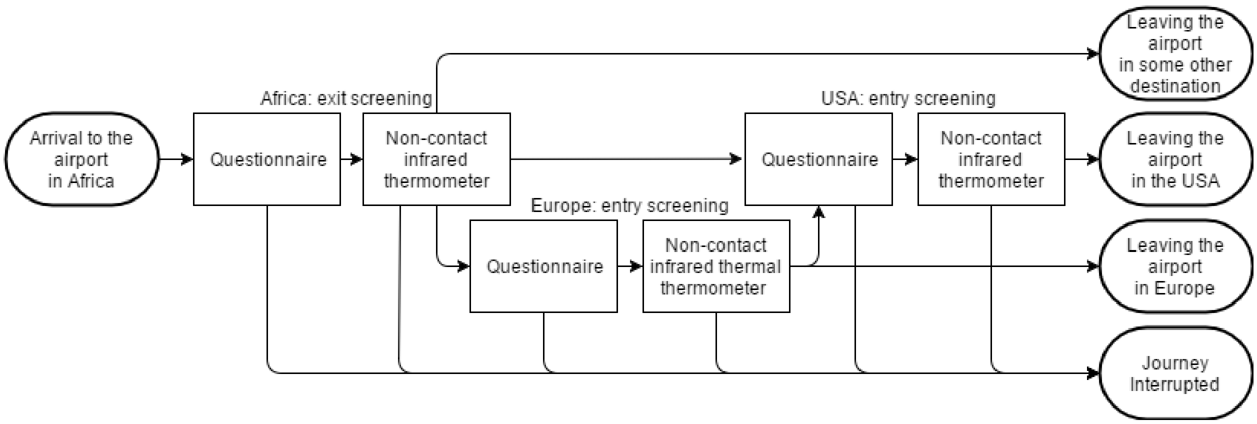

Figure 4.4: Scenario 3 Flowchart

4.1.2 Scenario 4: Local Station Design Scenario

Scenario 4 is focused on a local design of an entry screening "station" which uses questionnaires and non-contact infrared thermometers. The aim of this scenario is to analyze the trade-off between the time spent by passengers at the screening station and the number of devices (which is directly related to the number of staff and hence staff and equipment cost).

Since there is no direct (non-stop) flight from the affected countries (Guinea, Liberia, and Sierra Leone) to the U.S., but there are a few direct flights to Europe, a European airport was selected as the test site for the screening station design. Further details are described in the next section. The visual representation of this scenario can be seen in the flowchart below.

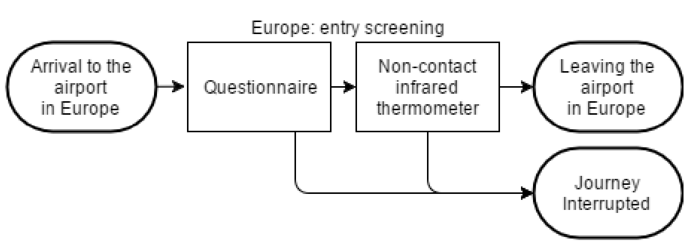

Figure 4.5: Scenario 4 Flowchart

4.2 PARAMETERS

This section describes all the parameters used in the simulation experiments.

4.2.1 Duration of the Outbreak

This parameter, similarly to the others, is based on the Ebola outbreak which occurred between December 2013 and June 2016. The exact number of days was determined according to the duration of PHEIC which made the exit passenger health screening in the affected countries compulsory. The PHEIC was declared by WHO on August 8, 2014 (WHO 2014) and terminated on March 29, 2016 (WHO 2016) which was exactly 600 days.

4.2.2 Passengers

There are three groups of passenger parameters: number of passengers and their flows (travel paths), passengers' categories (health status), and prevalence of diseases and fever among those categories.

4.2.2.1 Number of Passengers and Their Flows

The number of passengers traveling from the affected countries was calculated based on a report issued by CDC (2014). The report said that from August until October 2014, approximately 80,000 passengers used air transportation to travel from the affected countries. It means that there were approximately 870 departing passengers per day. According to the report, 12,000 out of the 80,000 departing passengers were heading to the U.S. during the reported period which is 15% of all departing passengers.

Because of the lack of publicly accessible passenger flow database, one can only assume the percentage distribution to other destinations (with the help of flight frequencies and seat capacities found at airlines websites). For the simulation experiment, the following values were used: Among the passengers who departed from western African airports, 35% went to Europe, 15% went to the U.S., and the remaining 50% had other countries as the final destinations. From those 15% travelers heading from Africa to the U.S., 50% flew via Europe and 50% via some other destination (e.g. via Casablanca, Dakar, or Lagos) because there is no direct flight.

Table 4.1: Number of Passengers, Their Paths, and Destinations

<table>
<tr><th colspan="2">Parameter</th><th colspan="2">Value</th></tr>
<tr><td colspan="2">Passengers daily</td><td colspan="2">870</td></tr>
<tr><td rowspan="2">Destination U.S.</td><td>Flying via Europe</td><td rowspan="2">15%</td><td>7.5%</td></tr>
<tr><td>Flying some other way</td><td>7.5%</td></tr>
<tr><td colspan="2">Destination Europe</td><td colspan="2">35%</td></tr>
<tr><td colspan="2">Other destination</td><td colspan="2">50%</td></tr>
</table>

For the fourth scenario (local station design), the arrival rate was set based on the capacity of the largest plane which operates the direct flights from western Africa to Europe. Such a plane is currently Airbus A330-300 operated by Brussels Airlines with the capacity of 288 passengers. Another assumption is that the plane will be disembarked in 20 minutes after the doors were opened giving an arrival rate of 14.4 passengers per minute at screening stations.

4.2.2.2 Passenger Categories

For the purpose of the simulation experiments, five categories of passengers were created. Firstly, all the passengers were divided into two groups: sick (marked as S) and "non-sick" (marked as S'), i.e. healthy. Then, sick passengers were divided again into two groups: those who actually have the dangerous infectious disease (denoted as SE) and those who were sick with some other disease which did not pose a serious risk to the healthy population, e.g. running nose, cough, seasonal flu etc. (denoted as SE'). Finally, each of these groups were divided based on the presence of fever: the letter F indicates fever (SEF, SE'F), the letter F with apostrophe indicates no fever (SEF', SE'F').

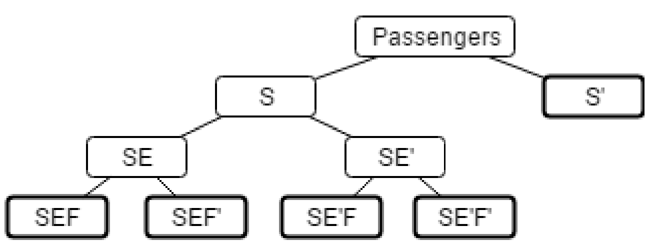

Figure 4.5: Passengers Categories

4.2.2.3 Prevalence of the Disease and Fever

Next, the prevalence of the disease in the population was determined. Based on the data by WHO (2016), there were 28,610 cases of Ebola in those three affected countries between 2013 and 2016. The total population of these countries was 23,207,613 (CIA 2017). This gives the prevalence of 0.123% (prevalence of SE). It is assumed that the same prevalence occurs among air travelers. Furthermore, 87% of infected passengers (category SE) had a fever (Gostic et al. 2015) which gives the prevalence of 0.107% for SEF and 0.016% for SEF’.

In addition, different rates of febrile passengers (those who are in the SE’F category) were investigated as well since the presence of fever should trigger an alarm. The different percentage of febrile passengers creates three subscenarios for each global design scenario. The other investigated percentage of febrile passengers (SEF) among SE passengers was set to 50% and 13% – refer the table below to see the probabilities.

Prevalence of any other disease (SE’) was set to 1% out of which 95% do not have a fever (0.95% for SE’F’) and 5% do (0.05% for SE’F). The rest of 98.877% are healthy passengers (S’).

The following table gives an overview of the prevalence parameters.

Table 4.2: Prevalence of Different Passenger Categories in Population

Percentage of SEF among SE (Subscenarios)			13%	50%	87%
Passenger Category			Prevalence in Population (in %)		
S	SE	SEF	0.016	0.062	0.107
		SEF’	0.107	0.062	0.016
	SE’	SE’F	0.050		
		SE’F’	0.950		
S’			98.877		
Total			100.000		

4.2.3 Screening Methods

As it was described before, a questionnaire and NCIT were used for the health screening procedure. Based on the findings in Chapter 3 and with several assumptions, the following parameters for the two devices were set:

Table 4.3: Screening Methods Parameters

Parameter	Questionnaire	NCIT
Probability of Detection of SEF (in %)	25.0	90.0
Probability of Detection of SEF’ (in %)	20.0	0.5
Probability of Detection of SE’F (in %)	15.0	90.0
Probability of Detection of SE’F’ (in %)	10.0	0.5
Probability of Detection of S’ (in %)	0.0	0.5
Capacity (entities at once)	2	1
Service Time (in seconds)	30	5
Service Time Distribution	Random Exponential	Random Exponential

Note that the capacity and service time of a questionnaire refer to the manual evaluation of the questionnaire by an officer.

The non-zero probability of the detection of a passenger without the dangerous disease (SE’) means the questionnaire was evaluated wrongly or the symptoms are similar. Similarly, the probability of detection of a non-febrile passenger by NCIT reflects a possible device error.

4.3 SIMULATION SOFTWARE

The experiments were conducted using the simulation software SIMIO created by Simio LLC (version 8.139.13727.0), University Enterprise Edition with no limitations.

SIMIO describes itself as *“a unique multi-paradigm modeling tool that combines the simplicity of objects with the flexibility of processes to provide a rapid modeling capability without requiring programming.”* (Simio 2017). It can be used in various fields, e.g. transportation, healthcare, military, manufacturing, supply chain, or mining.

SIMIO can be considered as an object-oriented modeling software. However, it allows also an event, process, and agent modeling view. The framework is domain neutral and supports both discrete and continuous systems. Another SIMIO advantages is its focus on graphical representation which allows also the 3D view of the model.

The following SIMIO objects were used in the model.

Table 4.4: SIMIO Objects

SIMIO Object Type	Used Defined Name	Representation of
Source	Arrival (to a western African airport)	Generator of Passengers
Server	Questionnaires, NCITs	Screening Method / Station
Sink	U.S., Europe, Other Destination, Journey Interrupted	Final Destination or Journey Interruption
Path	N/A	Passengers' Movements (Flights, In-Terminal Moves)
Basic Node	N/A	Crossroads of Passenger's Journeys
Entity	S', SEF, SEF', SE'F, SE'F'	Passengers' Categories

Figures 4.6 to 4.10 below show how the models for the different scenarios look like in 2-D graphical representation in SIMIO.

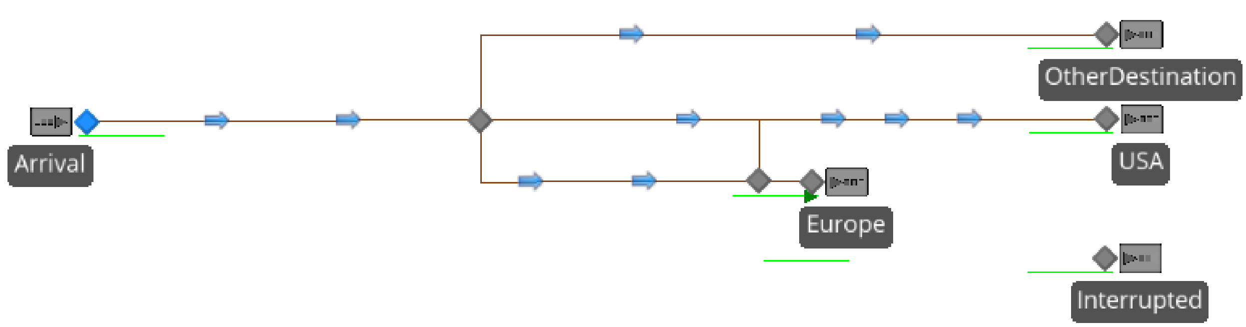

Figure 4.6: Scenario 0 in SIMIO

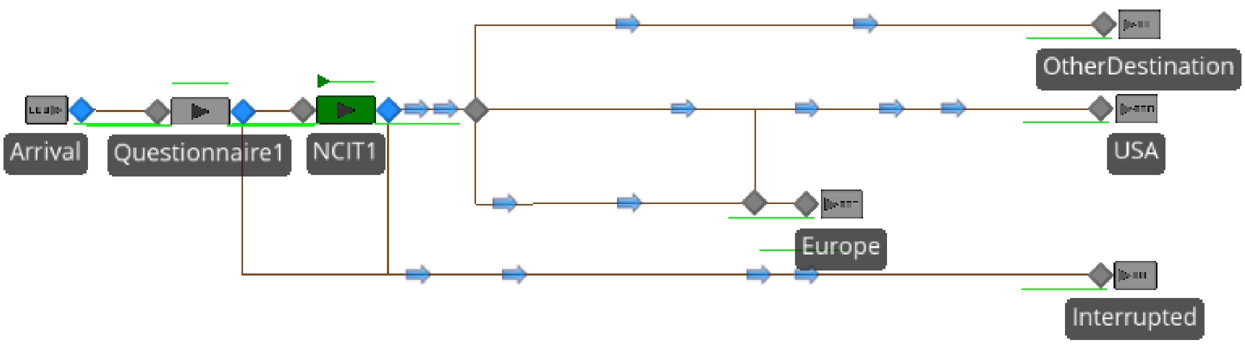

Figure 4.7: Scenario 1 in SIMIO

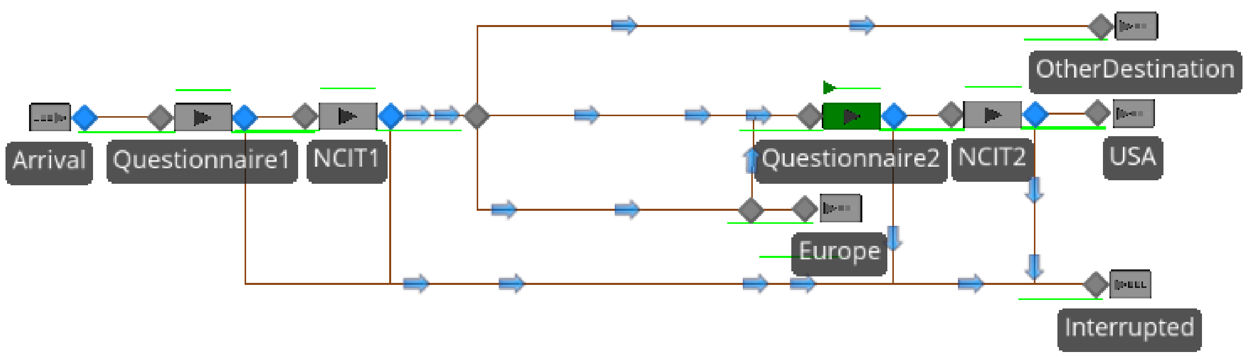

Figure 4.8: Scenario 2 in SIMIO

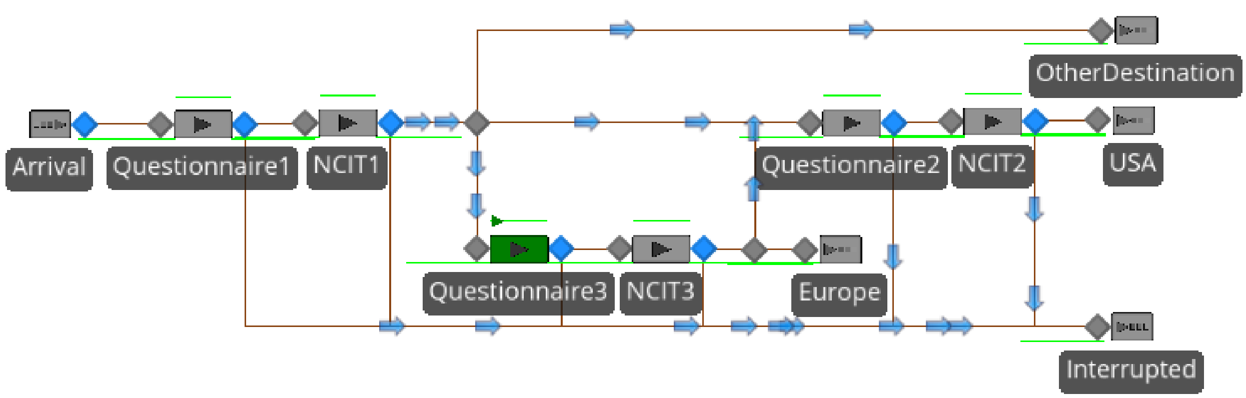

Figure 4.9: Scenario 3 in SIMIO

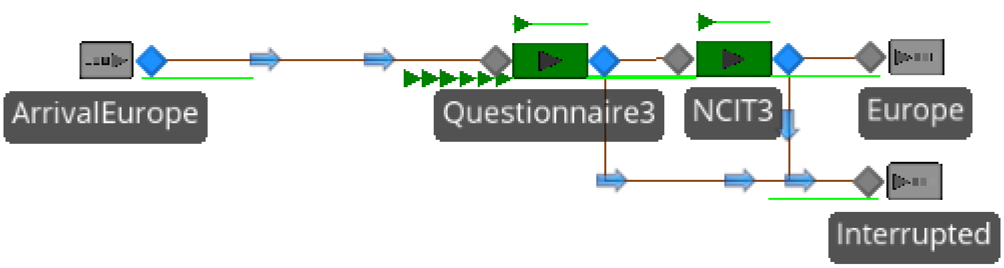

Figure 4.10: Scenario 4 in SIMIO

Chapter 5: Simulation Results

This chapter analyzes the results of the simulation experiments in detail and compares the results of different scenarios. Before that, information about the execution of the simulation runs and about how the results will be presented is provided.

5.1 Simulation Runs

The simulation of each scenario or subscenario consisted of 100 replications to reduce the influence of a stochastic event on the outcome. These 100 replications of each subscenario of the global scenarios (Scenarios 0 to 3) took 1 to 2 hours on a typical PC or laptop computer. On the other hand, each subscenario of the local scenario (Scenario 4) took only tens of seconds.

5.2 Results Presentation

This section describes how the results will be presented. There is a significant difference between the presentation of the results of the global scenarios (Scenarios 0, 1, 2, and 3) and the local station design scenario (Scenario 4).

5.2.1 Global Scenarios Results Presentation

These results are primarily expected to provide an information about how successful the specific design is in detecting the passengers infected with the dangerous disease. However, it is also important to know how all the other passengers are affected by the screening procedure.

To evaluate each design scenario, a confusion matrix (or an error matrix) is used in which the rows represent test (screening) results (the journey is either interrupted or not) and columns list the actual prevalence in the population of air passengers.

Table 5.1: Confusion Matrix (Absolute Numbers)

	Disease (SE)	Non-Disease (SE' + S')	Total
Interrupted (I)	True Positive	False Positive	Total Positive
Not Interrupted (I')	False Negative	True Negative	Total Negative
Total	Total Disease	Total Non-Disease	

As can be seen from the Table 5.1, the screening procedure has four outcomes:

- **True Positive** – Number of passengers correctly detected.
- **False Positive** – Number of passengers incorrectly detected.
- **False Negative** – Number of passengers incorrectly cleared.
- **True Negative** – Number of passengers correctly cleared.

Next, for a better comparison, the absolute numbers are converted into percentage as shown in the following table.

Table 5.2: Confusion Matrix (Percentage)

	Disease (SE)	Non-Disease (SE' + S')	Total
Interrupted (I)	True Positive Rate	False Positive Rate	100 %
Non-Interrupted (I')	False Negative Rate	True Negative Rate	100 %
Total	100 %	100 %	

Now, the outcomes have different names:

- **True Positive Rate (Sensitivity)** – Probability of correct detection.
- **False Positive Rate (False Alarm Rate, Type I Error)** – Probability of incorrect detection.
- **False Negative Rate (Miss Rate, Type II Error)** – Probability of incorrect miss.
- **True Negative Rate (Specificity)** – Probability of correct miss.

The targets are obvious: to have the true positive and the true negative rates as high as possible and on the other hand, the false positive and the false negative rates as low as possible. The results should ideally converge to the target table below.

Table 5.3: Target Results Table

	Disease (SE)	Non-Disease (SE' + S')
Interrupted (I)	100%	0%
Non-Interrupted (I')	0%	100%

Besides those four outcomes, the percentage of false negative passengers who disembark in the U.S. and Europe is observed because those passengers pose a serious health threat at the destination.

5.2.1 Local Station Design Results Presentation

Results of this scenario should show what the best configuration (i.e. number of devices) of a screening station is in order to minimize passenger delay. Therefore, different performance characteristics of the simulation model are observed.

The following four attributes, known from the queueing theory, are used for the evaluation:

- **Maximum Time in the System**
- **Average Time in the System**
- **Maximum Waiting Time**
- **Average Waiting Time**

Time in the system is the time spent waiting in queues for screening of all devices plus the time spent processing (i.e. evaluation of the questionnaire and temperature measurement). Waiting time is only the time spent waiting in queues.

5.3 GLOBAL SCENARIOS RESULTS

The global scenarios results are analyzed according to the subscenarios, i.e. according to the percentage of febrile passengers among those with the dangerous infectious disease (percentage of "SEF" among "SE").

Table 5.4 lists the average number of the passengers with the different health status in all the simulation runs:

Table 5.4: Generated Passenger Volume in Global Scenarios

Parameter	Average Value
Number of Passengers	521,992
- S’	516,134
- SE (SEF + SEF’)	642
- SE’F	261
- SE’F’	4,955

5.3.1 13% of Febrile Passengers

The first subscenario represented a situation when only 13% of the passengers with an infectious disease had fever. This setting should negatively affect the overall screening sensitivity.

The following table shows how many febrile and non-febrile passengers that were generated in the model during the 600 days of simulation period. Complete results of all the scenarios and subscenarios can be found in the Appendix.

Table 5.5: Average Number of SEF and SEF’ Passengers with 13% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Average number of SEF passengers	84.22	84.01	83.23	82.56
Average number of SEF’ passengers	555.31	561.72	558.05	557.60
Total (avg. number of SE passengers)	639.53	645.72	641.28	640.16

On average, there were 83.5 passengers with fever and almost 560 without fever. In total, there were “only” about 640 passengers with the disease (SE) among the population of more than 520,000 passengers.

Now, the results will be described based on the tables below which show all four confusion matrices next to each other. The first table shows absolute values, the second percentages.

Table 5.6: Confusion Matrices (Absolute Numbers) with 13% SEF

	Scenario 0		Scenario 1		Scenario 2		Scenario 3	
	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'
I	0.00	0.00	193.07	3,346	204.75	3,794	243.92	5,080
I'	639.53	521,342	452.65	517,978	436.53	517,601	396.24	516,269

Table 5.7: Confusion Matrices (Percentage) with 13% SEF

	Scenario 0		Scenario 1		Scenario 2		Scenario 3	
	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'
I	0.00%	0.00%	29.90%	0.64%	31.93%	0.73%	38.10%	0.97%
I'	100.00%	100.00%	70.10%	99.36%	68.07%	99.27%	61.90%	99.03%

Without any surprise, there was zero sensitivity (true positive rate) in Scenario 0. On the other hand, this scenario had 100% specificity (true negative rate). This means that not a single passenger's journey was interrupted.

In Scenario 1, the sensitivity reached only 30% while the specificity stayed high – at 99.36% (see Figure 5.1). This means that only 193 out of 645 SE passengers were caught and "only" 3,346 travelers' journeys were interrupted wrongly out of the whole population.

In Scenario 2 with the added screening at the U.S. airports, the improvement in overall sensitivity is only two percentage points but the specificity remained high.

Scenario 3 brought higher sensitivity by approximately 6 percentage points (244 passengers correctly detected) and with this improvement, the specificity decreased to 99.03%. This means that 5,080 passengers were incorrectly interrupted.

Visual representation of the results is given by the two graphs below.

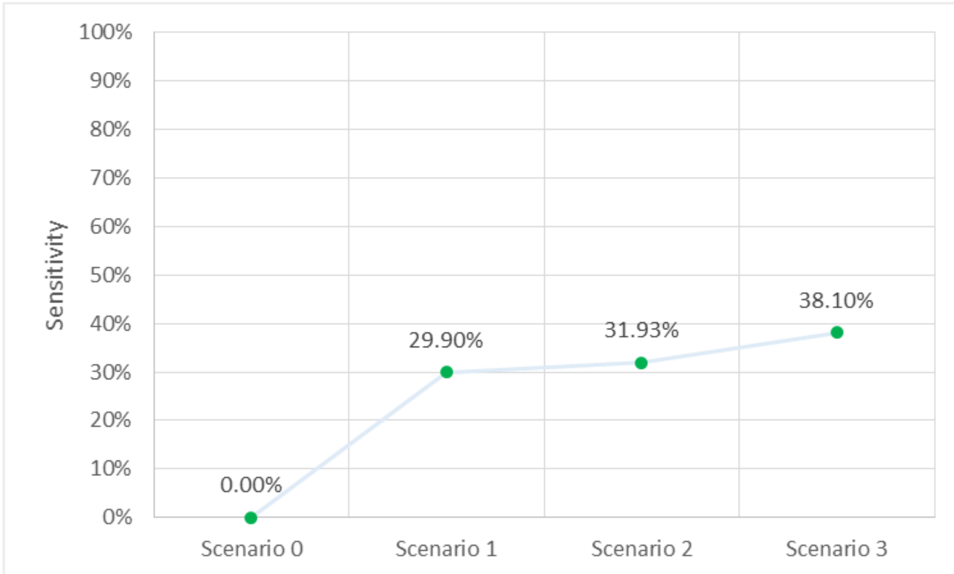

Figure 5.1: Sensitivity with 13% SEF

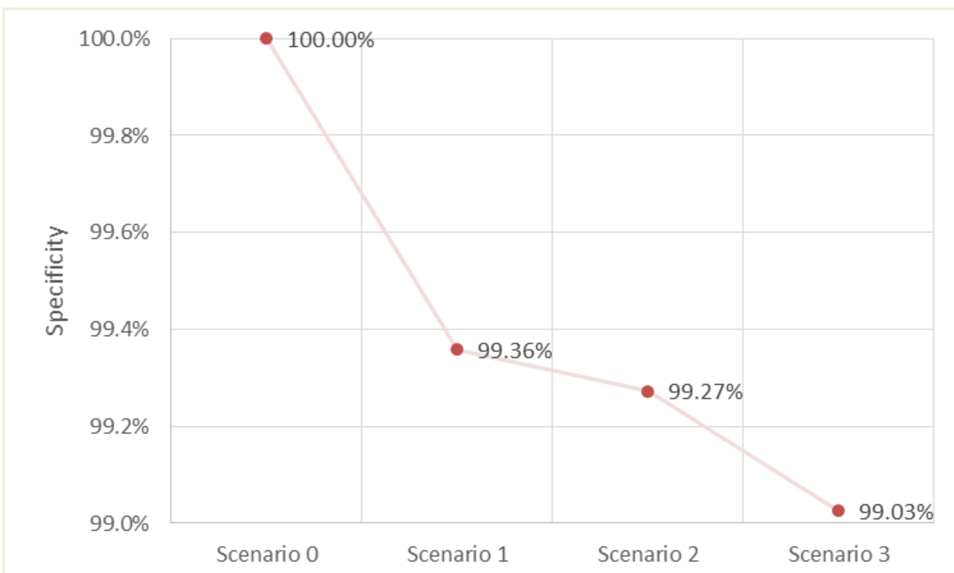

Figure 5.2: Specificity with 13% SEF

As can be seen, the sensitivity of all three scenarios with any form of screening (Scenarios 1 to 3) is between 30% and 38%. Naturally, the specificity decreases with the number of screening stations. In another words, with more screening stations, more (SE' and S') passengers will be wrongly interrupted. Scenario 3 brought more significant changes in both performance characteristics because additional entry screening in Europe affects more travelers.

The last set of results relates to the number of wrongly cleared passengers (false negative) at each continent. The numbers are presented in the table below. The percentage is calculated from all generated SE passengers.

Table 5.8: False Negative Cases with 13% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Passengers with the disease (SE) cleared to the U.S.				
Absolute number	93.43	69.59	53.48	47.25
Percentage (of all cases)	14.6%	10.8%	8.3%	7.4%
Passengers with the disease (SE) cleared to Europe				
Absolute number	223.77	157.92	158.68	124.41
Percentage (of all cases)	35.0%	24.5%	24.7%	19.4%

There were approximately 93 to 47 sick passengers cleared to enter the U.S. and 224 to 124 to enter Europe. The higher number on the European side is also influenced by the higher total number of passengers with destinations in Europe (15% vs. 35%).

Results for both continents are shown in the graph below.

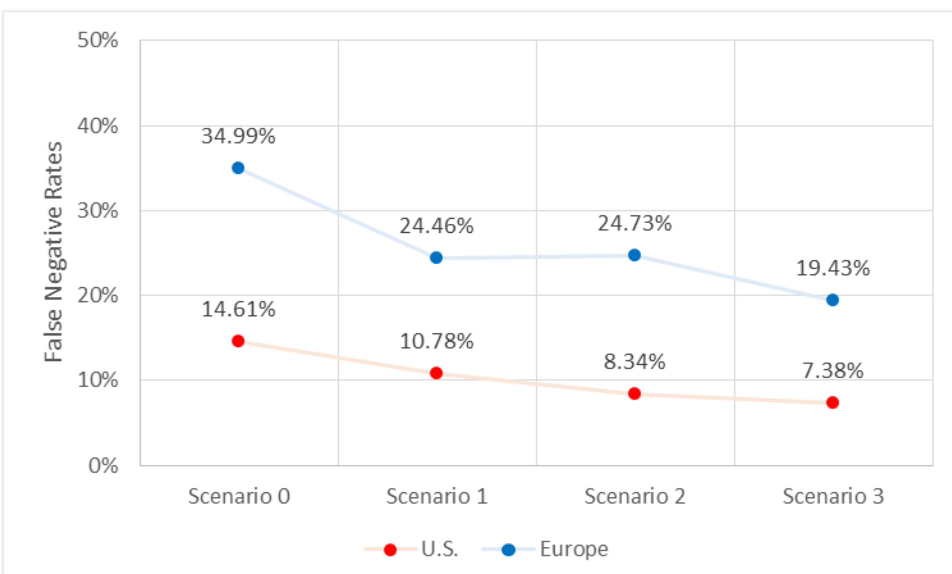

Figure 5.3: False Negative Rates with 13% SEF

For both continents applies that the more screening, the better. Due to the passenger flows, additional entry screening in Europe affects positively the number of false negative cases in the U.S. which, of course, does not apply vice versa. Thus, the best scenario for the U.S. is Scenario 3. However, the improvements are relatively small for all the scenarios. For Europe, Scenario 3 is the best, although the improvement between Scenarios 1 and 3 is not very big – only 5 pp.

5.3.2 50% of Febrile Passengers

The second subscenario assumed an approximately equal portion of febrile and non-febrile passengers among the SE passenger group. Again, the number of specific passengers can be seen in the table below. The numbers are not exactly equal because of the randomness present in the model.

Table 5.9: Average Number of SEF and SEF' Passengers with 50% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Average number of SEF passengers	320.33	323.28	321.71	317.29
Average number of SEF' passengers	319.20	322.88	319.28	322.40

Since the total number of SE passengers in all scenarios and subscenarios remained almost the same at 640, approximately 320 febrile and 320 non-febrile passengers were generated.

Now, one can take a look into the confusion matrices to see how the higher presence of fever changed the simulation results.

Table 5.10: Confusion Matrices (Percentage) with 50% SEF

	Scenario 0		Scenario 1		Scenario 2		Scenario 3	
	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'
I	0.00%	0.00%	56.54%	0.64%	58.37%	0.73%	62.59%	0.97%
I'	100.00%	100.00%	43.46%	99.36%	41.63%	99.27%	37.41%	99.03%

It is obvious that the higher percentage of febrile passengers led to better results. The sensitivity ranged between 56% and 62%. The specificity did not change from the previous subscenario since the percentage of healthy passengers and passengers with any other not dangerous disease (S' + SE') among the population also did not change.

Graphical representation of sensitivity is provided below. From the same reasons stated above, a graph of specificity is not provided because it looks exactly the same as the one in the previous section.

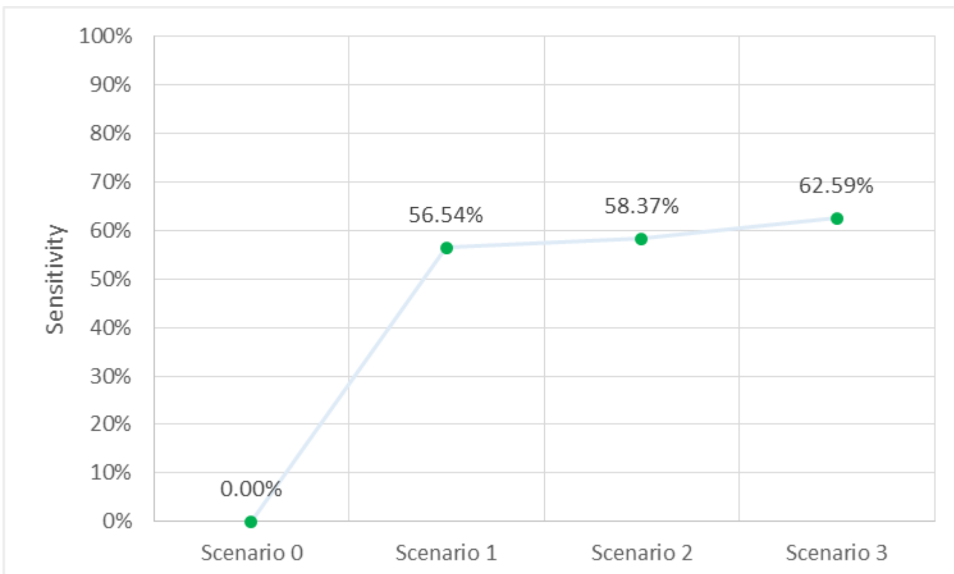

Figure 5.4: Sensitivity with 50% SEF

Similarly to the previous subscenario, no significant improvements can be observed between scenarios 1, 2, and 3.

False negative cases (Table 5.11) also changed to better results (of course, results of Scenario 0 remained the same):

Table 5.11: False Negative Cases with 50% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Passengers with the disease (SE) cleared to the U.S.				
Absolute number	93.43	43.53	30.58	27.42
Percentage (of all cases)	14.6%	6.7%	4.8%	4.3%
Passengers with the disease (SE) cleared to Europe				
Absolute number	223.77	97.95	97.83	72.55
Percentage (of all cases)	35.0%	15.2%	15.3%	11.3%

The number of wrongly cleared passengers ranged from 43 to 27 for the American side and between 98 and 73 for the European side when at least one screening was used.

The graph below provides a visual representation.

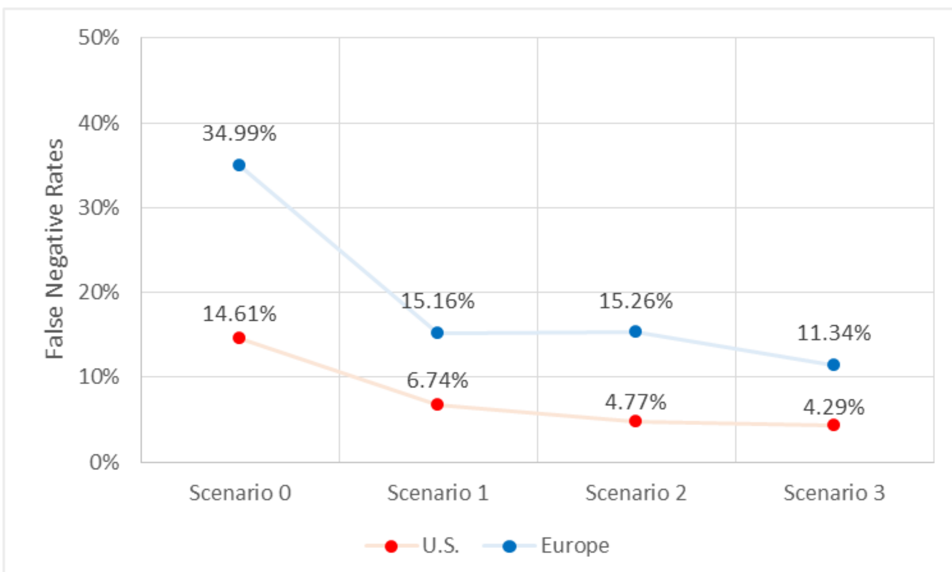

Figure 5.5: False Negative Rates with 50% SEF

The graph is very similar to the one from the previous section. Since the detection rate was higher, naturally the number of false negative cases was lower. In this subscenario, the

improvement between Scenario 1 and 0 is more significant. Nevertheless, the conclusion is the same as in the previous subscenario.

5.3.3 87% of Febrile Passengers

The last subscenario assumed the highest portion of febrile passengers and thus the best results were expected. As can be seen from the table below, on average, around 558 febrile and 84 non-febrile passengers were generated in the simulation period of 600 days.

Table 5.12: Average Number of SEF and SEF' Passengers with 87% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Average number of SEF passengers	556.98	562.09	558.26	554.57
Average number of SEF' passengers	82.55	84.09	82.41	85.03

The following set of tables again shows how the sensitivity and specificity in all scenarios look like.

Table 5.13: Confusion Matrices (Percentage) with 87% SEF

	Scenario 0		Scenario 1		Scenario 2		Scenario 3	
	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'	SE	SE'+S'
I	0.00%	0.00%	83.16%	0.64%	84.50%	0.73%	87.36%	0.97%
I'	100.00%	100.00%	16.84%	99.36%	15.50%	99.27%	12.64%	99.03%

In this subscenario, the sensitivity increased significantly compared to the previous percentages of febrile passengers and ranged between 83 and 87% among the scenarios with at least one screening station while the specificity still remained between 99.03 and 99.36%.

The following figure shows the values of sensitivity graphically.

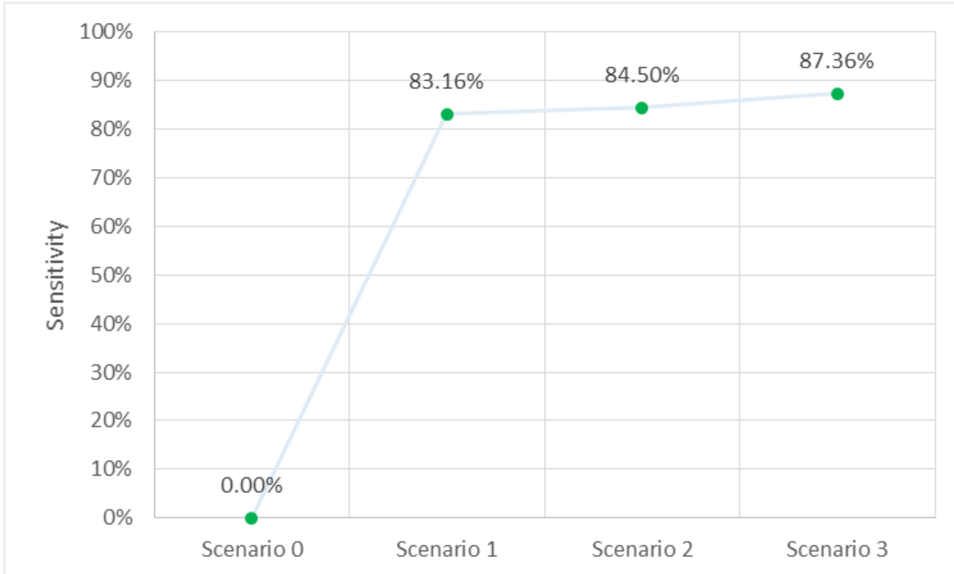

Figure 5.6: Sensitivity with 87% SEF

Again, the improvement in the overall sensitivity in scenarios 2 and 3 compared to Scenario 1 was not very significant. In fact, the improvements were the smallest among all three subscenarios.

The table below shows numbers and percentages of incorrectly missed passengers on both continents. In the U.S., the values were relatively low – between 7 and 17 passengers (1.2 to 2.6%), in Europe, again the numbers were higher because of higher passengers' volume.

Table 5.14: False Negative Cases with 87% SEF

Parameter	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Passengers with the disease (SE) cleared to the U.S.				
Absolute number	99.43	16.73	8.17	7.37
Percentage (of all cases)	14.6%	2.6%	1.3%	1.2%
Passengers with the disease (SE) cleared to Europe				
Absolute number	223.77	37.19	37.85	19.73
Percentage (of all cases)	35.0%	5.8%	5.9%	3.1%

The graphical representation of the results can be found below.

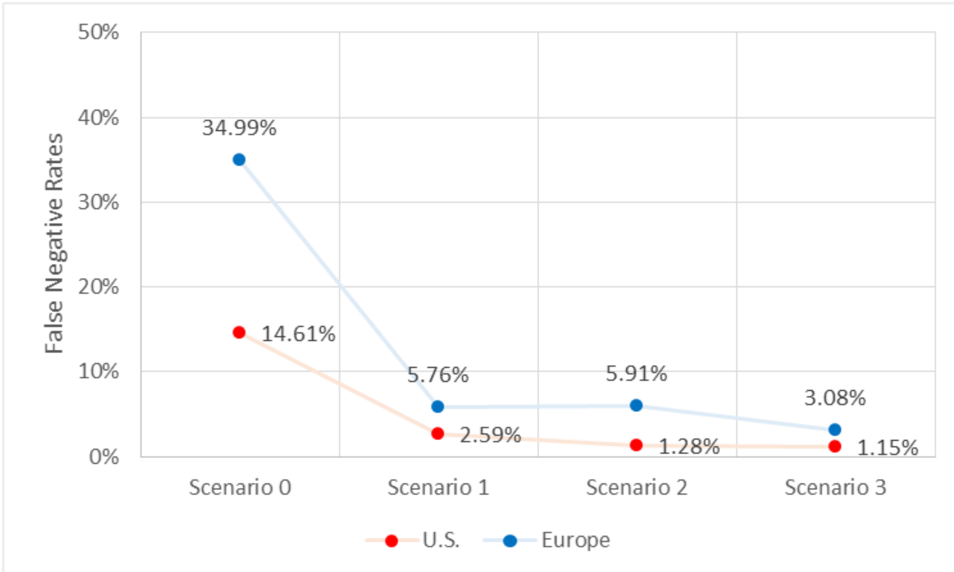

Figure 5.7: False Negative Rates with 87% SEF

Again, the best scenario for both continents is Scenario 3. However, the improvements are not very significant – especially for the U.S. Note that the slightly increased percentage of false negative cases in Scenario 2 in Europe is caused by the presence of randomness in the model.

5.3.4 Comparison

This section brings a comparison of all the scenarios and subscenarios of the global design. First of all, the sensitivity is compared in the table and graph below.

Table 5.15: Sensitivity Comparison

Percentage of SEF	Scenario 0	Scenario 1	Scenario 2	Scenario 3
13%	0.00%	29.90%	31.93%	38.10%
50%	0.00%	56.54%	58.37%	62.59%
87%	0.00%	83.16%	84.50%	87.36%

Figure 5.8: Sensitivity Comparison

The results proved that the presence of fever is truly a key factor which affects the overall sensitivity substantially. With only 13% of febrile passengers (SEF), the sensitivity reached on average 33% (among scenarios 1, 2, and 3). With 50% of SEF it was already 59% and with 87% of SEF, the sensitivity reached 85%.

On the other hand, the presence of a screening station significantly changed the results only in the Scenario 1 (compared to Scenario 0) and partially also in Scenario 3 (compared to Scenario 2). In the other scenarios, despite some improvement was observed, the changes were very little.

The next table and graph compare the specificity, i.e. percentage of passengers who were correctly cleared to their final destination.

Table 5.16: Specificity Comparison

Percentage of SEF	Scenario 0	Scenario 1	Scenario 2	Scenario 3
13%	100.00%	99.36%	99.27%	99.03%
50%	100.00%	99.36%	99.27%	99.03%
87%	100.00%	99.36%	99.27%	99.03%

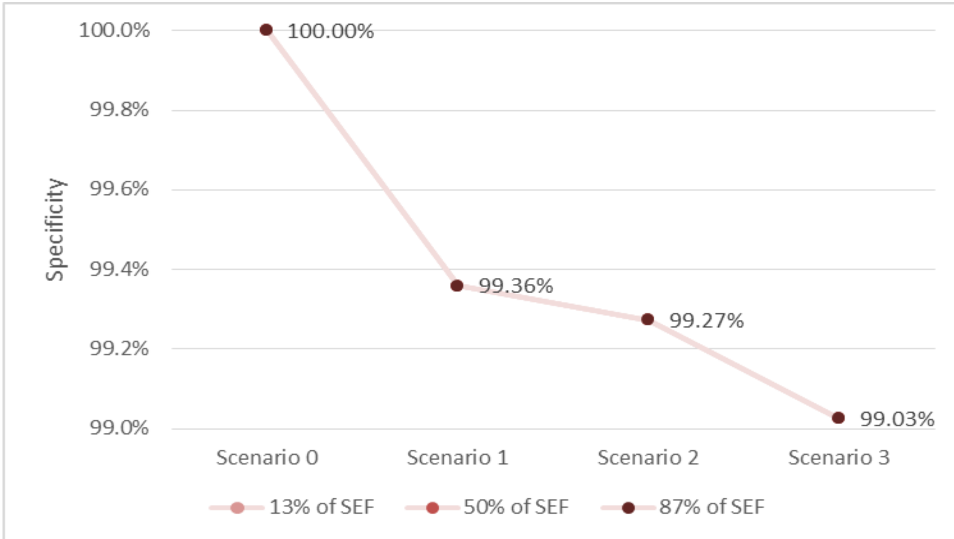

Figure 5.9: Specificity Comparison

As it was mentioned in previous sections, the specificity remained the same in all subscenarios because the number of healthy (S') and not dangerously sick (SE') passengers who only affect this parameter did not change in those subscenarios.

Thus, it can be concluded that no matter the percentage of SEF passengers, the best specificity is achieved when no screening at all is conducted. However, this can be concluded even without any model. More interesting are the results of scenarios with at least one screening station. Unsurprisingly, the specificity decreases with the number of stations: between scenarios 1 and 0, the drop is 0.64 percentage point, from 1 to 2, it is only 0.09 pp and from 3 to 2, it is 0.24 pp.

Next, the false negative cases, i.e. dangerously sick passengers (SE) who were cleared to their destination, are compared for each continent separately.

First, the results for the U.S. side are presented in following table and graph.

Table 5.17: False Negative Rates Comparison – U.S.

Percentage of SEF	Scenario 0	Scenario 1	Scenario 2	Scenario 3
13%	14.61%	10.78%	8.34%	7.38%
50%	14.61%	6.74%	4.77%	4.29%
87%	14.61%	2.59%	1.28%	1.15%

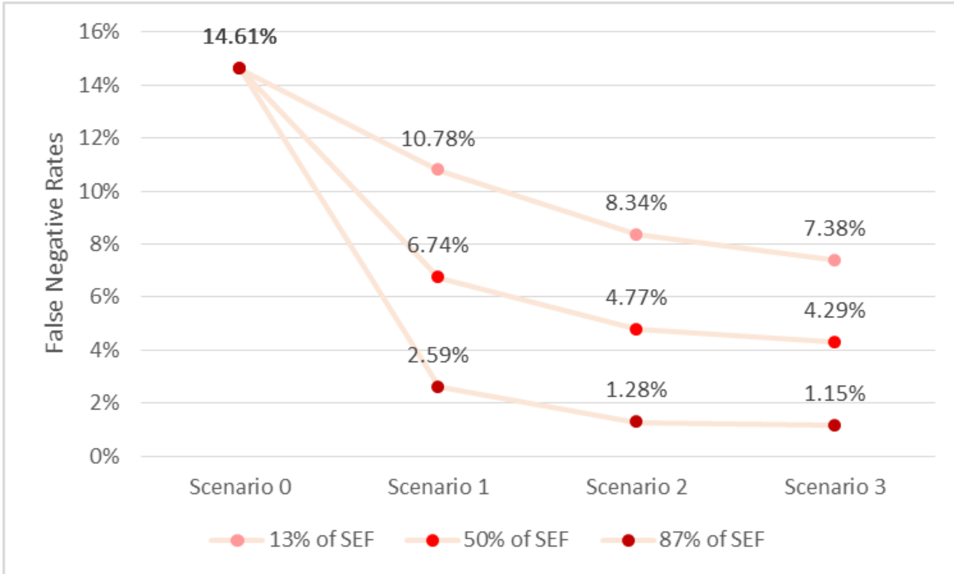

Figure 5.10: False Negative Rates Comparison – U.S.

Here again, the percentage of febrile passengers affected the results significantly. In Scenario 1, the improvement is only 4 pp when 13% of SE passengers have a fever. When 50% have a fever, the positive change is 8 pp, and when 87% is febrile, the improvement is 12 pp.

Also, in all scenarios, Scenario 2 brings another one to two pp improvement, while Scenario 3 means only a very little additional improvement (Scenario 3 introduces another screening station in Europe).

The same comparison is also presented for the European side – see the table and graph below.

Table 5.18: False Negative Rates Comparison – Europe

Percentage of SEF	Scenario 0	Scenario 1	Scenario 2	Scenario 3
13%	34.99%	24.46%	24.73%	19.43%
50%	34.99%	15.16%	15.26%	11.34%
87%	34.99%	5.76%	5.91%	3.08%

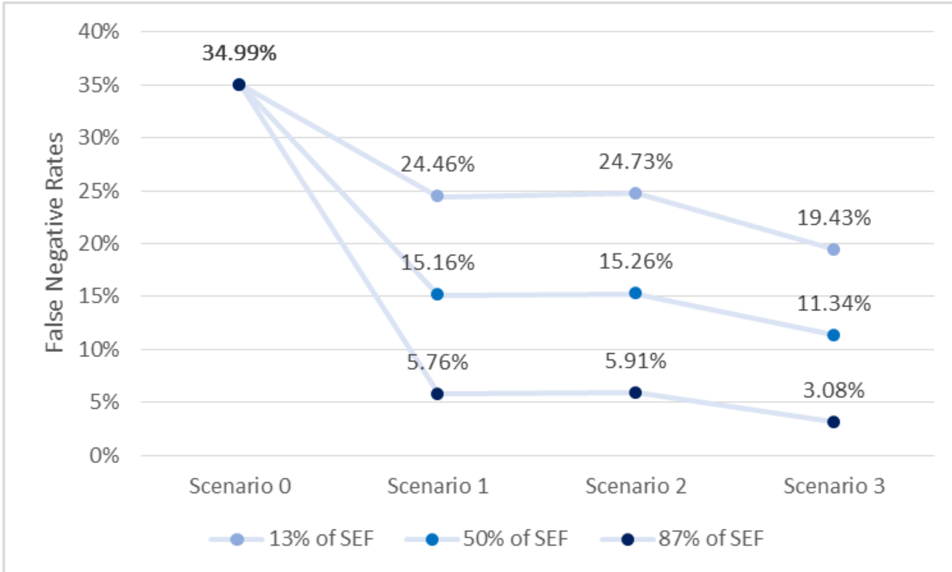

Figure 5.11: False Negative Rates Comparison – Europe

Here, the improvement compared to Scenario 0 is much higher – 10, 20, and 29 pp respectively. At the first sight, the change between Scenario 2 and 1 seems to be slightly negative despite there should not be any change but that was caused by the presence of randomness, as it was already explained before. So the only further improvement was reached in the Scenario 3 – 3 to 5 pp which again does not seem to be very significant.

5.4 Local Station Design Results

There are two parameters which can be changed in the local station design (assuming the screening technology remains the same). The two parameters are: the number of questionnaire evaluation stations and the number of temperature measurement stations.

Since the processing time for the questionnaire was set to 30 seconds and the temperature measurement to 5 seconds, the questionnaire evaluation seems to be the potential system bottleneck. This was proven by a simple simulation in which the maximum time in the system was observed depending on numbers of servers of both screening methods.

The difference in the maximum time in the system was negligible when using 1 or 5 NCITs but the difference became significant when the number of questionnaire evaluation stations increased (see the table below).

Table 5.19: Local Station Design Key Parameters

Questionnaire Capacity	NCIT Capacity	Maximum Time in the System (minutes)
1	1	51.07
1	5	51.17
2	1	43.58
2	5	43.19
3	1	29.70
3	5	28.26
4	1	17.86
4	5	17.17

Based on the above results, only the number of questionnaire evaluation stations was changed in further simulations while the number of NCITs was set to one.

Next, simulations runs were performed and the characteristics of the queueing system as mentioned in Section 5.2.1 were observed and recorded into the following table and graphs. Note that all the values are average values obtained from 100 simulation runs.

Table 5.20: Local Station Design Performance Characteristics

Questionnaire Capacity	Time in the System (minutes)		Maximum Waiting Time (minutes)		Average Waiting Time (minutes)	
	Maximum	Average	Questionnaire	NCIT	Questionnaire	NCIT
1	51.07	25.98	50.88	0.33	25.54	0.02
2	43.58	22.17	43.23	0.49	21.65	0.04

Questionnaire Capacity	Time in the System (minutes)		Maximum Waiting Time (minutes)		Average Waiting Time (minutes)	
	Maximum	Average	Questionnaire	NCIT	Questionnaire	NCIT
3	29.70	14.85	28.40	0.68	14.06	0.08
4	17.86	8.92	16.25	0.89	8.07	0.15
5	11.25	5.52	9.04	1.48	4.42	0.39
6	7.17	3.48	4.15	2.13	1.96	0.82
7	7.33	3.40	2.40	3.52	1.03	1.66
8	6.72	3.00	1.06	4.22	0.26	2.04
9	7.23	3.18	0.69	4.82	0.12	2.35
10	6.92	3.03	0.42	4.64	0.04	2.29

Table 5.20 contains two main station performance characteristics: time in the system and waiting time in queue. The time spent in the system is first analyzed by plotting Figure 5.12.

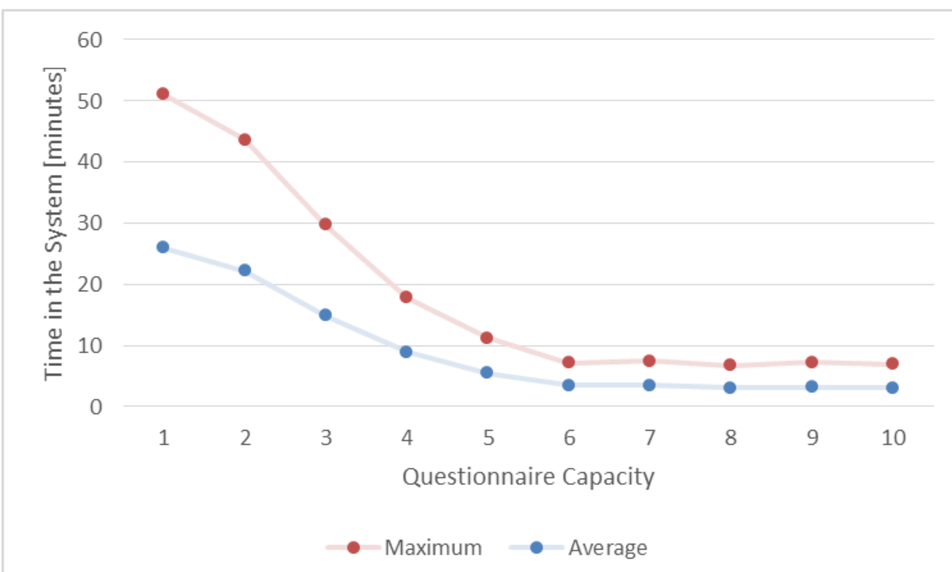

Figure 5.12: Time in the System

Both the maximum and average time spent in the system decrease with increasing number of questionnaire evaluation stations. The biggest improvement can be observed by

adding the third and fourth station. On the other hand, seven and more stations do not bring any further significant time reduction. Thus, six questionnaire stations and one NCIT station can be considered as the optimum setting with the average time spent in the system of 3.5 minutes and maximum of seven minutes. These values represent a delay in the passenger's journey caused by the entry health screening procedure at a specific airport.

Another important performance characteristic is waiting time since waiting is perceived as the most negative experience of the whole procedure (unlike the processing/service time). The two graphs below (one for the maximum and the second one for the average waiting time) show the trends.

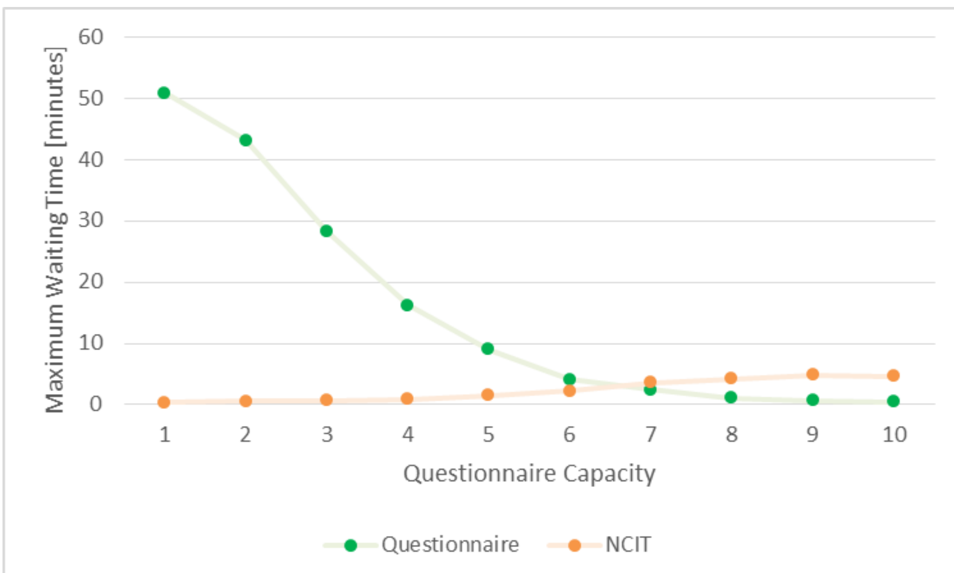

Figure 5.13: Maximum Waiting Time

In Figure 5.13, while the maximum waiting time for questionnaire evaluation stations decreases with additional stations, it slightly increases for NCIT which is caused by the position of NCIT being placed after the questionnaire station: more questionnaire stations means more people approaching the NCIT station at the same time.

Again, the best setting seems to be seven or six questionnaire stations and one temperature measurement station with maximum waiting times of about six minutes combined.

The results for the average waiting time look similarly: optimum of less than three minutes waiting – see below.

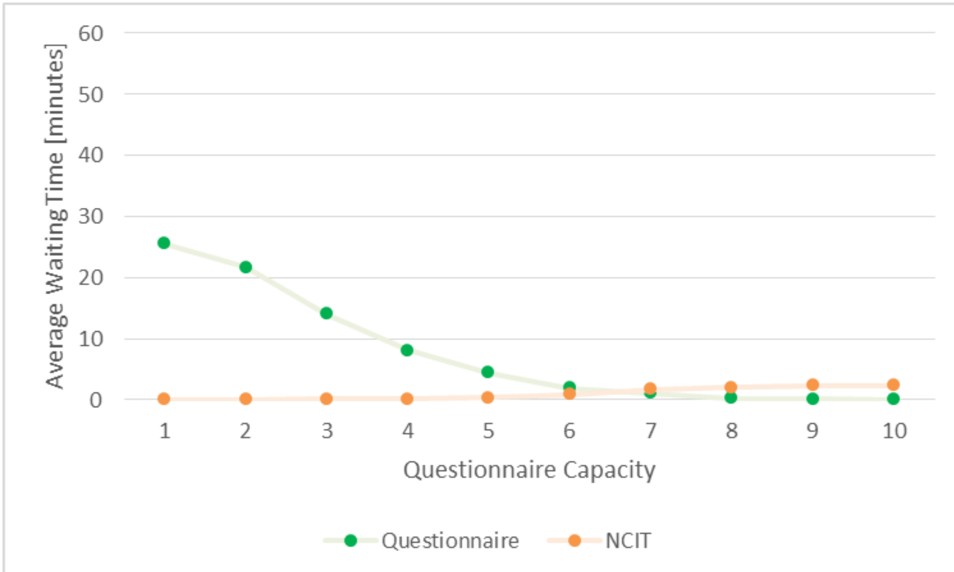

Figure 5.14: Average Waiting Time

Chapter 6: Recommendations on Design of Health Screening System

This chapter provides recommendations on the deployment and design of passengers' health screening stations for international organizations such as WHO or ICAO, state governments, local authorities, and airport operators based on the simulation results presented in the previous chapter.

6.1 Global Design Recommendations

There are two possible views on the global design: The first one is truly global and its target is to stop the spread of a dangerous infectious disease to any other country. This point of view is represented mostly by WHO and other international organizations with a global scope of activity, such as ICAO, IATA, or ACI (see Chapter 3).

The other view, which could also be named as "regional", is represented by particular governments and responsible authorities which the main goal is not to let any infected person into their country and thus to keep their citizens safe.

While both the goals may seem to be identical, in fact, the practice showed that the approaches are slightly different. In general, the governments tend to be more protective than the international standards. This difference will be taken into consideration in following recommendations.

6.1.1 Recommendations for International Organizations

Sensitivity and specificity are the basis used for establish this set of recommendations. The results showed that the sensitivity did not change much among Scenarios 1, 2, and 3 (i.e. scenarios with at least one screening station, see Figure 5.8) which indicates that exit screening in the affected countries may be sufficient. The selection of the Scenario 1 as the best scenario is also supported by the decreasing specificity of the scenario results – one of the principles which should be followed when introducing any kind of passenger screening is to minimize passengers' disruption or delay.

Since the International Health Regulations issued by WHO require the member states to introduce an exit screening in case of an international health threat and do not require any entry screening (see Chapter 3), from this point of view, the current state is satisfactory and this practice does not need to be modified.

6.1.2 Recommendations for Government Authorities

The recommendations are specific for each geographical area and are based on different results of the simulation – in this case, on the numbers and percentages of wrongly cleared passengers (false negative cases) at each continent.

First, recommendation for the U.S. authorities will be given. The question is whether entry screening should be introduced or not assuming that there is already exit screening in the affected countries. Adding an entry screening at the U.S. airports was simulated in Scenario 2. The measures in Scenario 3 are independent of American authorities and thus can be ignored at the moment.

According to the results, the improvement brought by Scenario 2 expressed as a percentage decrease of wrongly cleared passengers is from 23% to 52% depending on the presence of fever (percentage of SEF and SEF' passengers). On the other hand, the absolute number of such cases is relatively small even without introducing an additional screening at the U.S. airports. The simulation model generated a maximum of 70 dangerously sick travelers (SE) coming to the U.S. during the 600-days period and maximum improvement of 16 additionally detained passengers when the entry screening was introduced. It is a question for further research whether the costs related to the entry screening are adequate to the risk of exposing such amount of sick passengers to the rest of the population.

Therefore, the recommendation is not unequivocal. It seems that with such a small number of sick passengers, it is not very efficient to conduct an entry screening. However, the possible improvement (decrease of false negative cases) expressed as a percentage is significant

so the entry screening is justifiable especially when the volume of incoming passengers is higher than it was assumed in the simulations herein.

In Europe, the recommendation is based on the results of Scenario 3 (compared to Scenario 1) since the layout of Scenario 2 has no effect on the European side. Again, the recommendation should help the responsible authorities with the decision whether to implement entry screening at relevant airports or not.

The improvement in reducing the number of wrongly cleared sick passengers (false negative cases) ranges between 21% and 47% depending on the presence of fever but also here, the absolute numbers are relatively small – there was a maximum of 158 SE passengers coming to Europe during the whole simulation period and maximum of 34 additionally detained travelers thanks to the entry screening.

Thus, the recommendation for European airports is similar to the case of the U.S. airports. Entry screening is probably not necessary if the volume of passengers is similar to the simulated one. With an increasing number of incoming travelers from affected countries, the entry screening becomes more justifiable.

6.1.3 Global Design Recommendations Summary

The simulation results have showed that exit screening in affected countries is critical and it should be required by the international organizations as it was during the recent outbreaks. On the other hand, the benefits of the entry screening are not so clear. The additional screening may not be necessary when the volume of potentially infected passengers is small (i.e. similar to the numbers used in the simulations). However, this requires further analyses.

6.2 LOCAL STATION DESIGN RECOMMENDATIONS

In the local design, the optimum number of questionnaire evaluation stations and temperature measurement stations at a specific airport that receive direct flights from the affected countries was being sought. The recommendations should help the airport operators to design a health screening station with a minimum delay for passengers.

The simulation results showed that only one NCIT station is necessary at the assumed arrival rate thanks to the high service rate. While the bottleneck of the screening station is the process of evaluation of the questionnaires. The optimum number of the latter stations from the passengers' point of view (minimum time spent in the system and minimum waiting time) is six which represents only a few minutes of delay.

From the airport operator's point of view, the goal of screen station design is to minimize the number of devices and thus minimize the costs. It is up to the operator what it is considered as an acceptable additional delay to the current time spent at the airport. Assuming that the maximum allowable passenger's delay is ten minutes on average, four questionnaire evaluation stations would fulfill the standard.

At the modeled arrival rate represented one wide-body airplane arriving from an affected country, the optimum layout of a screening health station is one NCIT screening station and six questionnaire evaluation stations. In order to minimize costs while keeping the screening time at an acceptable level, the airport operator is recommended to install at least one NCIT station and four questionnaire kiosk or windows.

Chapter 7: Conclusion

This chapter provides the summary of the research, its contributions and limitations, and suggestions on possible future research directions in this field.

7.1 Summary of Research

The research presented in this thesis dealt with health screening systems in air transportation and their contribution in reducing the spread of dangerous pandemic diseases from a certain region with a focus on health threats to the U.S. and Europe. The main goal was to identify the optimum health screening system design using a simulation software under certain assumptions.

Firstly, several infectious diseases which became pandemic in last decades were described to provide the necessary background information.

Secondly, health screening devices and procedures were reviewed including their characteristics, advantages, and disadvantages.

Based on the findings from the literature review and after making several assumptions, models of different scenarios were prepared in a simulation software and described in Chapter 4 of the thesis. There were two kinds of scenarios. The first group, so-called “Global Scenarios”, operated with the presence of a health screening station at different nodes in the transportation network. The other group, “Local Station Design Scenario”, worked with a different number of devices inside one screening station. Different characteristics were observed in each group.

In Chapter 5, the simulations’ results were presented and analyzed.

Finally, using the results, recommendations on the health screening system design were given to different stakeholders.

The research showed that from the global perspective, exit screening in the affected countries is the most important measure to slow down the spread of an infectious disease. Adding another screenings (entry screenings) at the destination airports did not bring much improvement.

From the perspective of the local design, a screening station should consist of four to six questionnaire evaluation stations and one non-contact infrared thermometer.

7.2 Contributions

The perspective of this research is relatively unique since it has not receiving much attention from the transportation research community. The research produced models which can be replicated and adjusted according to the actual health thread and air transportation network in the future. Thus, their results can serve as a input for different decision makers: for international organizations such as WHO, for government and local authorities and for airport operators.

7.3 Limitations

The research presented herein has two major limitations. The first one is a lack of data. To making the results more accurate, better data about passenger flow would be needed as well as the performance specifications of the screening devices. The actual prevalence of the diseases and fever among the air travelers also has impact on the results.

Another significant limitation is a lack of resources. Since this is an individual research, it was not possible to examine more possible screening procedures systematically, to experiment with more input parameters more times, and to model the procedure with more detail.

7.4 Future Research

This topic provides many directions of possible future research. The models and inputs can be adjusted to better represent the reality if more accurate input data become available. For example, secondary inspection can be added to the model, or the spread of the disease in the aircraft can be modeled. Furthermore, other destinations besides the U.S. and Europe can be added to model the spread to other countries.

Another topic of future research is, as discussed in Chapter 6, to conduct a cost-benefit analysis to find the threshold at which entry screening pays off.

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Glossary

ACI – Airports Council International

AI – Avian Influenza

CBP – U.S. Customs and Border Protection

CDC – Centers for Disease Control and Prevention

EVD – Ebola Virus Disease

IATA – International Air Transport Association

ICAO – International Civil Aviation Organization

IHR – International Health Regulations

IR – Infrared

MERS – Middle East Respiratory Syndrome

NCIT – Non-Contact Infrared Thermometer

NCITC – Non-Contact Infrared Thermal Camera

PHEIC – Public Health Emergency of International Concern

SARS – Severe Acute Respiratory Syndrome

U.K. – United Kingdom

U.S. – United States of America

WHO – World Health Organization

ZVD – Zika Virus Disease

Appendix

Scenarios 0, 1, 2, and 3 at 0.13% SEF								
Input								
Days of simulation	600							
Replications	100							
	Scenario 0		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Generated Passengers								
S'	516142.96		516108.22		516177.92		516114.04	
SEF	84.22		84.01		83.23		82.56	
SEF'	555.31		561.71		558.05		557.60	
SE'F	261.53		262.52		260.21		261.77	
SE'F'	4937.32		4953.01		4956.65		4973.93	
TOTAL	*521,981*		*521,969*		*522,036*		*521,990*	
Output								
All Passengers Whose Journey Was Interrupted								
S'	0.00		2586.52		2967.51		4044.86	
SEF	0.00		77.77		78.03		79.54	
SEF'	0.00		115.3		126.72		164.38	
SE'F	0.00		239.67		240.36		249.83	
SE'F'	0.00		519.68		585.83		785.79	
TOTAL	*0*		*3,539*		*3,998*		*5,324*	
Passengers Incoming to the U.S.								
TOTAL	*78,157*		*77,689*		*77,702*		*77,419*	
- which were cleared to enter								
S'	77285.09		76951.85		76581.71		76348.9	
SEF	12.05		0.97		0.08		0.06	
SEF'	81.38		68.62		53.4		47.19	
SE'F	38.66		3.30		0.24		0.24	
SE'F'	739.74		664.13		593.92		565.58	
TOTAL	*78,157*		*77,689*		*77,229*		*76,962*	
Passengers Incoming to Europe (incl. transfer passengers)								
TOTAL	*221,869*		*220,334*		*220,389*		*220,386*	
- which were cleared to enter								
S'	180799.75		179822.96		179864		178988.12	
SEF	29.75		2.06		2.16		0.17	
SEF'	194.02		155.86		156.46		124.24	
SE'F	91.25		8.21		8.32		0.70	
SE'F'	1727.45		1551.81		1555.02		1395.83	
TOTAL	*182,842*		*181,541*		*181,586*		*180,509*	
Results Summary								
Confusion matrix								
Absolute numbers	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00	0.00	193.07	3,346	204.75	3,794	243.92	5,080
I'	639.53	521,342	452.65	517,978	436.53	517,601	396.24	516,269
Percentages	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00%	0.00%	29.90%	0.64%	31.93%	0.73%	38.10%	0.97%
I'	100.00%	100.00%	70.10%	99.36%	68.07%	99.27%	61.90%	99.03%
Passengers with the disease cleared to the U.S.								
Absolute number	93.43		69.59		53.48		47.25	
Percentage (of all cases)	14.6%		10.8%		8.3%		7.4%	
Passengers with the disease cleared to Europe								
Absolute number	223.77		157.92		158.62		124.41	
Percentage (of all cases)	35.0%		24.5%		24.7%		19.4%	

Scenarios 0, 1, 2, and 3 at 0.50% SEF								
Input								
Days of simulation	600							
Replications	100							
	Scenario 0		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Generated Passengers								
S'	516142.96		516102.48		516179.88		516105.47	
SEF	320.33		323.28		321.71		317.29	
SEF'	319.20		322.88		319.28		322.40	
SE'F	261.53		262.83		260.01		261.51	
SE'F'	4937.32		4953.48		4956.53		4972.66	
TOTAL	*521,981*		*521,965*		*522,037*		*521,979*	
Output								
All Passengers Whose Journey Was Interrupted								
S'	0.00		2587.41		2966.12		4044.65	
SEF	0.00		299.50		301.86		305.27	
SEF'	0.00		65.87		72.3		95.10	
SE'F	0.00		239.84		240.18		249.61	
SE'F'	0.00		519.26		586.13		785.82	
TOTAL	*0*		*3,712*		*4,167*		*5,480*	
Passengers Incoming to the U.S.								
TOTAL	*78,157*		*77,660*		*77,681*		*77,396*	
- which were cleared to enter								
S'	77285.09		76948.63		76586.69		76350.15	
SEF	46.77		3.63		0.23		0.18	
SEF'	46.66		39.9		30.35		27.24	
SE'F	38.66		3.30		0.22		0.23	
SE'F'	739.74		664.31		593.82		565.20	
TOTAL	*78,157*		*77,660*		*77,211*		*76,943*	
Passengers Incoming to Europe (incl. transfer passengers)								
TOTAL	*221,869*		*220,259*		220318.77		*220,308*	
- which were cleared to enter								
S'	180799.75		179824.33		179868.17		178981.85	
SEF	112.18		8.01		8.28		0.59	
SEF'	111.59		89.94		89.55		71.96	
SE'F	91.25		8.28		8.31		0.70	
SE'F'	1727.45		1552.34		1554.73		1395.78	
TOTAL	*182,842*		*181,483*		*181,529*		*180,451*	
Results Summary								
Confusion matrix								
Absolute numbers	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00	0.00	365.4	3,347	374.2	3,792	400.4	5,080
I'	639.53	521,342	280.8	517,972	266.8	517,604	239.3	516,260
Percentages	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00%	0.00%	56.54%	0.64%	58.37%	0.73%	62.59%	0.97%
I'	100.00%	100.00%	43.46%	99.36%	41.63%	99.27%	37.41%	99.03%
Passengers with the disease cleared to the U.S.								
Absolute number	93.43		43.53		30.58		27.42	
Percentage (of all cases)	14.6%		6.7%		4.8%		4.3%	
Passengers with the disease cleared to Europe								
Absolute number	223.77		97.95		97.83		72.55	
Percentage (of all cases)	35.0%		15.2%		15.3%		11.3%	

Scenarios 0, 1, 2, and 3 at 0.87% SEF								
Input								
Days of simulation	600							
Replications	100							
	Scenario 0		**Scenario 1**		**Scenario 2**		**Scenario 3**	
Generated Passengers								
S'	516142.96		516090.67		516168.87		516130.40	
SEF	556.98		562.09		558.26		554.57	
SEF'	82.55		84.09		82.41		85.03	
SE'F	261.53		262.65		260.22		261.44	
SE'F'	4937.32		4955.09		4956.16		4973.17	
TOTAL	*521,981*		*521,955*		*522,026*		*522,005*	
Output								
All Passengers Whose Journey Was Interrupted								
S'	0.00		2587.13		2965.31		4044.92	
SEF	0.00		520.27		523.40		533.13	
SEF'	0.00		17.11		17.97		25.62	
SE'F	0.00		239.72		240.34		249.55	
SE'F'	0.00		519.20		585.61		786.26	
TOTAL	*0*		*3,883*		*4,333*		*5,639*	
Passengers Incoming to the U.S.								
TOTAL	*78,157*		*77,631*		*77,653*		*77,380*	
- which were cleared to enter								
S'	77285.09		76946.27		76585.17		76358.00	
SEF	81.44		6.42		0.44		0.23	
SEF'	11.99		10.31		7.73		7.14	
SE'F	38.66		3.30		0.22		0.23	
SE'F'	739.74		664.64		593.70		564.92	
TOTAL	*78,157*		*77,631*		*77,187*		*76,931*	
Passengers Incoming to Europe (incl. transfer passengers)								
TOTAL	*221,869*		*220,180*		220244.49		*220,250*	
- which were cleared to enter								
S'	180799.75		179820.42		179866.25		178994.09	
SEF	195.38		14.35		14.84		1.04	
SEF'	28.39		22.84		23.01		18.69	
SE'F	91.25		8.23		8.29		0.69	
SE'F'	1727.45		1552.55		1555.13		1395.80	
TOTAL	*182,842*		*181,418*		*181,468*		*180,410*	
Results Summary								
Confusion matrix								
Absolute numbers	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00	0.00	537.4	3,346	541.4	3,791	558.8	5,081
I'	639.53	521,342	108.8	517,962	99.3	517,594	80.9	516,284
Percentages	E	E'+S'	E	E'+S'	E	E'+S'	E	E'+S'
I	0.00%	0.00%	83.16%	0.64%	84.50%	0.73%	87.36%	0.97%
I'	100.00%	100.00%	16.84%	99.36%	15.50%	99.27%	12.64%	99.03%
Passengers with the disease cleared to the U.S.								
Absolute number	93.43		16.73		8.17		7.37	
Percentage (of all cases)	14.6%		2.6%		1.3%		1.2%	
Passengers with the disease cleared to Europe								
Absolute number	223.77		37.19		37.85		19.73	
Percentage (of all cases)	35.0%		5.8%		5.9%		3.1%	

Vita

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