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Title of Design: Airport Smart Drainage System

Design Challenge Addressed: Airport Environmental Interactions

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Airport Smart Drainage System

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Executive Summary

On July 6th, 2013, Asiana Airlines Flight 214 crashed on its final approach to San Francisco International Airport (SFO). The right wing of the aircraft came to rest directly over a storm drain catch basin, spilling jet fuel into the storm drainage system. In response to the crash, two pump stations that outflow to the bay were taken offline. Although the airport has a well developed response plan that was successfully implemented, unfortunately, a certain portion of the spilled fuel still made it into the San Francisco Bay. The pump stations themselves were completely contaminated, requiring multiple cleanings and flushing to remove any trace of fuel and prevent any further pollution of the bay. The entire cleanup process proved to be expensive and time consuming, but successfully executed.

The Asiana Airlines Flight 214 incident is the driving factor behind our design for the Smart Drainage System. The proposed system consists of valves and sensors installed before the pump stations of the current drainage system at SFO. These sensors will be able to detect the presence of spilled fuel and activate valves that will redirect the spilled fuel to a designated storage tank, preventing contamination of the pump station and spillage into the bay. Although some of the storm drainage pipes will still be contaminated, the cleaning of these pipes will be a very simple process. The pipes only need to be flushed with water, and any used water can be collected in the storage tank and easily disposed of. The storage tank will contain many safety features such as leak protection, overfill protection, and fire protection to make sure any spilled fuel is stored in a safe manner. The valves will also have a built it fail safe mode of closing the flow to the pump station so that even if they malfunction, the contaminated fluid will still be redirected. The shortest path method and dynamic programming was used to find the optimal path of building the pipes and placing the storage tank in order to make our design the most cost efficient. The design is based on SFO but can be easily applied to any airport with a sophisticated storm drainage system.

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1. Background

Historically, aircraft crashes, emergency landings and other catastrophic events have led to the modernization of air traffic control methods and the improvement of aviation safety and security. However, these changes have mostly disregarded the environmental impacts and consequences of such incidents. The most significant incident that serves as the motivation for our research is the crash of Asiana Airlines Flight 214.

On July 6, 2013, Asiana Airlines Flight 214 made a crash landing at San Francisco International Airport (SFO). The aircraft crashed in such a position that the right wing of the aircraft came to rest directly over a storm drain catch basin spilling over 2,950 gallons of fuel into the storm drains and surrounding environment (Figure 1). The resulting firefighting efforts to put out the burning aircraft also caused firefighting foam to spill into the drainage system (Acton, 2014).

Following the crash, intensive efforts were made to clean up the contamination. Because SFO has a well developed response plan, cleaning up the contamination was successfully implemented. First, the pump stations that outflowed directly to the bay were taken offline to prevent any more fuel from flowing into the bay. Contaminated water was then pumped out of the pump stations so that the storm drains could be flushed. Approximately 3,200 feet of pipe were triple cleaned and flushed and the polluted water was removed from the storm drains and sent to an approved disposal facility. The pump stations were also thoroughly cleaned and treated to completely remove any trace of the spilled fuel. Samples were then collected to make sure that contaminants within the pipes and pump stations were eliminated. The whole process required $205,000 in costs (SFO, 2014). However, even after extensive cleanup operations, an estimated 81,000 gallons of water and 2,839 tons of soil were still contaminated from the disaster (Acton, 2014). As a result, it is our goal to minimize environmental damages from such incidents, especially pollution of the bay. We propose a smart drainage system that can instantaneously detect the presence of spilled fuel, automatically shut off flow to the vulnerable pump stations, and prevent any form of environmental harm.

Figure 1: Asiana Airlines Flight 214 right wing directly over catch basin (Acton, 2014)

2. Literature Review

2.1 Sources of Fuel Spills

Although our design serves as a response to the Asiana Airlines Flight 214 accident, airline crashes are not the only source of large fuel spills. Despite the fact that current airport practices have reduced the frequency of fuel spills, such incidents still occur. These spills can have a major impact on airport operations and the surrounding environment.

One such incident occurred in 2011 at Mitchell International Airport in Milwaukee (MKE), Wisconsin where a pipe carrying jet fuel leaked approximately 9,000 gallons of fuel into the soil and the nearby Wilson Creek, managing to spread through local waterways and even into neighboring communities. The discovery of the leak was delayed due to the negligence of the safety inspector. The response and cleanup for the fuel spill cost approximately $19.3 million (Vielmetti, 2015). Had a system of fuel sensors been installed, airport officials would have instantaneously known about the presence of a leak and would have not gone unnoticed as long.

Yet another incident occurred in 2013 at Jacksonville International Airport (JAX) in Florida where a tanker truck carrying 10,000 gallons struck a yellow bollard and spilled 7,000 gallons of jet fuel. The fuel managed to contaminate a large amount of soil and the storm drain system (Jacksonville, 2013). In this case, the accident is very similar to Asiana Airlines Flight 214 and system of fuel sensors and valves could have prevented some of the pollution of the storm drains.

Many fuel spills often occur during day-to-day airport operations, but on a much smaller scale than the incidents at MKE and JAX. Our proposed system is compatible and will completely neutralize any pollution into the surrounding environment. The Van Nuys Airport (VNY) Storm Water Pollution Prevention Plan (SWPP) summarizes the most likely areas for potential pollutants to enter the storm water (VNY, 2011). Table 1 summarizes the risks of such fuel spills.

Aircraft, Vehicle, and Equipment Maintenance Areas

Small leaks or spills from maintenance activities are not uncommon. These leaks are immediately cleaned up with the use of absorbents, limiting the chance of significant pollution discharge. Runoff that spills into floor drains in maintenance facilities usually run through oil/water separators before entering a sanitary sewage system, limiting the potential for pollution discharge into the storm drain system.

Aircraft and Vehicle Fueling Areas

Transfer of fuel from storage tanks is conducted with closed hose transfer connections. These operations are conducted throughout the airport but only on concrete ramps or paved areas. Any spills that occur are contained by absorption materials and vacuum pump clean-up methods before entering a catch basin. Despite these efforts, it is still possible for fuel to enter the storm drainage system.

Aircraft and Vehicle Washing Areas

Designated wash areas are located at specific locations throughout the airport and generally contain a wash rack and an oil/water separator. Non-designated wash areas are locations in the airport without wash racks or oil/water separators. These areas are the primary source of non-storm water discharges to the storm drain system. Undetected spills and petroleum residue on aircraft or vehicles being washed can be a potential source of pollution to the storm drain system.

Material Loading/Unloading Areas

Various petroleum products are regularly transferred between facilities at VNY. During petroleum product loading, spills, leaks, or the release of residues on the exterior of drums or containers could result in pollutants entering the storm drains.

Fuel Storage Areas

Chemicals, oils, waste oils, and petroleum products may be stored indoors or outdoors in 55-gallon drums. During a winter rain season, any residues on the containers or residues from spills or leaks in the storage areas are potential sources of that could contribute to pollutants entering the storm drain system.

Fuel Spill Source	**Risk**
Aircraft, Vehicle, and Equipment Maintenance Areas	low
Aircraft and Vehicle Fueling Areas	potential
Aircraft and Vehicle Washing Areas	potential
Material Loading/Unloading Areas	potential
Fuel Storage Areas	potential

Table 1: Sources of fuel spills at ORD (ORD, 1996)

The most environmental damage will occur in the event of a large fuel spill. Our system will work well with these types of spills. The different sources of large fuel spills are given by the Chicago O'Hare International Airport (ORD) Spill Prevention Control & Countermeasure Plan (SPCCP) and are summarized below (ORD, 1996).

Aircraft Crashes

In the event of an aircraft crash, large amounts of fuel can be spilled. The worst case scenario is based on the largest aircraft that an airport services being fully loaded with fuel and losing all of its fuel. For this chart, the largest aircraft refers to the Boeing 747-400 which can hold 53,985 gallons of fuel in four tanks. The worst case scenario is defined as two of the tanks being punctured and losing all of its fuel, about 27,000 gallons of fuel (Table 2). Such accidents, if they occur would most likely happen on the runways and in close proximity to storm drains.

Storage Tank/Pipes Leaking

Storage tanks or piping can also rupture or leak which can result in the release of fuel. These leaks have the potential to spill massive amounts of fuel if left undetected. Such accidents may occur in close proximity to storm drains.

Fueling Operations

Fueling operations can include filling or removing fuel from different sources, i.e. from fueling an aircraft from a tanker truck. During these operations, a fuel spill can occur. It is also possible for an aircraft to collide with ground service equipment and rupture its fuel tank, spilling large amounts of fuel. These incidents are limited towards airport aprons and ramps which are in close proximity to storm drains.

Vehicle Accidents

A vehicle at an airport can possibly have a ruptured tank or other malfunction that results in the spilling of fuel. The worst case scenario involves a fully loaded fuel tanker truck spilling all of its contents. Such accidents are most likely to happen on airport aprons or ramps which are in close proximity to storm drains.

Potential Source	Type of Material	Worst Case (gallons)	Actual
Aircraft Crash	Jet Fuel	27,000	0
	Aviation Gasoline	2,000	0
Storage Tank & Fueling Operations	Jet Fuel	4,000	600
	Aviation Gasoline	500	10
	Diesel	1,000	0
	Gasoline	200	50
	Waste Oil	100	0
	Ethylene Glycol/Urea	2,500	0
	Heat Transfer Oil	50	0
Vehicle Accident	Diesel Fuel	7,000	75
	Gasoline	8,000	0
	Hydraulic Oil	20	10
	Ethylene Glycol	5,000	0

Table 2: Sources of fuel spills at ORD (ORD, 1996)

2.2 Fuel Spill Response

To determine how fuel spills are currently handled, we reviewed existing fuel spill response strategy documents of many other airports, specifically the ORD SPCCP, the Darwin International Airport (DIA) Spill Management Handbook, the FAA Advisory Circular 150/5200-18C and 150/5230-4B. Many of these strategies proved to be similar, with most airport fuel spill strategies only focusing on identification, containment, and cleanup methods. These strategies are merely responses to spill incidents, which can happen a significant time after the incident has occurred. In fact, for many airports fuel spills are identified by airport personnel who have to report it first before any measures are taken. During this time, there is a high chance that large volumes of fuel can spill into drainage systems. The only preventative measures taken to prevent fuel spills were the safety training of staff who might handle fuel spills. The safety training program included information about current FAA codes, fire safety, safe handling procedures, proper fueling procedures, different fuel types, different fueling methods, leak and spill protection, spill reporting procedures, spill control, cleanup procedures, and emergency procedures (FAA, 2012).

For the case of ORD, a fuel spill notification process starts with the discovery of a leak or spill. Personnel must then contact the airport command center to report about the fuel spill. The person reporting the spill must provide information about the location of the spill, the type of material spilled, the approximate volume and area of the spill, the direction of movement of the spill, and action being taken to contain the spill (ORD, 1996). If a large enough spill occurs, the fire department is contacted to help clean up the fuel. According to the DIA Spill Management Handbook, once a fuel spill occurs, it must be established whether there are many storm drains nearby that need protection. These drains are then checked to determine whether any fuel has entered the storm drains. The spill is stopped from spreading by placing absorbent material in a down slope position and by blocking any catch basins (DIA, 2013). We believe that these processes are too slow in preventing the contamination of storm drains, pump stations, and any surrounding bodies of water. It would be ideal to have storm drains automatically redirect the pollutants if a spill is detected. After reviewing numerous airport spill management documents, we believe there is no existing method to automatically detect and redirect fuel entering a storm drain system.

There are indeed many existing fuel leak detection systems. However, these systems are mostly used to detect leaks in pipes and fuel storage facilities in industrial settings and have not been employed in airport storm drain systems. We believe that these sensors can be used to help us automatically detect contaminants in an airport storm drain system. If contaminants are detected, the sensor can notify a valve and automatically redirect flow in the affected area. Through our research, we have identified which sensors and valves will best fit our needs and detailed these specifications in Section 6 of this report. Upon reviewing literature, we have concluded that our system is a novel approach and many airports can benefit from our system.

3. Problem Statement

Fuel spills are a major concern with regard to safety, and can have devastating effects on the local environment. Due to the threat that fuel spills pose, it is of critical importance that suitable measures are taken to ensure that spills are contained using the safest and most efficient methods to minimize all health and environmental damages. Many airports are located next to bodies of water that may contain vulnerable ecosystems such as John F. Kennedy International (JFK), Los Angeles International (LAX), LaGuardia (LGA), Oakland International (OAK), Ronald Reagan Washington National (DCA), etc. Even a small amount of leakage may cause great harm to aquatic life. Fuel spills also impact the shorelines around contaminated waters and interact with sediments such as beach, gravel, rocks and vegetation. This can have direct and indirect impacts on the ecosystem as well as people's lives.

The FAA currently has a set of general procedural guidelines on containing fuel spills. The main method of containment used in these guidelines is for booms to be set up by the emergency response teams to control the flow of fuel. Once the spill is contained the fuel is removed using a pump or an absorbent and sent off to an approved disposal facility. This system of containment and cleanup leaves much room for improvements in safety and efficiency and also does not address the issue of fuel which enters the storm drain system. The Asiana 214 crash at SFO is a prominent example of why this issue needs to be addressed. The resulting spill from the crash sent approximately 3,000 gallons of fuel into the storm drain which clogged the system and necessitated an expensive cleanup of the pipes and, more importantly, the pump station. Our design focuses on addressing these problems by using a set of sensors to identify and react to a spill to reduce the possibility of human error and ensure the highest level of safety for passengers and emergency personal. By optimizing containment of the spill we also seek to make cleanup efficient so that normal airport operations can be resumed as soon as soon as possible. Our system will be a major improvement over the existing system (Table 3) and minimize the environmental impacts of such an incident.

Problem	**Existing System**	**Proposed System**
Fuel Spill Detection	Reported by personnel on site	Automatically detected
Fuel contaminates drainage system	Expensive cleaning of pumping stations and pipes	Clean pipes with flushing
Removal of spilled fuel	Multiple pump stations shut down, contaminated water pumped out	Contaminated water pumped out from single location
Fuel flows into bay	No method	Redirected to storage tank

Table 3: Existing system vs. proposed system

4. Problem Solving Approach

Our goal for the project is to minimize the impacts of a fuel spill, especially one that is caused by a catastrophic incident such as an aircraft crash. We decided to limit the scope of our design analysis to SFO in order to evaluate the feasibility of such a system on an existing airport that was affected by a major fuel spill event. However, our design can be easily implemented in any airport with a storm drainage system. First, we completed a case study on Asiana Airlines Flight 214 to determine the impacts this incident had on SFO and its surrounding environment. We then created a design to help mitigate the damaging effects of the crash. In order to produce the best possible design, we investigated, evaluated, and analyzed the design and methods for the smart storm drain system. If certain problems were found in the design, the same analysis process is repeated to establish an improved design. This was iterated until an acceptable final design that meets all of our objectives was determined. The main objectives for our design are summarized in Figure 2.

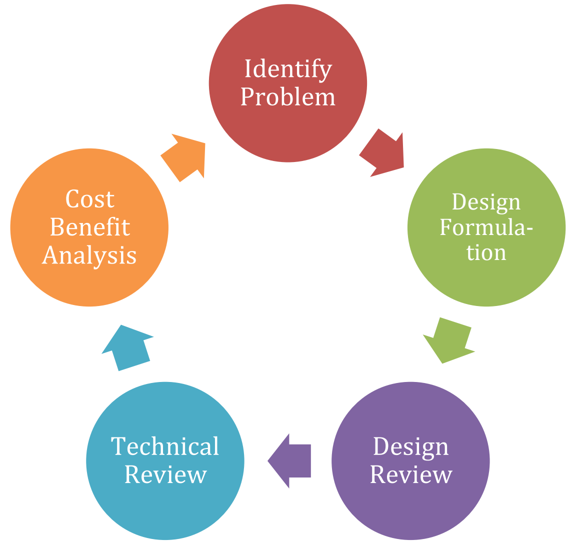

Figure 2: Design Process

Objectives of Smart Drainage System

- Immediate notification and response
- Automation/Eliminate human error
- Save time and costs on clean up
- Better containment
- Lower environmental risk

4.1 Design Phases

Our final design is a result of three iterations of the design process. Each phase of the design process (Figure 3) is summarized below.

Preliminary Design: Catch basin improvement

Probes and valves are installed in the majority of catch basins along the runway.

Intermediate Design: Separate optimized system

A new pipe system is to be designed and optimized. The new system will be connected to existing catch basins but will be separate from the storm drainage pipes.

Final Design: Partial enhancement

This design is derived from both the preliminary and intermediate designs and serves as a compromise between the two. We take advantage of the existing system by connecting additional sensors and valves before the entrance of pump stations. A new storage tank for spilled fuel is installed and will be connected by the additional pipes.

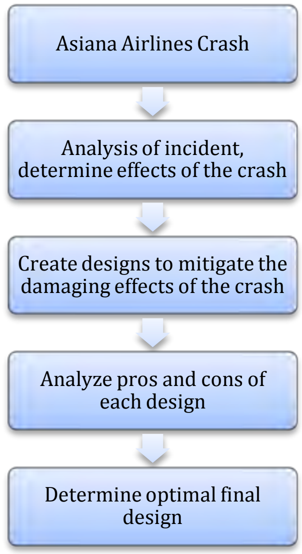

Figure 3: Design Analysis Process

4.2 Implementation at San Francisco International Airport

The storm drain system map of SFO shows the locations of catch basins, pump stations, and the existing pipe system (Figure 4). The storm water drainage map divides the airport into separate drainage areas and indicates the slope of each drainage area (Figure 5). When the two maps are combined, it is clear which catch basins serve which drainage area (Figure 6).

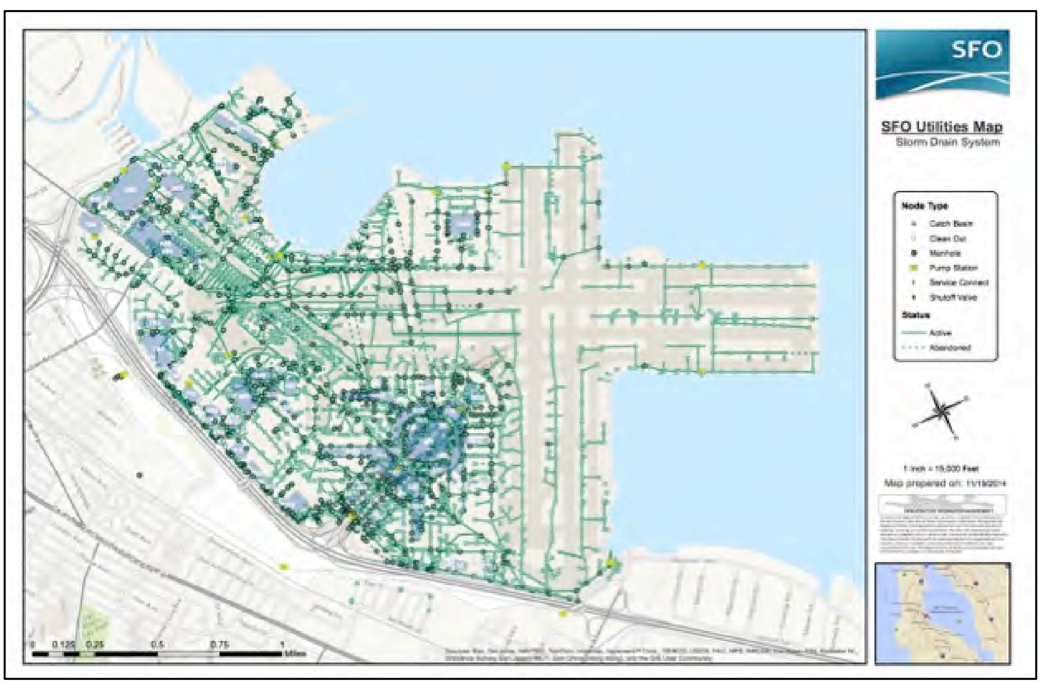

Figure 4: SFO pipes, catch basins, pump stations map (SFO, 2014)

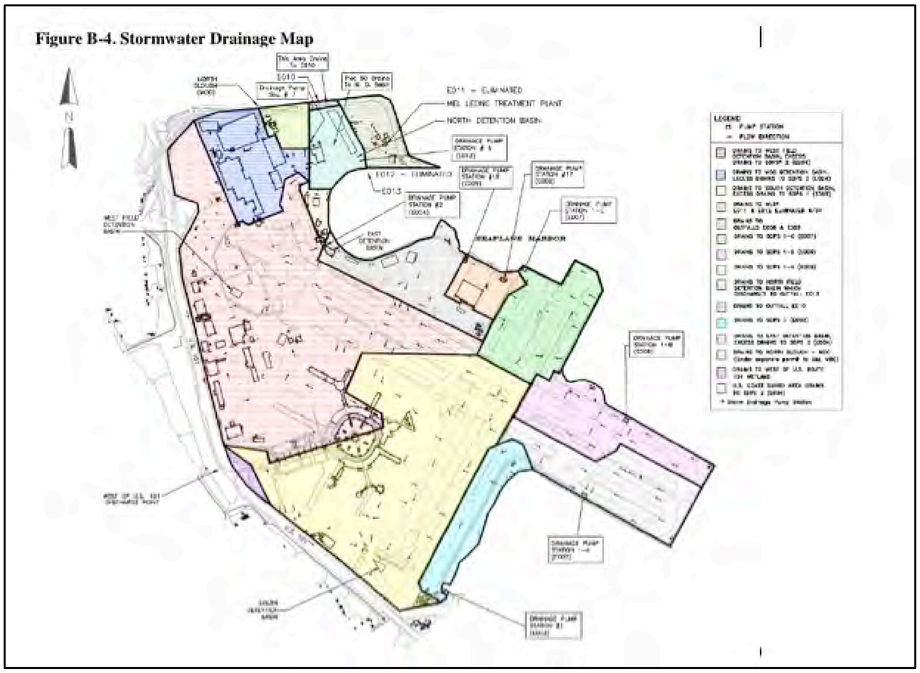

Figure 5: Storm Drain System of SFO (SFO, 2014)

Figure 6: The Combined Map and Marked Research Area (SFO, 2014)

The Asiana Airlines Flight 214 crash occurred in the drainage area highlighted with the red line (Figure 6). For the analysis, runways were assumed to have a higher possibility of a large fuel spill, especially for the case of aircraft crashes. To simplify our analysis and focus our study on the specific incident of the crash of Asiana Airlines Flight 214, we limited our design to the drainage area highlighted in red. However, other drainage areas on the map share the same characteristics as our highlighted area, specifically runways, ramps, and aprons located near catch basins. Although our analysis is constrained in the highlighted area, our design can be easily replicated in the other drainage areas.

5. Design Analysis

5.1 Preliminary Design

Description: In the preliminary design, the majority of catch basins will be fitted with sensors and valves. When a spill occurs, the sensors will detect the presence of fuel and the valves will shut down. The fuel would then be confined to the catch basin. Any overflow would be forced back up onto the pavement.

Design Goals:

1. Prevent fuel from entering the pipe network and bay
2. Reduce the effect to the airport operation during construction

Study Process:

The initial plan was to fit every catch basin with sensors and valves. We counted the number of catch basins within the research area on the satellites image and drainage system map. We found 87 catch basins in our study area. The cost of installing sensors and valves for every catch basin was too high. Also, after research on several crash reports, we found out that a large percentage of aircraft accidents occurred along the runways or on the sides of runways. Fueling operations and vehicle travel also occur on or near runways and pavements. As such, we determined these areas to have the highest chance of a fuel spill incident occurring.

However, if a spill occurs on a runway, there is still a chance that the fuel will leak out of the boundaries of the runway. In the case of a spill, ORD classifies large spills as spills with an area of 10 square feet (ORD, 1996), while Darwin International Airport classifies larges spills with an area of 2 square meters (DIA, 2013). In this case, even a large spill may not reach certain catch basins. However current airport standards are not very representative of spills during catastrophic events. To address this issue, ArcGIS was used to complete an analysis of the risks of catch basins being contaminated with fuel in the event of a large spill. The storm drainage plans were geo-referenced and a 50 foot buffer was set around the borders of the runway (Figure 7). Fifty feet was chosen to represent how far outside the boundaries of a runway fuel may spill during a large spill event. To account for an extreme fuel spill event, this value was chosen to be much larger than what is classified in current airport standards as large fuel spill. Even then, many catch basins are located far away from the most probable spill area. In this case, with an existing system, it is not necessary to install sensors and valves in every single catch basin. We decided to only implement the sensors and valves in the catch basins on the sides of runways and ignore the catch basins near the shore or far away from the runway (Figure 8), for they have a very low likelihood of collecting spilled fuel. Note: in a situation where cost is not an issue, it would always be better to install sensors and valves on every catch basin as there is a chance that an aircraft crash can occur anywhere.

Figure 7: Runway with a 50 foot buffer. Note that some catch basins are not at high risk of a large fuel spill (SFO, 2014)

Figure 8: Catch basins with sensors installed

Results:

The probes are installed at the entrance of catch basins (Figure 8). They can detect the presence of petroleum hydrocarbons in water and communicate with a central processor. Then the processor will command valves to shut down so that the pipes are protected from pollution of spilled fuel. The pipes are isolated and will not be polluted by the fuel. The pipe system is protected and if the fuel on the ground is removed timely, the drainage system can be back online quickly with no need to clean the pipe system and pump stations. However, in the event of a large spill, the fuel will overflow the catch basin and pollute the soil. Remediation will be necessary after the accident and the overflow fuel may be a fire hazard. Since the catch basins are closed, the drainage system will be partially inoperable after an accident. A coming storm would also exacerbate the situation after the spill.

5.2 Intermediate Design

Description: Our intermediate design contains an entirely redesigned pipe system for storm water drainage and fuel collection. The fuel collecting pipes will share the same catch basins with storm water drainage system. The sensors in the catch basins will be able to determine which system to divert the flow to. The location of the storage tank could be optimized to ensure an efficient pipe network.

Design Goal:

1. Storm drainage system and spilled fuel pipes operate separately
2. Easy clean up of an existing pipe system
3. Reduce potential fire hazards

Study Process:

The idea of an optimized storage tank location is inspired by civil systems optimization and shortest path problems. In order to complete our optimization, we used dynamic programming to calculate the cost of building the storage tank and pipes given the locations of catch basins. In the case of SFO, it is complex to work on the whole system and optimize. Thus, we set a simplified model to simulate the situation and complete the optimization.

A simplified map of SFO consisting of a scatter plot of weighted points on a 15x15 grid is first generated (Figure 9). Each weight represents a cost coefficient that differentiates the costs of building in different portions of the study area. The cost to build between the grassland would be the cheapest, so we assign a cost coefficient value of 1. The cost coefficient of installing pipes in the bay is 2 since installing pipes in the water would be more expensive and require more specialized equipment. The cost coefficient of building pipes across runways is 3. It is the most expensive since we do not want to disrupt runway operations with construction. In this case, we want to compare the cost of different drainage layouts and different storage tank location.

Step1: According to the geographical drainage area, we define the simulation into two sections (Figure 10).

Step 2: We calculate the shortest route from intersection (a*, b*), the potential location of an optimized storage tank on the grid in section 1 as defined in step 1. In this step, we set *i* and *j* as the indices of grid. In this case, the storage tank is expected to be constructed on any of the grid intersections except the ones on the runway area. The construction process is fixed in time *k*, which means that, with *k* plus 1, the end of a potentially optimized pipe is extended to the next grid. The process will be solved recursively from the destination of the pipe end, in this case, the intersection (a*, b*).

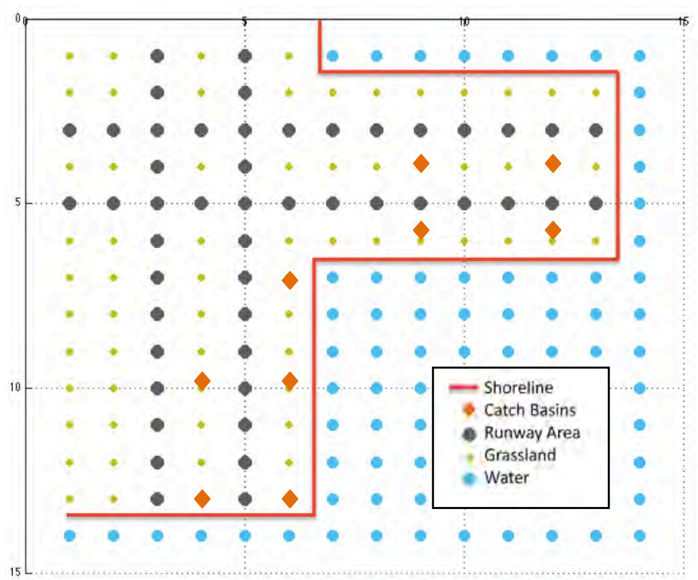

Figure 9: Simplified model of SFO runway study area

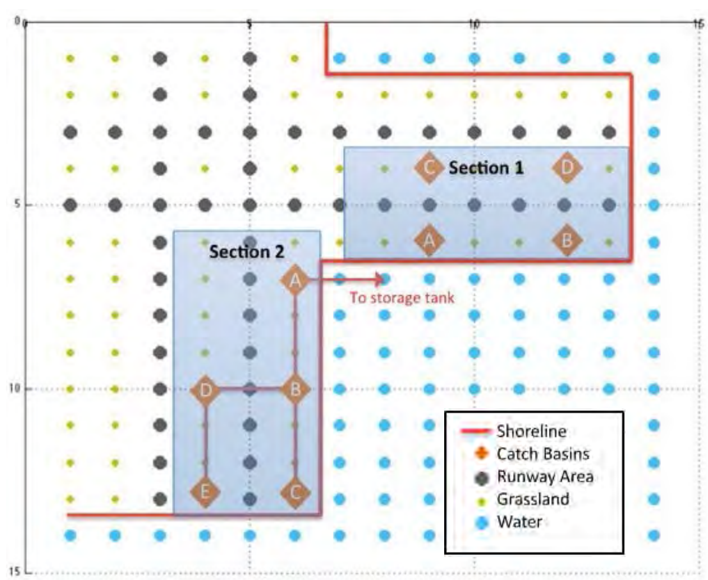

Figure 10: Runway sections for analysis in step 1

The objective function in this step is

$$\min \sum_{k=0}^{N-1} \sum_{i-1}^{M} g_k(X_k^i, U_k^i) + g_N(X_N^i)$$

where $g_k(X_k^i, U_k^i) = \alpha_k^i \| U_k^i \| = \alpha_k^i \sqrt{{U_k^i}^T U_k^i}$

and $X_k^i = [x_k^i, y_k^i]^T$

$U_k^i = [\, u_k^i, v_k^i]^T$

$(x_k^i, y_k^i) -$ The location of pipe i's end from (a*, b*) in time k;
$(\, u_k^i, v_k^i) -$The movement/extension of pipe i's end at the end of time k;
$\alpha_k^i -$The cost coefficient of pipe i's end at the end of time
($\alpha_k^i = 1$ if the area is grassland; $\alpha_k^i = 2$ if the area is bay; $\alpha_k^i =$
3 if the area is runway area)
$X_k^i -$ Matrix of the state variable (x_k^i, y_k^i);
$U_k^i -$ Matrix of the decision variable$(\, u_k^i, v_k^i)$;

The constraints of this objective function are:

$x_k^i \geq 1$ [The grid west boundary of pipe end];

$x_k^i \leq n_x$[The grid east boundary of pipe end];

$y_k^i \geq 1$ [The grid south boundary of pipe end];

$y_k^i \leq n_y$ [The grid north boundary of pipe end];

$(u_k^i, v_k^i) = \{1\ 0 - 1, 1\ 0 - 1\}$[The only one-step moving constraint];

$X_N = (a, b)(Final\ Position)$;

$k \leq N$ [The time step constraint]

For solving the optimization, we need to follow the principle of optimality. The process is as follows:

The value function is:

$$V_k(X_k) = \min_{U_k}\{g_k(x_k^i, u_k^i) + V_{k+1}(X_{k+1})\} = \min_{U_k}\{\alpha_k^i \sqrt{{U_k^i}^T U_k^i} + V_{k+1}(X_{k+1})\}$$

The principle of optimality equation and boundary conditions

$$V_k(X_k) = \min_{U_k}\left\{\alpha_k^i\sqrt{{U_k^i}^T U_k^i} + V_{k+1}(X_{k+1})\right\}$$

$$= \min_{U_k}\left\{\alpha_k^i\sqrt{{u_k^i}^2 + {v_k^i}^2} + V\left(x_{k+1}^i, y_{k+1}^i\right)\right\}$$

If the pipe i's end is at the final position, which is (a*, b*) in this case: $V\left(x_N^i, y_N^i\right) = 0$

Otherwise: $V\left(x_N^i, y_N^i\right) = \infty$

Step 3: Conclude the best solution for the particular storage tank (a*, b*). We can find the shortest path from the exit catch basin A to (a*, b*) using the process in last step. Defined as $S_{se\_c,}$ where *se* stands for the section number and *c* stands for the letters for catch basins. The values of S_{se_c} are saved for later steps to sum up the total cost in the situation when storage tank is located at (a*, b*).

Step 4: We now generalize for feasible storage tank locations on the grid. From the last step, we can get the lowest cost of intersection (a*, b*) connected with different exit catch basins. Since we do not know where the storage tank is exactly located and the relationship between section 1 and 2 yet, we cannot assert which catch basin is the exiting one. In this step, we will let the program go through every pair of intersections (a, b) with different exiting catch basins. Each pair of intersections (a, b) will have two reaches to the section 1 and 2 respectively. We will compare these pairs.

In mathematical expression, the cost function is:

$$C_{total} = C_{sectionplan} + C_{storagetank}$$

where $C_{storagetank} = C_{(a,,b)to\ section1} + C_{(a,,b)to\ section2} + \beta_{(a,b)} \times C_{installation\ of\ storage\ tank}$

The $C_{installation\ of\ storage\ tank}$ here could be the basic cost of installing a storage tank. The $\beta_{(a,b)}$ is a matrix assigning weight on the cost according to the land type, namely, 1 for grassland, 2 for bay, and infinity for runways. The infinity here means that it is impossible to install any storage tank on the runways.

$C_{sectionplan}$ is the cost of dranage design within two sections assigned to exiting catch basins.

$C_{storagetank}$ is the cost of the storage tank and connecting the storage tank to two sections. After the comparison, we can derive the best solution for the storage tank location and drainage system layout of the study area as shown below.

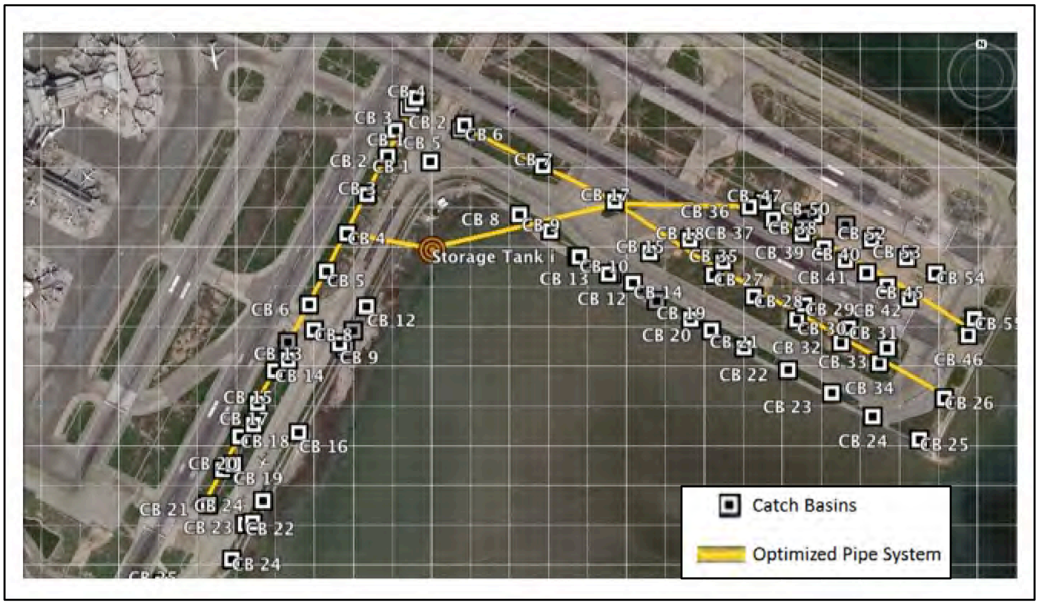

Figure 11: Initial solution for the new piping system

Results:

When applying the optimization method to the runways, it was determined that a possible location for the storage tank could be the open area in the intersection of the runways as seen in Figure 11. The yellow lines shown on the graph represent the fuel collecting pipe systems, which are connected to the catch basins on the sides of runways. After the optimization program was run with all the runways included, the fully optimized system of pipes can be determined (Figure 12).

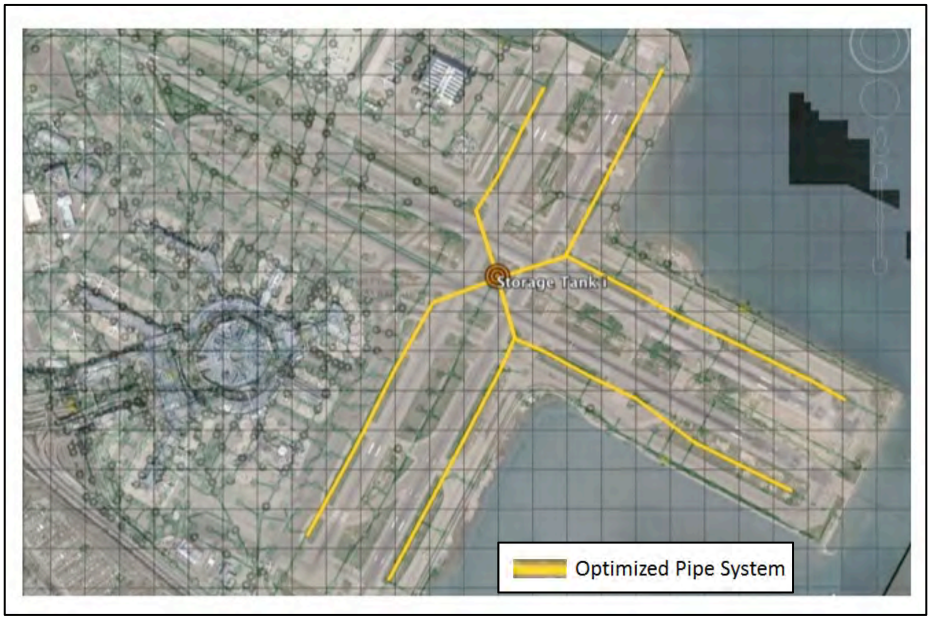

Figure 12: Optimized pipe system for all runways

Advantages: Storm water drainage will not be significantly affected by any spill. Thus the drainage system may operate well in a possible storm after emergency.

Disadvantages: The construction of this system may affect the operation of runways. This option is extremely costly for a running airport.

5.3 Final Design

Description: The final design serves as a compromise between our two previous designs. In this design, we use a new storage tank for captured fuel and connect the existing pipe system to that storage tank with new pipelines. The pipe system around the runways will not be changed. Valves and additional pipelines will be attached before the entrance of pump stations.

Design Goal:

1. Collect the fuel in storage basin
2. Easy clean up of existing pipe system
3. Reduce potential fire hazards

Study Process:

After studying the existing drainage system of SFO, we found the locations of the lowest elevations of the existing drainage system to correspond to the locations of the pump stations. The flow in the pipes is directed to the pump station through gravity. The concept of this design is to let the spilled fuel flow through the existing pipe system and redirect it to the additional pipelines before entering the pump stations. Then the fuel will be collected in the storage tank and transported to a designated disposal facility. The contaminated pipes could be cleaned by flushing with water. The flushed water will then be collected in the storage tank and treated properly. We determined the locations for the pipes and storage tank using the same optimization process detailed in the intermediate design. The only difference is that each section only has one exit catch basin.

When applying the final design, the exiting catch basins in each section have already been decided since we are using the existing pipe system. The layout of system is shown in Figure13.

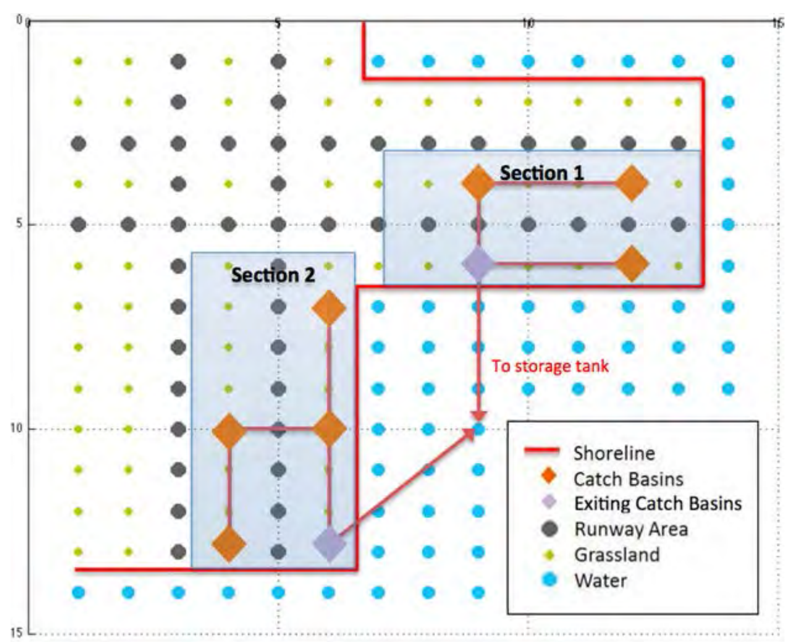

Figure 13: Section plans and exiting catch basins in SFO case

The purple diamonds in Figure 13 represent the catch basins and pump stations that connect to the storage tank. The optimization of storage tank follows the formula in intermediate design.

The total cost function in this SFO case is

$$C_{total} = C_{sectionplan} + C_{storagetank}$$

and $C_{sectionplan}$ is constant in this case. The only decision variable is $C_{storagetank}$.

$C_{storagetank}$ is the cost of storage tank and connecting the storage tank with two sections.

$$C_{storagetank} = C_{(a,,b)to\ section1} + C_{(a,,b)to\ section2} + \beta_{(a,b)} \times C_{installation\ of\ storage\ tank}$$

where $\beta_{(a,b)}$ is a matrix assigning weight on the cost according to the land type.

Results:

We believe that this design is a reasonable solution for SFO. In this case, the research area contains the two parts of the storm drainage area as mentioned in the intermediate design (Figure 10). To reduce the cost of storage tank installation, we assigned one storage tank to both storm drain areas. The location of the storage tank was determined to be in the area near the shore between two storm drains (Figure 14) by using the previous optimization methods. The additional pipelines are implemented along the shore, which connect the two existing storm drain systems to the storage tank. Their paths were also determined by using the previous optimization methods. We implement sensors and valves at the connection. In normal operations of an airport without fuel spill, the pipes to the storage tank will be shut down. Whenever the sensors detect fuel, the valve would automatically close the flow the pump station and open the pipes to the storage tank. After an emergency, the contaminated fluid would be transferred out of the storage tank and treated. Although our design is based on SFO, it can be easily used in any other airport.

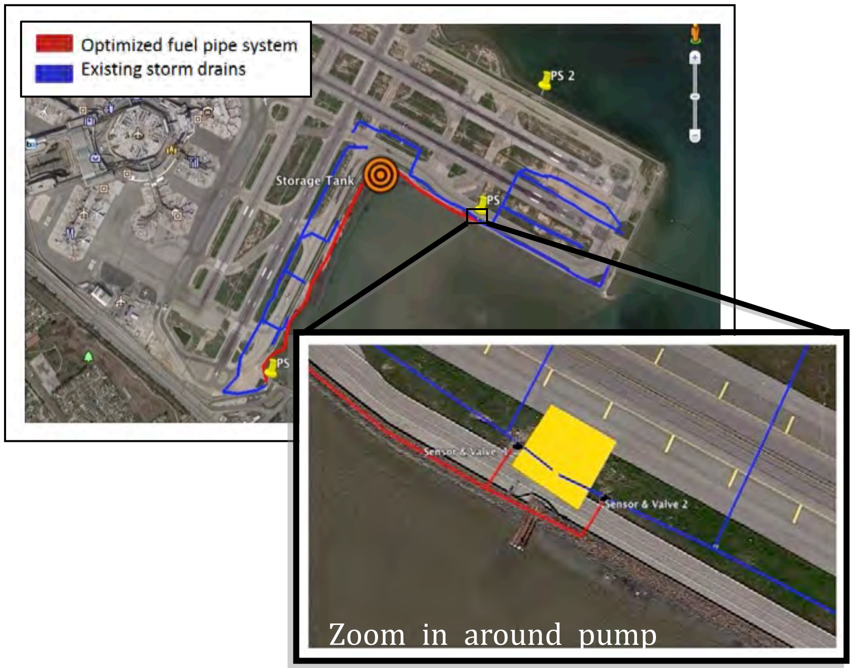

Figure 14: The pipes in Option 3 and details around pump station

Advantage: Spilled oil is confined in certain containers. The pipes end up within the container, so that the polluted pipes can be flushed and the wash water collected. Pump stations are also isolated from pollution and airport operations will seldom be affected.

Disadvantages: A large portion of pipes may be polluted depending on the spill location. However, contaminated pipes are relatively simple to clean.

6. Technical Details

6.1 Sensors

In order to select sensors that best fit the needs for the design a set of criteria was created to evaluate and select the most suitable option. The 4 main criteria set were accuracy, response time, cost, and required maintenance.

Accuracy is an essential part of the design because an inaccurate sensor would have one of the biggest impacts in reducing the effectiveness of the system. A worst case scenario would involve the sensors incorrectly detecting a spill and diverting the flow unnecessarily. Therefore one of the measures employed was the accuracy and precision ratings supplied by the manufacturers, where the sensors with the lowest accuracy ratings were automatically cut from consideration. Another failure to account for was a spill that goes undetected. For this the lower limits of detection were compared for each option, as well the types of hydrocarbons that each can detect to ensure that jet fuel would be detected.

The measures for response time and cost were relatively straightforward, with the amount of time and cost being taken and compared directly. Required maintenance however, was tested more subjectively and was based on recommendations given by the manufacturers.

Petrosense CMS-4000

The sensor that best fit the needs based off of the design criteria was the CMS-4000 (Continuous Monitoring System) which is manufactured by Petrosense, a company which specializes in real-time petroleum hydrocarbon monitoring systems. In terms of accuracy, the CMS-4000 proved to be the best option and it has the extremely important feature of continuous monitoring. Another important feature that this sensor boasts is that it has no moving parts and is corrosion protected so the maintenance time and costs are both kept quite low. The CMS-4000 employs a Fiber Optic Chemical Sensor to detect the presence of hydrocarbons in the water. The scatter of light in the water is dependent on the concentration of hydrocarbons, and so by identifying this quantifiable relationship the sensor can determine that concentration. Once calculating the concentration, the probe can then remotely send that information to the data logger which will be connected to the drainage control system.

Fox Spill Control System SCS600

The Fox SCS600 is another diversion system which was found to be a good fit for the design. The SCS600 is a more complex system than the CMS-4000. The diversion system is installed in the catchment basin itself, and consists of a chamber, holding tank, and diversion valve. At the commencement of a rain or spill event the chamber fills to the level of the float, at which point the chamber contents is emptied into the wastewater holding tank. In the holding tank, the concentration of hydrocarbons in the water is measured, and if the set concentration limit is passed the holding tank's contents are sent through the diversion valve to the main fuel holding tank. Some advantages of this method are that the influent is continuously measured in small volumes and the fuel can be diverted immediately before entering the existing storm drain pipe system. The main drawbacks of the SCS600 are its complexity and its cost. The implementation of the system would require a separate pipe network devoted to fuel spill management as indicated in our final design. The cost of the SCS600 would also necessitate a comprehensive analysis of locations where fuel spills are most likely to occur in order to deploy the system only in locations where it is most needed, which ensures its financial feasibility.

Sensor Notification Process

When fuel is detected, the sensors will send out electronic signals to two locations, the airport operation control center and the corresponding valves. The airport operations control center serves as the command, coordination, and control center for the entire airport and monitors many processes including fueling. In many airports, fuel spills are only reported to the control center once spotted by airport personnel. With sensors installed, the fuel spill can be instantaneously communicated with the control center and allow for a quick response time to the incident. Sensors will also activate the valves to redirect flow away from the pump stations. Only valves that are located on pipelines that are affected by a fuel spill will be activated.

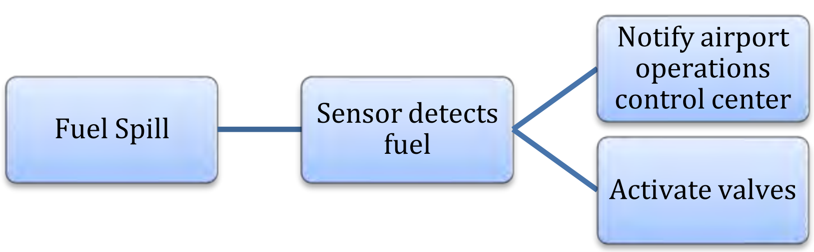

Figure 15: Sensor notification process

6.2 Pipes

We selected PVC (Nonmetallic pipe in Table 4) as the material used to construct our pipelines. PVC is a thermoplastic material derived from common salt and fossil fuels. It is resistant to many chemicals, in our case petroleum fuels, and is commonly used in industry to transport different types of fuels. The additional piping for the system was chosen to be PVC due to the material's strong chemical resistance, durability, and longevity. If installed correctly, PVC pipes can have a useful lifetime of up to 100 years. The auxiliary piping will not be used unless a spill occurs and will not experience high pressures so it was decided the higher unit cost of steel pipe was not justified for this design, and that PVC would suffice.

MATERIAL	STANDARD (see Chapter 15)
Brass pipe	ASTM B 43
Copper or copper-alloy pipe	ASTM B 42; ASTM B 302
Copper or copper-alloy tubing (Type K)	ASTM B 75; ASTM B 88; ASTM B 280
Labeled pipe	(See Section 1302.4)
Nonmetallic pipe	ASTM D 2996
Steel pipe	ASTM A 53; ASTM A 106

Table 4: Different types of fuel pipe materials (NYC 2008)

6.3 Control Valves

Control valves are an important component in any system where fluid flow must be monitored and manipulated. A complete control valve consists of a valve and an actuator. Actuators are the mechanical equipment that supply the force needed to open or close a valve. Selection of the proper type of valve and actuator involves a comprehensive knowledge of the process for which it will be used.

Valves mostly come in the following 4 major types: ball, butterfly, globe, and plug valves. A ball valve consists of a ball that can be spun to open or close a flow. These valves can operate quickly for an on/off application and are easy to clean but are limited in size. A globe valve is a plug that moves into and out of a globe to open, throttle, or close flow. These valves can be used for precise throttling but are limited by high pressure drops and are also difficult to clean. A plug valve consists of a plug that rotates to open, throttle, or close flow. It is good for quick shutoffs but has a limited throttling ability and has a high cost. A butterfly valve consists of a disk that is rotated about its diameter to open, throttle, or close flow. These valves are cheap, good for low pressure drops, and suitable for handling large flow capacities but suffer from some torque issues. We believe that the butterfly valve is the most suitable valve for our system due to its numerous advantages. Large fuel spills will necessitate a valve that is capable of flow control at large capacities. The valve's inexpensive cost is also desirable, especially in our preliminary design in which valves are fitted at many catch basins *(Katzman et. al, 2007)*.

When selecting an actuator, one of the most important features to look at is whether the fail-safe is opened or closed. In an event where all the power goes out or an emergency occurs, the fail-safe mode of the valve can be a huge factor in preventing disaster and even saving lives. In our case, it would be advantageous to select an actuator with a fail-safe mode of being closed in order to have the system set to be ready to divert spilled fuel.

The different types of actuators are summarized in Table 5. After reviewing current applications of different actuators, we felt pneumatic or hydraulic actuators were the best fit. However, pneumatic actuators have a delayed response time while hydraulic actuators have an almost instantaneous response time. This delayed response time is not suitable for our design in which one of the objectives is to divert the flow as quickly as possible to prevent any contamination. We believe that the hydraulic actuator is the best fit for our design despite its high cost.

Actuator	Description	Advantages	Disadvantages
Pneumatic	Compressed air fills a chamber and pushes against a spring, operating the valve	Failsafe action, reliability, low cost, and ease of maintenance	Limited force applications
Motion Conversion	Consists of a disk connected to a rod. The rod moves axially and pivots the connection with the disk, causing the disk to also pivot.	Inexpensive and can be used for rotary valves	Limited to applications of 90° or less rotations.
Hydraulic	Similar to pneumatic, but a uses an incompressible fluid	Small size with large force	High cost
Electric	Electric motor with a rotating gear that moves the valve.	Low overshoot and accurate positioning	Needs a backup battery in case
Manual	Typically either a level or wheel connected to a screw	Good for an override in case of failure of	Not efficient as primary

Table 5: Different types of actuators (Katzman et. al, 2007)

Figure 17: Butterfly valve with actuator (Pauly, 2009)

6.4 Storage Facilities

As mentioned previously, the design calls for the implementation of a fuel storage facility capable of handling spilled fuel entering the drainage system. Since this tank is required to hold large amounts of volatile fluids, safety and standards of the tank are of upmost importance. It is crucial that none of the fuel escapes into the surroundings, since one of the main design goals is to reduce the incidence of environmental damage. The design addresses this problem with the use of an underground storage tank (UST).

Although a UST proves to be more expensive than an aboveground storage tank (due to excavation and necessary mechanisms mentioned later in this section), a UST is a much better fit for the Smart Drainage System design. In the context of a drainage system retrofit for SFO, utilizing a UST takes advantage of the existing layout of the storm drain system. Based on the suggested locations in for our final design, the UST will be fed by a gravity-driven pipeline. This reduces the need for pumps to propel the contaminated flow, reducing the overall cost. Installing an UST also saves ground space that can otherwise be used for runway, taxiway, or any surface on the air side. Storing fuel below ground increases the likelihood of leaks; thus, regulations must be set to minimize the occurrence of spillage.

EPA Regulations

In order to protect the environment, the U.S. Environmental Protection Agency (EPA) regulates the installation and operations for USTs. As described in Musts For USTs: A Summary Of The Federal Regulations For Underground Storage Tank Systems (EPA 510-K-95-002)

The EPA stipulates that four requirements be met for an UST to be approved:

- Tank and piping are installed according to industry codes.
- The UST must have leak detection.
- The UST must have devices that provides spill and overfill protection.
- The UST must have corrosion protection.

Installation

Here installation encompasses excavating soil, assembling the tank, positioning the tank, backfilling around the tank, and grading the surface. Following proper guidelines when installing the UST ensures that no leaks will result from a faulty mechanism or any structural failures. Correct installation is fulfilled by using a qualified installers who follow industry codes (EPA, 1995).

Leak Detection

USTs must be monitored to alert owners when a leak occurs and must meet three requirements (EPA, 2011):

1. Owner can detect a leak from any portion of the tank or its piping that routinely contains petroleum
2. Leak detection is installed, calibrated, operated, and maintained in accordance with the manufacturer’s instructions
3. Leak detection meets the performance requirements described in the federal regulations

One or any combination of the following monitoring methods and mechanisms can be used to create a system that fulfills the leak detection standards. First, interstitial monitoring detects any leak that occurs in the space between the UST and secondary containment unit. Another method utilizes an automatic tank gauging system monitors the current level of fluids in the UST (Figure 16). Monitoring for vapors in the soil is also an important aspect of leak detection. This is accomplished by sampling vapors in the surrounding soil for any petroleum products. Monitoring for liquids in the groundwater ensures the water table is protected from contamination. Here, the actual water table is monitored to detect any fuel that may have been released into the groundwater. This is one of the most frequently checked areas due to the severity of the consequences (EPA, 2011).

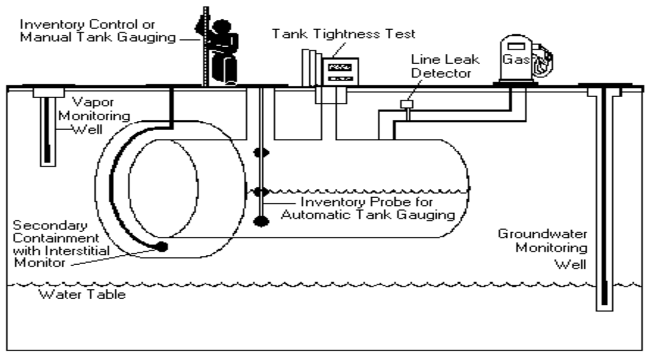

Figure 16: Some Leak Detection Methods (EPA, 2011)

Spill and Overflow Protection

While spill and overflow protection mainly apply to fuel storage tanks intended for refueling purposes, several of these standards can be applied to the USTs selected in our design. Since the Smart Drainage System does not include a fill pipe to the UST, spill protection requirements can be ignored. The occurrence of overflow is solved through the use of overfill protection devices (Figure 18). The Smart Drainage System will operate by pairing an automatic shutoff device with an overfill monitor and alarm. In the event of a volume of contaminated fluid entering the system exceeding the capacity of one storage tank, the overfill monitor will trigger the automatic shutoff device (ASD) when the tank is at 90% capacity or within 1 minute of overflowing. Once triggered, the ASD will slow down the flow and ultimately stop the delivery. As soon as flow to the full tank is blocked, the remaining contaminated fluid will be diverted to a secondary UST (EPA, 2011).

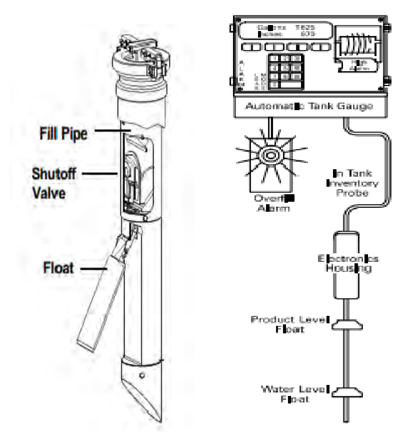

Figure 18: Some Spill and Overfill Prevention Devices (EPA, 2011)

Fire Protection

In the event of a fuel spill, it is imperative to prevent ignition of fuel once it enters the UST. A high concentration of fuel in one location is prone to ignition which must be prevented. In order to prevent this problem, the UST will include a Subsurface Foam Injection System (Figure 19) designed by Williams Fire and Hazard Control, Inc. This system utilizes a foam fire retardant that lies above the product in the UST. The foam's function is twofold. It acts both to cool the temperature of the fire as well as smother the fuel to prevent contact with oxygen. This foam is created by a High Back Pressure Foam Maker and distributed from a single or dual foam chamber, and it is dispensed through piping installed in the bottom of the tank (Williams, 2011).

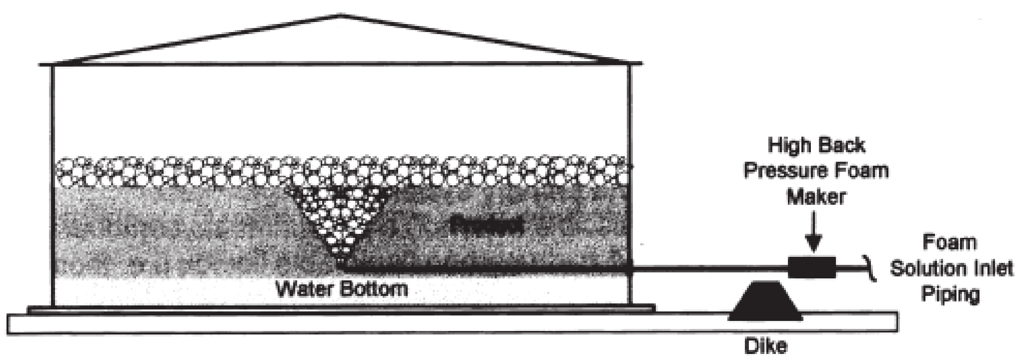

Figure 19: Subsurface Foam Injection (Williams, 2011)

Subsurface injection has several advantages. For one, supplying the foam through the product reduces the exposure to the heat and flame, maximizing the foam's effect. Also, the piping for foam injection is located at the bottom of the UST – away from the heat of the fire and further from areas potentially damage due to explosions. To deliver foam at its coolest temperature, foam bubbles are percolated into the UST from the injection point. All of these components of subsurface injection qualify it for fire protection *(EPA, 2011)*.

7. Safety Risk Considerations

Any new designs and implementations to an airport require an in depth safety analysis before being utilized. The FAA provides a Safety Management Systems Manual (SMS) that details the methodology of conducting a safety risk assessment of such a design. Our design is a response to the catastrophic Asiana Airlines crash and follows the steps set by the SMS. While our design does not focus on preventing crashes, there still needs to be some safety considerations when employing the design. This approach is described in FAA AC 150/5200-37 which includes describing the system, identifying the hazards, determining the risk, assessing/analyzing the risk, and treating the risk (FAA, 2007). Following the example given in the guide, we are able to come up with the resulting safety risk assessment:

Phase 1) Describe the system

- A smart system of sensors that will identify fuel contaminated fluid and divert it to designated storage tanks

Phase 2) Identify the Hazards

- Storage tank overflow, leaks, corrosion, flooding
- Leaks in pipes for the drainage system
- Breakdown of sensors/ valves in the event of a fuel spill event
- Ignition of spilled fuel

Phase 3) Determine the Risk

- Toxicity and flammability of the jet fuels spilled
- Environmental hazards from spilled fuels

Phase 4) Assess and Analyze the Risk

- Leaks in pipes for the drainage system are determined to be probable and major.
- Storage tanks risks of overflows, leaks, corrosion, and flooding are determined to be probable and major.
- The risk of one of the many sensors and valves breaking down can be probable but they only need to function during an event such as a large fuel spill or plane crash. However, if it does malfunction, spilled fuel is still redirected due to the built in fail-safe mode of the valves. As such, sensor malfunction is determined to be remote and major instead of hazardous.

- Due the safety standards of airports themselves, the risk of spilling large amounts of fuel is determined to be extremely remote and major. Actually igniting spilled fuels is determined to be improbable and catastrophic.

Phase 5) Treat the Risk

- Make sure entire system is well maintained and any leaks in the drainage system are detected and fixed.
- Make sure storage tank is in accordance to the safety standards mentioned in section 3 of this report.
- Make sure that the sensors and regularly maintained to check that they are in working order.

Using the predictive risk matrix described in FAA AC 150/5200-37 (Table 6) ignition of spilled fuels was determined to be medium risk. Leaks in pipes and storage tank safety were determined to be high risk. Sensor malfunction was determined to only be a minor risk. As such, it is of upmost importance to make sure that the drainage system and storage tanks are well maintained and in accordance to safety standards to make sure that our design is safe. If such safety measures are abided by, the overall risk of the system is minimal.

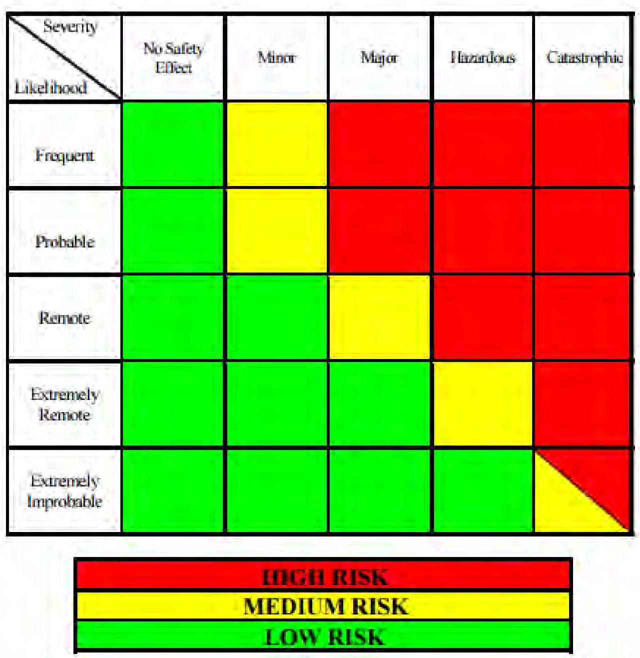

Table 6: Safety risk matrix (FAA, 2007)

8. Cost Analysis

To determine the feasibility of the design, a cost estimation was done for each design assuming the project was being implemented as a retrofit to SFO. Prices used for the probes and sensor materials were taken from quotes provided by the manufacturers. The pricing for the rest of the construction, including materials and labor, were taken from the RS Means catalogue, a construction estimation database used by professional estimators for projecting project costs. Maintenance costs were not included since maintenance tasks can be performed concurrently with current airport inspection tasks. Disregarding replacing faulty equipment, we do not believe there will be a significant increase in costs due to maintenance. The quantities and designs were based off of provided GIS data, our optimization model, and standard engineering practices (Table 7).

Material	Unit Cost
Fox SCS600	$20,000
Petrosense CMS-4000	$6,200
Petrosense DHP-485 (probe)	$7,995/probe
Petrosense Calibration Kit	$487
2,000 Gallon Fuel Storage Tank	$2,500
14” PVC Pipe	$25.50/L.F.
14” Butterfly Valve	$1,225/valve

Table 7: Cost of materials

Preliminary Design		
Material	**Quantity**	**Cost**
Petrosense CMS-4000	1	$6,270
Petrosense DHP-485	65	$519,675
14” Butterfly Valves	65	$79,625
Total		$605,570

Table 8: Preliminary design materials/costs

Final Design		
Material	**Quantity**	**Cost**
Petrosense CMS-4000	1	$6,270
Petrosense DHP-485	4	$31,980
14” Butterfly Valves	4	$4,900
14” PVC Pipe	6,000 L.F.	$153,000
2,000 Gallon Storage Tank	1	$2,500
Total		$198,650

Table 9: Final design materials/costs

Preliminary Design

The projected cost for our preliminary design was quite high and therefore not a good option for a retrofit in this case (Table 8). The cost for this design was mostly dependent on the number of catchment basins that are to be monitored due to the need to have a probe and valve in every basin that the design is implemented in. A large reduction in cost can be made for the preliminary design by doing a thorough analysis on spill location probabilities, and narrowing the scope of the project by only monitoring basins near locations with high spill probabilities.

Intermediate Design

A full cost estimation of the intermediate design was not made because it was deemed to be infeasible for a retrofit project. The implementation of this design requires the construction of an entire new pipe network, much of which would run beneath the existing runways. Not only would the cost of construction be quite high, but lost revenue due to runway closure would leave the airport at a huge loss. It was therefore determined that the intermediate design would be ideal for the construction of a new runway, but our final design would be the best option for a retrofit of an existing runway.

Final Design

Our final design had a low estimated project cost and was determined to be the best option for a retrofit at SFO (Table 9). The difference in cost mostly stems from the fact that the number of probes and valves needed for the design is significantly reduced due to monitoring and diversion occurring in the pipe network instead of in each catchment basin. A large portion of the cost for our preliminary design came from the additional piping required to divert the fuel from the existing pipe network to the fuel storage tank were able to reduce our costs by $406,920. Our final cost, $198,650 is also relatively inexpensive (Table 10) when compared with the total cleanup costs of the pipes and pump stations cost ($205,000) (SFO, 2014). Our final design is indeed an effective yet cost efficient system.

Asiana Airlines Flight 214 Cleanup Costs	Final Design Cost
$205,000	$198,650

Table 10: Cleanup vs. Final design costs

9. Interaction with Industry Experts and Airport Operators

Throughout the development of the smart drainage concept, our team was in contact with numerous aviation professionals from airports, airlines, consulting firms, and the FAA. We also communicated with other UC Berkeley faculty who are noted experts in environmental engineering. In order to understand airports' perspectives of the smart drainage design, we first wanted to understand the impacts and the magnitude of aircraft crashes and aviation incidents on airports and the flying public. Hence, we first communicated with the FAA, pilots, and airlines.

We communicated with Steven Wallace, former FAA Director, Office of Accident Investigation, who had the overall responsibility for FAA accident investigation activities, and implementation of corrective measures based on investigation findings. We learned first-hand how commercial aviation became so safe, from post-WW II to the present. We understood how aviation safety moved from technological advances to error trapping and improvements in human performance, and improvements in safety that are based on both catastrophic and precursor events. Fuel spills were reviewed from safety and environmental perspectives.

We also communicated with Captain Robert E. Rip Torn (Delta Airlines pilot), Committee Chair, Air Traffic Services Group, International Federation of Airline Pilot Association. The objective of our communication was to learn about accidents, fuel spills and emergency handlings from a pilot's perspective and check if our optimization model for location of storage tanks was logical.

Communication with Airline Ramp operators (Virgin America Airlines), Jason Lazich and Daren McFarland added to better understanding about frequency and location of fuel spills at airports, and in the ramp area.

The next step was to communicate with civil engineers, consultants and airport operators in order to deeply understand the challenges of designing good drainage systems, common spill areas, and environmental consequences of certain fuel spills:

We communicated and contacted many officials and engineers at SFO, where our main communication was maintained through Sam Mehta, Environmental Services Manager at San Francisco International Airport. First, he introduced us to SFO's presentation on "Asiana Flight 214: Storm Drain and Soil Remediation" that was presented at the 2014 ACI-NA Environmental Affairs Conference in Baltimore. The presentation helped understand the fuel spill initial contamination and the efforts SFO undertook to minimize the environmental impact of the spill. SFO airport also provided a GIS Storm Drain Map Layout, which was coordinated by Jason Hill, SFO GIS Administrator, Infrastructure Information Management, and Design & Construction. The SFO GIS map was used in the design project to formulate a mathematical model for optimizing a location of a storage tank.

M. Mitch Monroe, PG, Burns & McDonnell Engineering Company, Inc., San Francisco, pointed out that the need for a proposed system at SFO would be more appropriate for incidents with higher volumes of spilled fuel. He emphasized that in disaster preparedness, frequency is not often the key input as much as the possibility, so if our proposed system would prevent a significant release of fuel to SF Bay, then SFO might find it a viable solution. He also believes that the proposed system is feasible to construct, but would require a significant amount of expansion and evaluation to determine its viability for a real-world application.

Robert Adams, Executive Vice President, Landrum & Brown, Head of Environmental Services Division, agreed that our proposed system could have some reductions in environmental impact and emphasized that the cost of the solution should be justified for the assumed level of reduction. He expressed his opinion about the nature and location of catastrophic events (unpredictability) and further pointed out that "the location of catastrophic events like Asiana are unpredictable, and the exact location an aircraft will end up and begin releasing fuel is almost impossible to predict to a degree that would allow for a system like this to be effectively implemented". Our response to his comment regarding difficulties in determining a right location is that we developed a comprehensive mathematical model and used an optimization technique to find the optimum location of a storage tank. Our optimization model is robust enough to yield an optimal solution taking into consideration location of elements such as runways, pipes and grass areas.

As a part of the UC Berkeley Airport Design course, we visited SFO, including the Communication Center and Control Room. We also spoke to a number of airline representatives and asked about common location, frequency, and containment of fuel spills. The Communication Center is a place where officers control the security of SFO using thousands of cameras and communication devices. The facilities are especially useful during emergency situations, such as the Asiana Airline crash, when the Communication Center was in charge of dispatching personnel to perform rescue tasks. While we were in the Communication Center, we witnessed an oil spill that occurred below an aircraft in real time, and learned how the officer in the communication center can effectively contact workers to clean up the site in a timely manner, and keep in contact with the fire department.

10. Conclusion

After reviewing the three alternatives, we found that each case can be applied to different airports. Our preliminary design is relatively simple in construction; however, the cost rises with the increase of catch basins. Thus, this design may be suitable for an airport with a smaller drainage area and simpler drainage system. The intermediate design is the ideal solution and entirely solves the problem of a fuel spill. However, the construction of the intermediate design would be very complex and would interfere with regular runway operations. As a result, the design will cost a lot in terms of construction costs and lost revenue from shutting down a runwayThe final design is derived from the previous designs and it is a balance between the two. This design is practical to implement at airports such as SFO. The final design is supplementary to existing drainage systems, which is suitable for larger airports with busy flight schedules. Because these airports have a larger number of catch basins and flight operations, there is a higher chance of fuel spilling into storm drains. Additionally, it will be much more expensive to implement the previous two designs for busy airports. Our improvements to the existing system are summarized in Table 11.

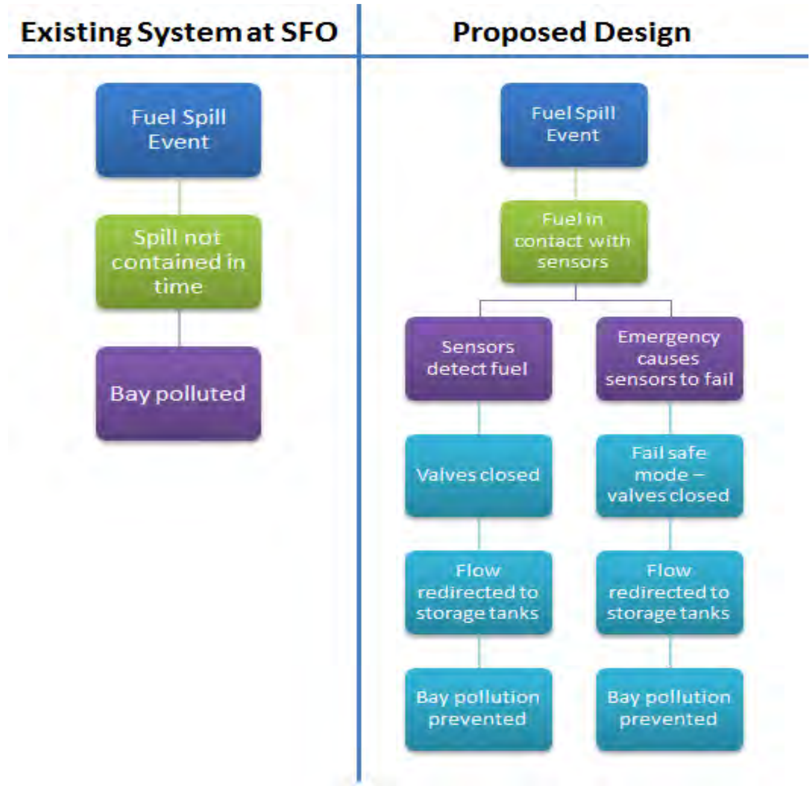

Table 11: Comparison between existing system and proposed system

Although our final design works well at SFO, it can be easily implemented at other airports. Our design process applies to any airport with a sophisticated storm drainage system (Figure 20). The problems that our system addresses are also existent in almost all airports around the world. Any airport will definitely benefit from our design, especially large and busy airports were the risk of a fuel spill incident is higher.

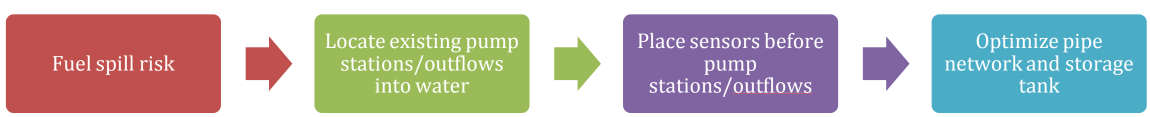

Figure 20: Steps to implement system at any airport

We hope that our design will pave the way and inspire more environmentally friendly designs at airports. We believe that our proposed automated smart drain system will be a viable option for many airports. Our system is cost- and time-efficient and will definitely help improve airports around the world and the fragile ecosystems that surround them.

Appendix A: Contact Information

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Appendix B: Description of the University

University of California, Berkeley is the world"s number 1 public university in the Academic Ranking of World Universities for 2010. It serves as a home for higher education for 36,000 students, including 25,700 undergraduates and 10,300 graduate students. UC Berkeley holds 1,455 permanent faculty and 7,059 permanent staff serving among 14 colleges and schools with 130 academic departments and more than 100 research units. More than half of all UC Berkeley seniors have assisted faculty with research or creative projects and more UC Berkeley undergraduates go on to earn Ph.D.s than any other U.S. university. The Civil and Environmental Engineering department consistently ranks at the top of the best civil engineering programs in the country by U.S. News and World Report.

The Department of Civil and Environmental Engineering has fifty full-time faculty members and twenty-two staff dedicated to the education of more than 400 undergraduate students and 360 graduate students. The education in the department prepares students for leadership in the profession of civil and environmental engineering and sends approximately one-quarter of its undergraduates into a graduate education. Our CEE laboratories for teaching and research are among the best in the nation, providing opportunities for hands-on experience for all students. There is no other location with comparable resources in the San Francisco Bay Area that can provide students with ground-breaking local civil and environmental engineering projects and participate in professional activities.

UC Berkeley was chartered in 1868 as the first University of California in the multicampus UC system. The school houses a library system that contains more than 10 million volumes and is among the top 5 research libraries n North America. Throughout its full history, Berkeley has had 21 Nobel Laureates, 234 American Academy of Arts and Sciences Fellows, 213 American Association for the Advancement of Science Fellows, 363 Guggenheim Fellows, 32 MacArthur "genius" Fellows and 4 Pulitzer Prize winners. Just as important as academic excellence, UC

Berkeley has held a respectable active history of public service. More than 7,000 UC Berkeley students every year do volunteer work in 240 service-oriented programs while there are more Peace Corps volunteers from UC Berkeley than from any other university. Clearly, UC Berkeley is not solely focused on academia as countless research and outreach initiatives focused on public benefits to the community, nation and world.

Appendix C: Description of Non-University Partners Involved in the Project

N/A

Appendix E: Evaluation of the educational experience provided by the project

For the Students

1. Did the FAA Design Competition provide a meaningful learning experience for you? Why or why not?

The greatest benefit for our project was the development of a research that was of our own interest. Unlike ordinary school assignments, this project provided us the freedom to explore the different topics of aviation and choose an issue we believed we could improve. Through the course of this project, we learned how to address a current, real issue and develop a research topic about it that is meaningful and potentially practice-changing. Another great learning experience was the exposure to writing a technical report similar to that of a graduate studies thesis. As undergraduate students, we have never written a research report such as this before. The experience of conducting literature review was a good preparation as some of us continue our academic pursuit in graduate school.

2. What challenges did you and/or your team encounter in undertaking the Competition? How did you overcome them?

While the faculty was completely receptive to our efforts, it was difficult to recruit more students, whether undergraduate or graduate. This issue mostly caused an obstacle in our optimization development. We overcame this challenge by self-teaching the programs and consulting our professors frequently with questions.

Being only a group of 4, it was difficult to cover such a large project. Nonetheless, we began our research early in fall, which allowed us a lot of time to cover most of our literature review and focus on perfecting the model in the spring. We assigned leaders of different tasks, i.e. literature review researcher, data analyzer, system designer, and collectively assisted each other in accomplishing each task.

Another challenge that we encountered was obtaining the data we required for the drainage system layout of SFO to review the existing situation and do the modification. To solve this issue, we contacted numerous professionals in industry and they provided us several layouts in different formats. We edited them and rearranged for the purpose of research.

3. Describe the process you or your team used for developing your hypothesis.

After filtering our own potential research topics proposed by the competition, we spoke with Dr. Rakas and developed the model of implementing the concept of system optimization on the airport drainage system. Our drive was based on developing a method to develop the system that can protect the ordinary drainage system and surrounding environment from potential fuel spill with economical feasibility. This was to lower the risk of jet fuel pollution in any accidents or everyday operation under the current status of our economy and green movement.

As a group, we furthered our scope with the idea of creating a simulation model to measure its benefits in terms of operation costs saved and the reduction of environmental impact. We wanted to develop a concept that would be implemented in building new airports and updating running airports.

4. Was participation by industry in the project appropriate, meaningful and useful? Why or why not?

Our collaboration with industry, specifically with SFO, was particularly useful in aiding us obtain the data we required for our analysis. With these collaborations, industry provided us a feasibility mind that we otherwise would not have developed.

5. What did you learn? Did this project help you with skills and knowledge you need to be successful for entry in the workforce or to pursue further study? Why or why not?

We learned a great amount about the operation of drainage system in an airport. Also, it was a great experience collaborating with industry and meeting with our professors frequently to develop our design. This project definitely provided us the experience in working with a mentor similar to that of working under a senior engineer in the work force. During the project we also learned how to build implement some optimization tools into practical situation and how to make complex problems feasible to work out. Furthermore, we learned to work in a group efficiently and effectively by peer-accountability/performance monitoring in completing our tasks.

Again, in writing the technical paper, we developed skills for writing a research paper in our graduate studies. This project was a good preparation in conducting literature review, developing a concept, and analyzing our proposal.

Faculty

l. Describe the value of the educational experience for your student(s) participating in this Competition submission.

My students gained tremendous educational value from this Competition. They went through the entire creative process of designing a concept of a smart drainage system from the initial stages to the end by designing a drainage system, applying it to a busy airport and testing its feasibility. As some of the students are planning to apply to various graduate programs, this educational experience was an excellent way for them to learn about how to start creating new concepts and new knowledge. Once they start their graduate programs, the experience gained while participating in this Competition submission process will help them make a smoother transition towards conducting more advanced research that is expected in any graduate program.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

The learning experience was quite appropriate for the context in which the competition was undertaken. It tested the intellectual capability of the students at the right level, and offered challenging insight into practical, "real-world" problems. Although the research group was relatively small (four students), this Competition also allowed students collaborate in smaller teams (two students per a team), which required them to co-operate, organize and designate tasks within a complex goal-oriented endeavor.

3. What challenges did the students face and overcome?

There were many challenges the students faced and successfully overcame. First, these are undergraduate students with no prior experience in conducting research. Furthermore, they had very little previous knowledge or understanding of aviation or airport systems. The Airport Design class that some of the students took the previous semester was their only formal education in aviation. Hence, the beginning of the research process included a long learning process about how to conduct research and how to understand more advanced aviation concepts, such as the concept of aviation safety and runway design.

4. Would you use this Competition as an educational vehicle in the future? Why or why not?

I would definitely use this Competition as an educational vehicle in the future. In previous years I conducted a significant amount of undergraduate research through the UC Berkeley Undergraduate Research Opportunities (URO) program. This program was designed to assist undergraduate students in developing research skills early in their college education. On average, half of my students from the Airport Design Class would participate in aviation research projects in the following semester, and would formally be funded and sponsored by URO. However, due to recent budget cuts, this program had to be closed. By using this Competition as an educational vehicle, I am not only continuing research with undergraduate students, but also teaching them how to structure, organize and present their work to a large number of experts in the field.

5. Are there changes to the Competition that you would suggest for future years?

I would expand Challenge Areas by adding more emphasis on the Next Generation Air Transportation System (NextGen) requirements and expectations, as well as on aviation sustainability.

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