Baggage Hygiene Monitoring System

Airport Cooperative Research Program: University Design Competition

Airport Operations and Maintenance

Tufts UNIVERSITY | School of Engineering

Undergraduate Team Members: Nicholas Nopprapun, Erick Garcia, and Noah Kagan

Advisor: Gary Leisk, Senior Lecturer, Department of Mechanical Engineering, Tufts University

Executive Summary

Baggage jamming is a primary source of delays in a baggage handling system (BHS); furthermore, 60 - 90% of baggage jamming is caused by poor bag hygiene according to airport officials. Bag hygiene refers to characteristics of a bag and its placement onto a BHS system that impact the likelihood of a bag making it through a BHS without causing a jam. These characteristics include aspects related to bag's dimensions, shape, and weight, as well as the orientation of the bag once placed onto the BHS. The solution was to create a semi-automated Bag Hygiene Monitoring System (BHMS) that can both enable management to make baggage policy decisions based on quantifiable data collection, and provide real-time feedback or engagement to workers in order to promote proper bag hygiene.

After implementing a stage-gate design approach, the team developed an alpha prototype of the BHMS that identifies a bag's orientation on the conveyor belt and quantifies it to collect data. After conducting tests at Manchester-Boston Regional Airport and receiving feedback from various industry experts, the team identified the necessary components and functionalities that would be present in a final product: identifying all aspects of bag hygiene, the presence of an optimal user interface, and high performance equipment.

The team believes that with this final product, airports will be able to significantly reduce the occurrence of baggage jamming. Furthermore, this will not only increase efficiency of baggage operations, but also save the airport substantial costs associated with baggage jamming.

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1.0 DEFINING PROBLEM

1.1 Baggage Handling Systems and Jamming

A Baggage Handling System (BHS) is a conveyor system used to move bags in and around an airport environment. A successful BHS moves customers' bags from point-to-point as fast as the customer. Delays in the system can lead to missing bags, flight delays, and angry customers, all of which have associated extra expenses for airports and airlines. One major source of delays in a BHS is baggage jamming. Furthermore, airport operators suggest that between 60-90% of baggage jams are caused by what is known as bad "bag hygiene" [1] [2].

1.2 Bag Hygiene

Bag hygiene refers to characteristics of a bag and its placement onto a BHS system that impact the likelihood of a bag making it through a BHS without causing a jam. These characteristics include aspects related to bag's dimensions, shape, and weight, as well as the orientation of the bag once placed onto the BHS. Table 1 below shows examples of different aspects of bag hygiene as well as the possible effect on the BHS [3].

Table 1: Aspects of Bag Hygiene and Potential Effects

Baggage Hygiene Aspect	Example of Bad Bag Hygiene	Possible effect on BHS
Bag Orientation		Incorrect bag orientation can create jam when bags pass through conveyor turn, or in TSA Screening machine

Loose Bag Straps/Handles		Loops straps/handles could get caught and jammed between the spacing of conveyor belts.
Small Bags in a Plastic Tub		Small bags not in a plastic tub are not heavy enough to pass through lead curtains of TSA screening machine which causes back up and tracking errors
Wheels in contact with belt		Wheels in contact with conveyor belt could cause bags to slide and shift, when on an inclined belt also causing tracking errors

There are three main causes of bad bag hygiene. The first is poor placement by baggage handlers, who become complacent over time due to the repetitive nature of their job. The second is poor placement by check-in staff, who are often distracted serving the many customer needs at check-in (their highest job priority). The third cause is indirect and related to a lack of accountability by the different parties involved in the baggage handling process. Since individuals who cause bad bag hygiene may face no consequences, they have little motivation to help prevent jams further down the BHS system by exercising proper bag hygiene.

1.3 Current Preventive and Remedial Strategies

Current strategies used in most US airports to combat bag hygiene are divided into two categories: preventive (preventing bad hygiene) and remedial (fixing bad hygiene). In terms of preventive strategies, many airports already have some measures in place such as management policies on bag hygiene, training programs for employees, and the use of plastic tubs for small bags. Some remedial strategies include BHS systems with bumpers to straighten bags on conveyor belts, having dedicated staff on call to deal with jams specifically, and even more automated systems to correct bad bag hygiene (discussed further in Section 3.0, Team Design Approach). Finally, in some cases, airport and airline management treat bad bag hygiene as an acceptable risk and just deal with resulting issues, such as assigning employees from different departments to manually fix jams (removing oversized bags, fixing orientation, etc.).

1.4 Problem Statement

The current strategies of dealing with bad bag hygiene do not adequately address the issue and needs of airport operators. The process described in this document was to create a product that could be used in either a preventive or remedial strategy to combat bad bag hygiene issues. The semi-automated approach chosen will both enable management to make baggage policy decisions based on quantifiable data collection and provide real-time feedback/engagement to workers dealing with baggage.

2.0 SUMMARY OF LITERATURE REVIEW

To best assess the nature of the problem and identify the most pressing needs, many interviews and airport visits were conducted. Little technical literature could be found on this subject and the team decided that first-hand experiences would provide a more comprehensive understanding of the issue.

2.1 General Background on Baggage Operations

Early in the design process the team realized that having a holistic understanding of the entire baggage process and all parties involved would be crucial to the success of the project. Interviews were conducted with persons at all levels of the baggage chain including baggage handlers employed by airlines [4] [5] [6], airport managers running the operations [7] [8] [9] [10], and industry consultants who work with airport BHS designs and renovations [11]. Further details of these conversations are discussed later in the report, see Section 4.0. All the different parties and their respective roles in baggage processing were identified, such as the TSA, the airport, the airlines, and a multitude of subcontractors and employees. Knowledge of every step a bag takes between check in and customer retrieval allowed the team to more easily pinpoint areas that had potential for innovative design solutions, such as bag hygiene.

2.2 Existing Bag Hygiene Policies and Solutions

Once bag hygiene was identified as a pressing issue at many airports, the team did additional research online into existing policies and programs related to bag hygiene at different airports across the United States. Memorandums and advisories by airports including San Francisco International and Baltimore-Washington International Airport discuss how the trend towards fewer, but faster in-line Explosive Detection Systems per airport (encouraged by the TSA) has made bag hygiene more critical than ever [3] [12]. The consequences of a jam in the screening machine are now a) more costly to repair and b) have greater potential to disrupt operations due to a reliance on fewer machines. Which aspects of bag hygiene are the most crucial to correct (e.g. orientation, placement of wheels not on belt, no straps hanging out), bag tubbing policy, and maximum allowable bag dimensions are also clearly laid out in these reports, and were vital when the team was imagining final product functionality, see Section 5.3. These advisories, as well as additional interviews with airline employees, also emphasize how during high volume periods employees often disregard hygiene and simply load bags as fast as possible because of other concerns (prioritizing customer interaction, bags piling up off-belt), which increases jam rate and system backups [25]. A rigorous, mandated hygiene training program was implemented at Southwest Florida International which, in conjunction with a revamped maintenance schedule for the conveyor system, succeeded in reducing jam occurrence to half the previous level.

At the same time research was done on companies and existing technologies that address bag hygiene problems at airports. Company websites were found and analyzed including Type 22 BagCheck [13], Herbert Systems Pathfinda and Sola [14] [15]. Relevant U.S. and Korean patents related both to bag hygiene and to jamming were identified as well [16] [17] [18] [19]. This research allowed the team to understand which aspects of hygiene and jamming had already existing solutions, such as straps hanging off bags [18], and which were potential targets for the team's design to improve upon.

2.3 Technical Literature on Image Processing

The team developed an image processing approach to assess bag hygiene. Several resources were used to assist the team with the image processing and coding requirements. Lab reports from a previous university course on image processing were utilized and the team had additional meetings with the professor to go over further questions in detail [20] [21]. The image processing and coding were both done using National Instruments LabVIEW software. The

LabVIEW support manuals were used heavily throughout the design process, and the National Instruments forums were also referenced consistently throughout [22] [23].

3.0 TEAM DESIGN APPROACH

The team implemented a stage-gate design approach, methodically and efficiently progressing from identifying the problem to testing a solution. Each stage included an element of feedback from the team's clients and consultants. Figure 1 summarizes the stage-gate design approach that the team took and that is discussed in the following subsections.

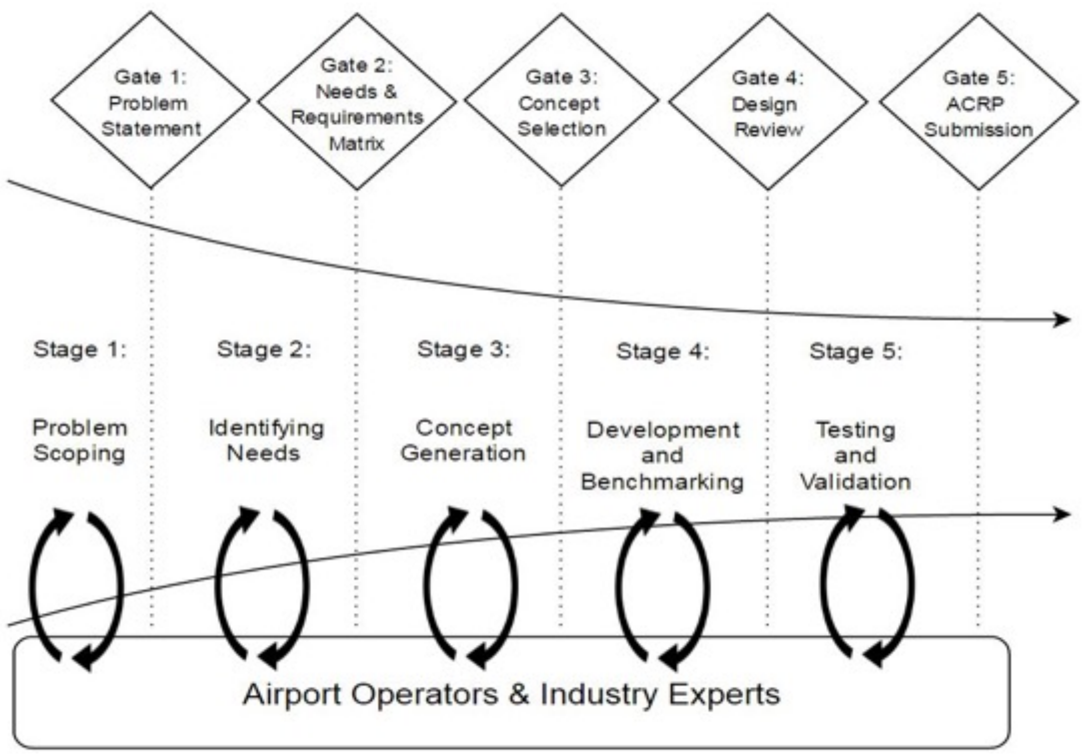

Figure 1: Stage-Gate Design Approach

3.1 Problem Scoping

To identify pressing needs in airport operations, the team visited Newark Liberty International Airport (EWR) to observe baggage operations first-hand and conduct interviews with airport employees including baggage handlers, airport managers, and baggage system technicians. It was during this visit that the team realized that one of the most critical pinch-points in baggage operations was the occurrence of baggage jams in baggage handling conveyor belt systems. More specifically, after speaking with different parties involved in the baggage handling process, the team identified a primary cause of baggage jams to be bad bag hygiene.

3.2 Identifying Needs and Requirements

For the rest of the design process, the team selected Manchester-Boston Regional Airport (MHT) as its primary customer. One advantage of selecting a small regional airport was easier access to employees, operators, and equipment at the airport. After multiple visits to MHT and interviews conducted with MHT operators as well as BHS consultants (BNP Associates, Connecticut, USA), the team identified key needs and requirements necessary for a successful solution. The needs identified are relative to MHT but do serve as a model for small regional airports in the USA. Future implementations of the proposed product could be scaled to fit the specific needs of different sized airports and different BHS's. The team determined that it was very important to have a product that could be easily adapted to and integrated with an existing BHS—to reduce costs and inconveniences associated with the installation of an entirely new system—and that would be accurate, reliable, durable, safe, and easy to use. Table 2 summarizes the top nine needs identified for the MHT model. The weight factor for each need was determined using a pairwise comparison approach: each need was individually compared to the others and determined to be either more or less important. Adaptability was determined to be the most important need, while bag size flexibility was the least important of the top 9 needs.

Table 2: Important Customer Needs

Needs	Weight Factor
Adaptability	15
Accuracy	14
Durability	13
Reliability (No Malfunctions)	12
Affordability	11
Bag Friendliness (No Damage to Bags)	9
Safety	8
Ease of Use	7
Bag Size Flexibility	5

Once the needs were identified, the team determined the design/engineering requirements that the product would have to meet with regards to performance and cost. Table 3 lists each requirement along with its corresponding unit, and the desired direction of improvement (increase +, or decrease -). In essence, the team determined that a desirable product would provide a low-cost yet effective solution to increasing baggage operation efficiency. The specific metrics by which cost would be determined would be upfront and running costs of the system, and the amount of time it takes for the product to pay for itself in savings to the customer. The product's performance would be measured by the amount of time it takes to process one bag (cycle time), the amount of times the product can be used before it fails (usage cycles), the amount by which it decreases errors in bag hygiene (e.g. spacing and orientation error), and the number of bags that the product could effectively handle in one minute (throughput).

Table 3: List of Requirements

Requirement	Unit	Desired Direction
Payback period	years	-
Operating Costs	$	-
Upfront Costs	$	-
Cycle Time	sec	-
Usage Cycles	No. cycles	+
Bag Spacing Error	in.	-
Bag Orientation Error	degrees	-
Throughput	bags/min	+
Maximum Bag Weight	lbs	+
Maximum Bag Size	in.	+
Compatibility	N/A	+

3.3 Concept Generation

The team came up with two possible directions for improving bag hygiene: 1) designing an automated system that would identify and correct poor bag hygiene, and 2) creating a system that would promote good bag hygiene by affecting human behavior. Sketches of three concepts generated are shown in Figure 2 which demonstrate a solution that affects human behavior, an

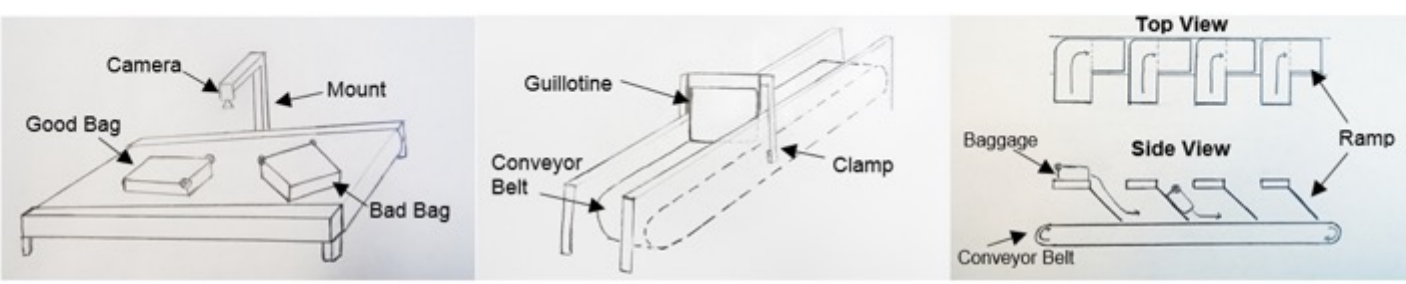

Figure 2: Bag Hygiene Monitoring System (left), Vertical Guillotine (center), Multi-Stage Ramp (right)

automated solution, and a hybrid of both approaches. The "Bag Hygiene Monitoring System"

(BHMS) detects incorrect bag orientation, size, dimensions, and spacing with a camera and image processing algorithms. The “vertical guillotine” detects if bags are spaced too closely together and automatically separates them by holding one bag for a brief period. The “multi-stage ramp” works by only allowing baggage handlers to insert bags in one specific orientation while also mechanically accounting for spacing between bags with a ramp system that only allows bags through if there is enough space.

3.4 Concept Selection

The team conducted multiple rounds of idea screening—each round incorporating customer and consultant feedback as well as market research—in order to select a final design.

Table 4: Concept Selection Decision Matrix

Concepts	Upfront Cost	Operating Costs	Usage Cycles	Error in Bag Hygiene	Compatibility	Throughput	
Weight	8.5	6	7.5	6.8	5.8	5.6	Sum Total
Vertical Guillotine	3.5	3	3	4	4.5	4	146
Turbulent Belt	2	4	4.5	1	1.5	4.5	115
Ridged Belt System	4	3	4	2	4	3.5	138
Multi Stage Ramp	2	4	4	4	3	3.5	135
Springed Walled Channel	2	4	4	3	3	2	120
Bag Hygiene Monitor	3	4	5	3	5	4	159

Table 4 shows the team’s final six concepts ranked against each other in terms of how effectively the concept fulfilled each requirement (column headers), with 5 being the most positive fulfillment of that requirement and 1 being the lowest. The score given to each concept was multiplied by the weight of the corresponding requirement and its total score was summed in the right-most “Sum Total” column. The weight of each requirement was determined based on how well it fulfilled the most important needs.

From the results of the decision matrix, the BHMS came out as the highest scoring concept that the team felt confident in pursuing. What was interesting to note from the results was that the top-ranking concepts in the decision matrix had a high score in the requirement for compatibility: how well the solution will integrate with the existing infrastructure of the airport. Although compatibility was not the highest weighted requirement, the team realized that this was in fact going to be an important requirement. Through the interviews at the airports, the airport officials explained how real estate can come at a high premium especially when installing new systems [11]. This means that when designing this system, the team must give high priority to making sure that the product fits seamlessly into any existing system and not require major infrastructure changes to existing operations.

3.5 Benchmarking Against Existing Products

The team benchmarked the chosen design concept against existing products (competitors) and relevant patents. Table 5 below shows the benchmarking comparison between the different products and the same requirements used in Table 4. Each competing product was given a score of -1, 0, or 1 for each requirement, based on whether it performed worse, the same, or better (respectively) than the BHMS concept. The net score was then summed in the “Total” column.

In addition to products that affect bag hygiene, the team also considered camera systems used in conjunction with conveyor belt systems in other industries. The Belt Vision Inspection System is used in mining operations to monitor belt wear and help with preventative maintenance [24]. It was helpful to look at systems like this to see what components are present

Table 5: Benchmarking Matrix

Concepts/Competitors	Upfront Cost	Operating Costs	Usage Cycles	Error in Bag Hygiene	Compatibility	Throughput	Total
Primary Direction							
Baggage Hygiene Monitor	0	0	0	0	0	0	0
Competitors							
Pathfinda	-1	-1	0	1	-1	-1	-3
BagCheck System (Type22)	-1	-1	0	1	-1	0	-2
Baggage positioner for baggage conveyor (Patent)	-1	-1	0	1	-1	-1	-3
Baggage jamming prevention structure (Patent)	1	1	-1	-1	0	-1	-1
Belt Vision Inspection System	n/a	n/a	n/a	n/a	n/a	n/a	n/a

to ensure high quality monitoring of a moving belt, such as light bars and camera specifications. Note that the Belt Vision Inspection System was not scored in Table 5 since it does not relate to solving baggage jamming.

The principal areas where competing products struggled against the BHMS were the cost and compatibility with existing systems. All the competing systems relied on large investments and on changing/adding machines to the conveyor system itself. The benefit of the team's design is that it can be implemented easily at any point in a conveyor system where there are potential bag hygiene problems. This could be at the point that inbound baggage is unloaded from the aircraft, where bags are checked in by passengers, or at the site that TSA agents place the bags back into the system after hand screening. In addition, the BHMS's simple design also gives it the potential to be adapted to other applications outside of baggage operations. The area where the BHMS falls short is that the system does not directly correct bag hygiene, but rather promotes behaviors and policies that results in good bag hygiene. Most competing products directly correct some aspect of bag hygiene. However, these systems can correct only one aspect of bag hygiene, e.g. bag orientation, bag spacing, or loose straps. On the other hand, the BagCheck, shown in Figure 3(above), can identify many aspects of bag hygiene and reroutes any problematic bags to a human that will correct the error. This solution approach makes it much more effective in

Figure 3: BagCheck by Type22 and Vanderlande Industries

correcting the problem, arguably the best amongst its competitors. However, the BagCheck's weakness is its higher cost and the additional conveyor belt infrastructure required.

The BHMS's low cost and high compatibility make it a desirable product to any airport that either does not have the real estate to install a large system, or is looking for a low-cost solution to reducing baggage jams. Therefore, the team feels confident that its proposed solution has the potential to reach markets that the BagCheck and its competitors do not.

Another important feature of the BHMS that sets it apart is its ability to collect two types of data: 1) data on which airlines (and potentially which employees) are most responsible for baggage jams, and 2) data on which aspects of bag hygiene are causing the most jams, as well as the locations that these jams are occurring. This data collection makes it possible for airport owners to reduce jams via a preventative approach by making informed policy decisions regarding bag hygiene and by holding contractors accountable for their performance. This feature is something that the BagCheck does seem capable of also implementing; however, it is not mentioned anywhere on their product website. Allowing parties involved to hold each other accountable would potentially solve the baggage jamming problem by either incentivizing or punishing those responsible for jams to change their behavior altogether.

3.6 Development

The team began to develop a proof of principle, alpha prototype of the product using the resources available at Tufts University including hardware components, software licenses, and advice from university professors in the mechanical and human factors engineering departments. Section 5.0 of this report discusses in detail the technical development process as well as the testing and validation conducted to evaluate the effectiveness of the alpha prototype in meeting the client's needs and the product's design requirements.

4.0 INTERACTIONS WITH AIRPORT OPERATORS AND INDUSTRY EXPERTS

4.1 Problem Scoping Interviews

During the process of narrowing the problem scope, interviews were conducted with many different employees at airports. Among those were interviews with Ricardo Barranco, Baggage Control Officer at LAX; Evelyn Espindola, Baggage Security Officer and Loading Monitor at LAX; Michelle Brown-Daly, BHS Consultant at BNP Associates; Frank Radics, Airport Operations Manager at EWR; Chris Perez, Duty Manager of International Facility at EWR; a United Airlines Baggage Operations Manager at EWR; and a Siemens BHS Maintenance Technician at EWR. These interviews gave the team a greater understanding of baggage operations from start to finish as well as the different parties and stakeholders involved.

Perhaps the most critical moment during these scoping interviews occurred during the interview with the Siemens technician. Initially, the team was under the impression that the efficiency of baggage operations could be improved by reducing the amount of time that it took baggage handlers to load/unload bags onto/off the system. This would mean having more baggage handlers simultaneously working at a given belt would enable faster throughput and therefore increased efficiency. However, as the team observed a group of four baggage handlers working a belt at EWR, the Siemens technician commented that he was worried that there were so many handlers working the same belt. When questioned about his concerns, he replied that the more people that worked the belt the higher the chance there was for error and therefore a jam downstream (that he would then have to fix). This was because having more handlers working simultaneously meant an increased chance of bad bag hygiene, such as inadequate spacing between bags. This was the first time that the team was exposed to the problem of baggage jamming as a result of bad bag hygiene practices. Later interviews with other airports industry experts confirmed this to be a major issue in baggage operations.

4.2 Needs and Requirements Identification Interviews

Having been tipped off to the issue of bad bag hygiene, the team visited Manchester-Boston Regional Airport (MHT) to confirm the severity of the problem and to identify latent client needs associated with this problem. John Adams, Building Superintendent at MHT provided several thorough tours of the facilities and explained his airport’s operations and pinch-points. When asked about baggage jams, Adams was eager to share his troubles regarding the issue. He confirmed that bad bag hygiene was indeed a leading cause of baggage jams at MHT, as had been the case at EWR. He attributed 90% of baggage jams to bad bag hygiene from airline employees (perhaps an over-estimate, but nonetheless significant) [2]. Adams also provided useful feedback throughout the design process regarding the features that he would like to see implemented in the product such as the ability to locate where baggage jams are occurring, and the ability to sort through images of baggage jams later in time, thus informing the alpha prototype's interface and features.

Another critical party interviewed was Tom Labrie, Southwest Airlines Station Manager at MHT. Hearing Labrie's perspective was crucial in understanding the role that the airline plays in the process and how baggage jams affect their operations. Labrie further confirmed that bad bag hygiene was a big issue but attributed only 60% percent of jams to his employee's bad bag hygiene and the rest to BHS malfunctions [1]. He also helped the team to understand the financial ramifications of baggage jams such as very costly flight delays, compensation fees to customers, and damage to the airline brand. Labrie also explained the training process for employees regarding bag hygiene—this was identified as an area needing improvement (something that the BHMS could potentially be used for, such as for corrective training).

Southwest Airline employees working the ticket counter and loading bags onto the BHS were also interviewed [25]. They admitted that sometimes their actions do not take bag hygiene into account despite their being aware of its importance and being periodically reminded of it. However, the team learned that this is not inherently their fault since they are juggling several tasks at once, such as customer service. The employees loading the bags are ultimately the ones who can affect the most change so their comments and feedback were greatly appreciated. From speaking with these employees, the team decided that it was best to create a non-invasive system that could integrate seamlessly behind the scenes without disturbing the already hectic operations of these employees, at least for the case at MHT's inbound baggage operations. Other implementations of the BHMS may be more appropriate in other situations, as is discussed further in Section 8.2 of this report.

4.3 Concept Generation and Concept Selection Interviews

Having identified the most important needs and requirements, the team went through several iterations of ideation and idea screening. Throughout this process professors from the Tufts University Department of Mechanical Engineering were consulted including industry expert Daniel J. Hannon (Professor of the Practice in Human Factors), James Intriligator (Professor of the Practice), Gary G. Leisk (Senior Lecturer & Research Assistant Professor), and Robert D. White (Associate Professor). Their feedback provided insightful direction in the fields of mechanical design, software design, and human factors design.

During the early iterations of concept generation, the team was considering creating a system that would encourage good bag hygiene from baggage handlers by providing real-time feedback on their performance. Professor Hannon proposed the idea of gamifying the system in such a way that the employees would be incentivized to perform their best [26]. He noted that it in order to make this work the game would have to be a game worth playing and that the feedback would have to be as close to the source, i.e. the baggage handler, as possible. Tom Labrie at MHT was intrigued and excited about this idea and saw it as something that he could integrate into Southwest's existing employee rewards program. This idea gained a lot of traction but was ultimately deemed to not be the best solution at MHT as mentioned in Section 4.2 above.

4.4 Development and Testing Interviews

Throughout the rest of the prototype development and testing process, MHT industry experts John Adams and Tom Labrie were frequently interviewed and consulted for feedback. Video footage of baggage operations at both peak hours and off hours was also captured at MHT for the team’s study of operations. This footage and live observation served to validate certain decisions regarding which aspects of bag hygiene are most important and to help the team learn the intricacies of baggage operations and its failure modes. Testing of the proof of principle prototype was also conducted on-site at MHT in front of the clients and useful user feedback was received (see Section 5.2).

5.0 TECHNICAL ASPECTS

A physical proof of principle model (alpha prototype) was created with limited functionality. Being able to successfully identify and quantify an aspect of bag hygiene with simple and affordable hardware was essential to creating a product that can satisfy the most important customer needs. As such, most of the technical work was focused on that goal. The team tested and validated the alpha prototype with airport operators at MHT. Their valuable feedback led to the realization that the user interface and data collection were an equally important part of the functionality of the BHMS. This feedback, and the knowledge learned during the creation of the alpha prototype, helped the team envision all the necessary components and functionality of BHMS that will go to market and increase the efficiency of baggage operations at airports across the United States.

5.1 Alpha Prototype/Proof of Principle Model

The proof of principle model that the team created can detect the orientation of a bag placed on a black background. The completed alpha prototype setup labeled with each of the primary components, and the user interface for the prototype are shown in Figures 4 and 5. The team did not have access to a working conveyor belt for most testing, and so did not prioritize the ability to detect the motion of the belt and automatically recognize when a bag was passing. This functionality can be easily incorporated in a fully implemented BHMS. Instead a user must manually click a button to tell the computer that a bag is present. Once the button is clicked, the computer analyzes the current camera feed relative to a template, outputs an orientation and determines if it is within the acceptable limit or not, and stores information in the appropriate array.

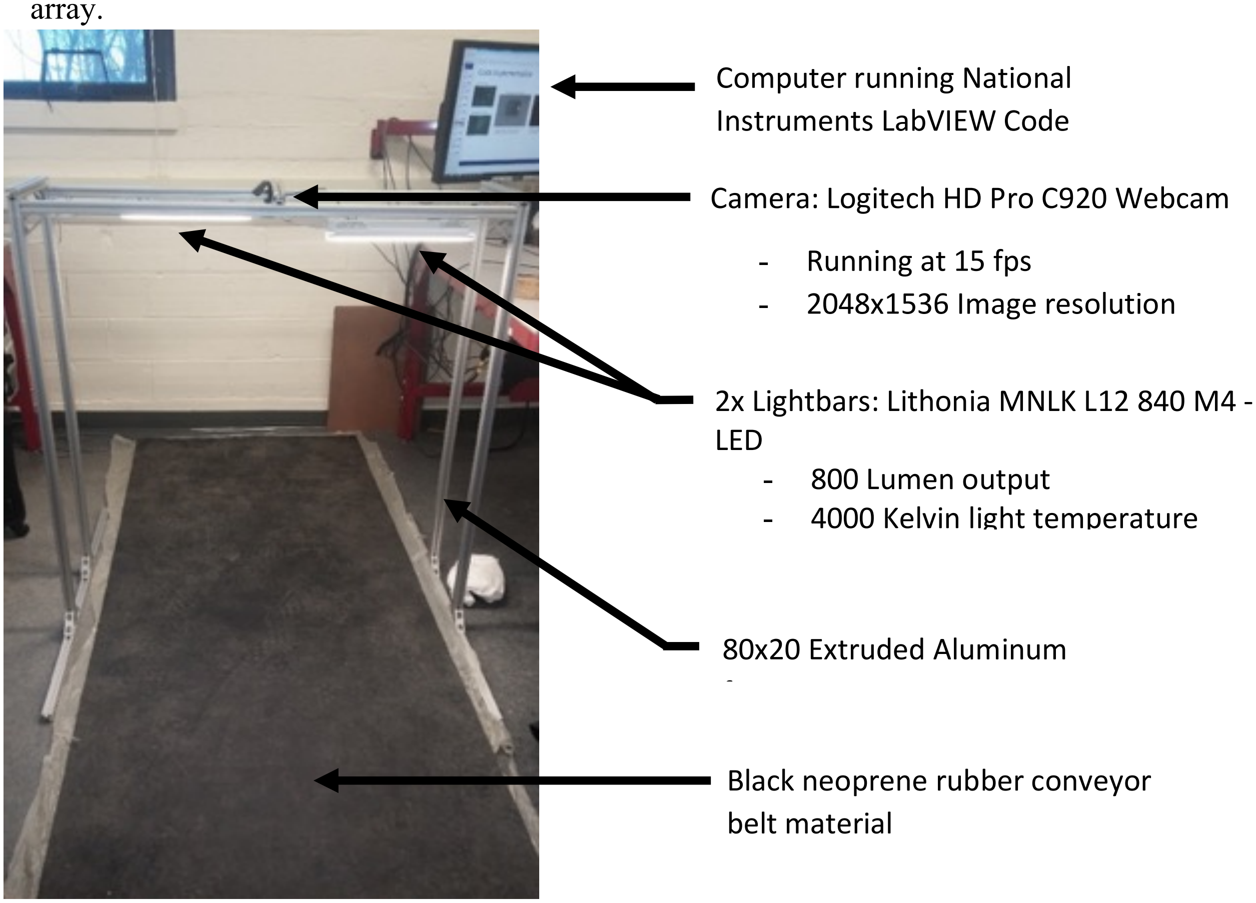

Figure 4: Proof of Principle Model, with Labeled Components

Figure 5: User Interface for Proof of Principle Model

The light bars were used to help create more uniform lighting conditions for the camera, to reduce the effects of background lighting changes and noise. The team had major difficulties before adding these lights; changes in ambient light, such as those caused by human activity nearby, would confuse the image processing before additional lights were added. The webcam was used in order to demonstrate that even with very cheap components, a working proof of principle model could be made, giving credence to the idea that the final BHMS would be affordable enough for airports across the country, particularly regional airports with smaller budgets like MHT.

The interface features: a scrollable array for both good bags and bad bags, a livestream from the camera, a running count of the number of good and bad bags, and the percentage of all bags classified as bad. There are also two buttons for creating a new template image and telling the computer there is a bag present. Both of these buttons would be unnecessary in the final product, as the computer would do both actions automatically.

Coding and Program Flow:

The flowchart shown below in Figure 6 describes the basic program flow the team used to detect the orientation of a bag underneath a single overhead camera.

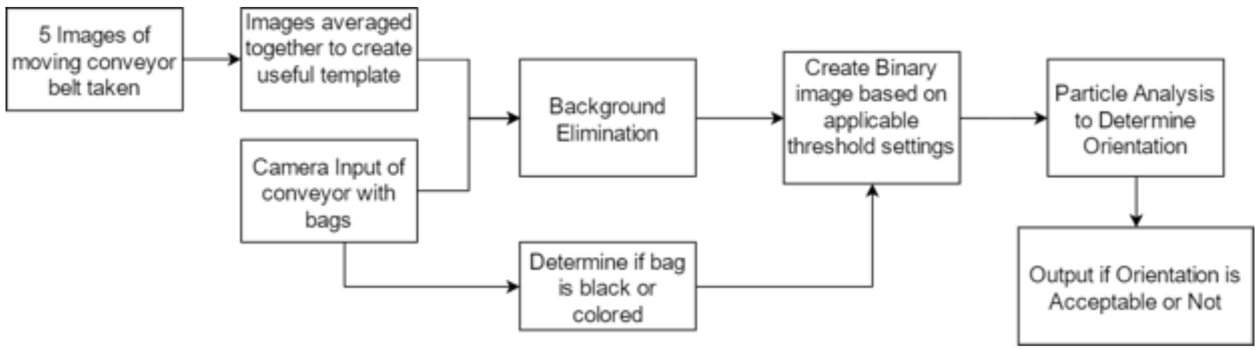

Figure 6: Code flow for Proof of Principle orientation detection

A template image is created with no bags present on the conveyor belt. The template is created by taking five separate images of the moving conveyor belt and then averaging them into one final template. Doing this helps smooth out any random imperfection in the belt surface or sudden changes in lighting to create a template that can be used in a larger variety of conditions. The template is then compared to images coming from the camera with bags present, to isolate the bags from the background to determine their characteristics. Two different algorithms are used for this task, depending on if the bag is black or colored. Detecting black bags on the black background was a major challenge for the team. The addition of the light bars that shine down on the bag to increase the contrast between the bag and the background helped tremendously with this problem. However, the algorithm does have trouble with certain types of bags such as hard-shell suitcases that tended to be very reflective. The reflective nature threw the additional light back into the camera lens and confused the algorithm. Further development is needed to be able to accurately identify the orientation of these types of bags. Once the bag is isolated from the background, the RGB image is converted into a binary image. These steps are illustrated below in Figure 7.

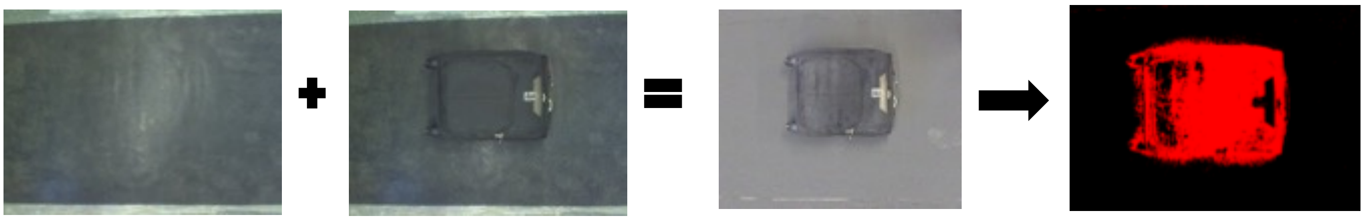

Figure 7: Image processing steps, from input image to binary image

Further work is then done on the binary image to clean it up to make the particle analysis easier, as shown in Figure 8.

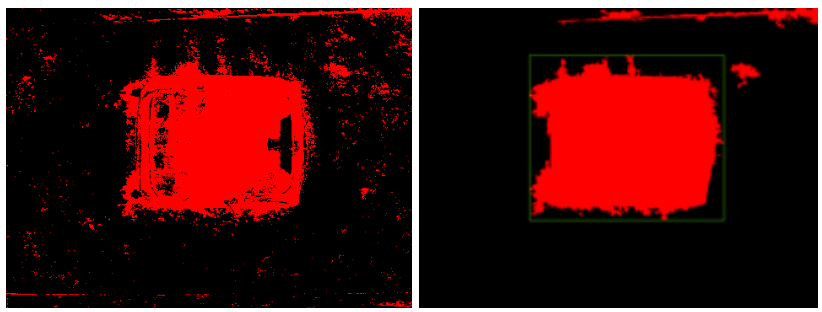

Figure 8: Before and after additional binary image cleanup

Next a particle analysis is done, and the orientation of the largest object remaining (the bag) is output for storage into a data array. This orientation is calculated by finding the axis that passes through the center of mass of the object that has the lowest moment of inertia. The angle between that axis and horizontal is output as the bags orientation and is compared to the acceptable limit.

Once the orientation is determined to be acceptable or not, the computer creates an entry for that bag consisting of: a clean unedited image of it, the time it passed, the detected orientation, and the binary image used for particle analysis (this was included mainly to help with troubleshooting the image processing). This entry is then placed into an array either of "good bags" or "bad bags" depending on if the orientation is within the limit. The user can then click through the two different lists of bags.

5.2 Testing and Validation at MHT Airport

The team set up the camera and connected laptop on an existing frame over the conveyor system at MHT Airport just after the Southwest Airlines check in counter, shown below in Figure 9. As bags came along the conveyor belt, the team intentionally changed their orientation to different angles to see how the system would respond. Unfortunately, due to technical and logistical difficulties the additional light bars could not be used while testing at the airport, which did reduce the success rate of the prototype.

Figure 9: Testing set up at MHT Airport

As it was, the proof of principle model performed almost as well in the laboratory, with a few key caveats. The bags were moving faster than expected on the conveyor underneath the camera, and the relatively low frames per second webcam could not take clean crisp pictures, resulting in blurred images that made the image processing less accurate. This demonstrated a clear need for a better camera with higher resolution and capable of more frames per second.

The computer could handle colored bags as well as it could in the laboratory, accurately identifying their orientation almost all the time. However, black bags posed a much larger challenge, and the algorithms had a hard time separating them from the conveyor belt background. This is shown clearly in Figure 10 that shows two bags on the conveyor belt at MHT, one brightly colored and one black. The black bag confused the software, and it was unable to accurate isolate it from the background.

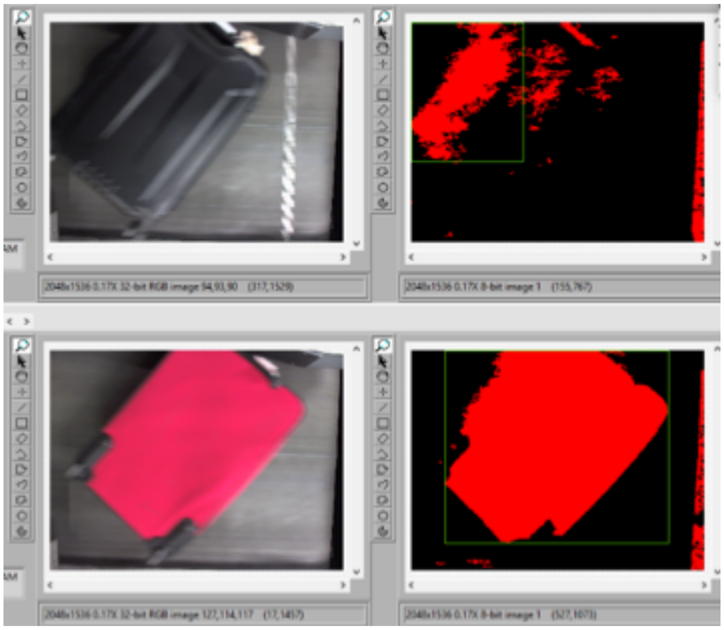

Figure 10: Difference between colored bag and black bag during testing at MHT

The lack of additional light bars contributed to this problem, as did the low frame rate of the webcam. Both problems affected the "crispness" of the edge between the bag and conveyor belt in the image.

The team received significant feedback from John Adams about the interface and display. He suggested that a more visual difference between good and bad bags be made when displaying the binary image, perhaps by making showing good bags in green as opposed to the default red. He also emphasized the ability to filter which bags to view, not just separated by good and bad but by time as well. For example, to be able to look at all bags that passed through on Monday and Tuesday mornings when a certain baggage crew is on shift, and then compare that to another crew's time slot to see which crew needs more reminding about hygiene policies.

5.3 Final Product Functionality and Components

The specifications and functionality listed below are based upon what the team learned throughout the creation of the alpha prototype, the feedback from airport operators and industry experts about the design idea, and the lessons learned after testing the alpha prototype in person at MHT Airport [27]. The described functionality will allow operators to accurately and reliably identify bags with poor hygiene, which crew/airline is responsible for those bags, and whether they lead to a jam. Being able to analyze real data about hygiene on their own conveyor system will allow operators to implement policies that are fine-tuned to achieve baggage excellence and reduce jams system wide.

Detecting Aspects of Bag Hygiene:

The BHMS will be capable of identifying all aspects of bag hygiene that can visually be determined. This includes:

- **Orientation** of bags with respect to belt flow direction
- **Straps or Handles** extending out from the bag
- **Real world dimensions** of the bag
- **Bulges** in the bag, and their position and direction
- **Slenderness/Shape** of bag
- **Spacing** between bags
- **Wheel location** and contact with conveyor belt

This information will be used to determine whether a bag is placed correctly. A score will be assigned to each bag based upon the computer's best guess at the chance that the bag will cause a jam, which it determines based upon these factors as well as information regarding bags with similar characteristics have caused jams in the past. The BHMS will collect the above hygiene data about each bag, and store it, along with a clean picture of each bag and the time the bag passed the machine in a fully indexed searchable array.

Operator Interface and Feedback:

The operator will be presented with an interface that allows them to view any bag and its hygiene characteristics. It will be possible to search and filter all bags by date and time, score that the computer system gave it, and its proximity to a jam occurrence. There will also be an interface that allows any employee to quickly and easily input if a jam has occurred, including its location. This will allow the computer to correlate bags with high potential to cause jams with actual jam occurrence.

There will also be an option for an operator to view all the bags the machine has scanned and manually approve or reject the machine's analysis of the hygiene of that bag. This will allow for machine learning, and will help the BHMS improve over time.

Hardware:

When fully installed the BHMS will consist of a network of modules placed at strategic locations throughout the BHS that the airport has identified as areas with a high potential for bag jamming. Each module will be Wi-Fi-enabled and connected to a central processing computer that handles the processor heavy image processing task. This will allow for monitoring of hygiene in more locations throughout the system, without the cost associated with have a powerful computer at each location. The components of each module are listed below, and are essentially the same as those in the prototype:

Cameras:

Each module will have at least two cameras, which will allow the BHMS to create multiple views of each bag which it uses to identify different aspects of bag hygiene. These cameras will be industrial grade capable of taking clear images of bags moving at up to 350 feet/min [28]. They must also have built in image stabilization software, which is essential given that they will be mounted on vibrating conveyor belt systems.

Lights:

The lights on each module will be LED's strong enough to create uniform lighting conditions for the cameras no matter what the background lighting and shadows may be. Based upon the alpha prototype and testing, a minimum of 2000 lumens is recommended.

Motion Sensors:

Motion sensors will allow the computer to detect when a bag is present for analysis, and when no bags are present. This is important both for accurate identification, and for dynamically updating the template image of the bag-free conveyor belt used during image processing.

Mounting System:

A modular system of steel bars and clamps will be used to mount each of the components into place, customizable to individual locations.

6.0 COST/BENEFIT ANALYSIS

For the cost section, the team generated a series of cost tables that were divided into four stages to illustrate the progression of costs for the development of the BHMS.

6.1 Research and Development Costs (Alpha)

Table 6 presents the costs associated with the initial alpha research and development stage of the project. The costs included developing alpha prototype and traveling to airports to conduct research.

Table 6: Alpha Prototype Cost Table

Item	Rate	Quantity	Subtotal	Remarks
Labor – University Design Competition				
Student Labor	$25/hr	210	$5250	3 students – 70 hours each
Expert Consultation	$70/hr (Avg. Salary)	4	$280	Consultation with Chris Perez and John Adams
Research Expenses				
Travel	$0.30/mi	560	$170	EWR Airport – 1x MHT Airport – 1x
Logitech Webcam	$80/piece	1	$80	Alpha Prototype
Conveyor Mat	$40/piece	1	$40	Alpha Prototype
80 x 20 Material (with fasteners)	$3/ft	30	$110 (included with fasteners)	Alpha Prototype
Subtotal			**$5930**	

6.2 Research and Development Costs (Alpha +)

Table 7 shows costs associated with the alpha + research and development stage. This stage is labeled as alpha + since the team felt that at this stage, they have not yet reached a functional beta prototype. The costs listed are associated with the further development of the alpha prototype and travel costs for the research/testing conducted at MHT airport.

Table 7: Alpha+ Cost Table

Item	Rate	Quantity	Subtotal	Remarks
Labor – University Design Competition				
Student Labor	$25/hr	150	$3750	3 students – 50 hours each
Expert Consultation	$70/hr (Avg. Salary)	8	$560	Consultation with Dan Hannon, John Adams, and Tom Labrie

Research Expenses				
Travel	$0.30/mi	400	$120	MHT Airport – 4x
Subtotal			**$4430**	

6.3 Production and Installation Costs

Table 8 represents the costs associated with the production and installation stage. The data in this table will be specifically addressing the costs associated with the final product that will be implemented in the airports. The costs listed below for the final product were estimated according to the final product's specific components and features listed in Section 5.3.

Table 8: Production and Installation Costs

Item	Rate	Quantity	Subtotal	Remarks
Labor- Installation				
Company Representatives	$50/hr	8	$250	Company representatives supervising installation of system
Electrician (assuming hired by company)	$45/hr	8	$360	Technical experts on electrical components installation
IT Technician (assuming hired by company)	$50/hr	8	$400	Technical experts on installation of software (central computer integration with wifi enabled modules)
Cost of Goods				
High Speed Camera	$1500/pc	10	$15,000	Basler 720p High Speed Camera
LED Light Strip	$120/pc	5	$600	Metalux 4ft. LED Light Strip
Motion Detector	$42/pc	5	$210	Seco-Larm Wall Mounted Photoelectric Beam Sensor
Mounting System	$100/pc	5	$500	Hague THM Twin Camera Mount
Wifi enabled circuit board	$35/pc	5	$175	Raspberry Pi Circuit Board - Wifi Enabled
Computer	$500/pc	1	$500	Dell Inspiron 5000 Laptop
Miscellaneous (TSA Inspection)	TBD	TBD	TBD	Dependent on whether camera module will be in TSA sensitive area.
Subtotal			**$18000**	

6.4 Operation & Maintenance Costs

The final table, Table 9 represents the operation and maintenance costs table. The costs in this table will be mainly associated with the labor/travel costs for the technical support and operators of the BHMS system that will conduct routine maintenance or troubleshooting.

Table 9: Operation and Maintenance Costs

Item	Rate	Quantity	Subtotal	Remarks
Labor- Operators & Technical Support				
Company Representatives	$50/hr	4	$200	Twice a month maintenance visits, two hour sessions.
Technical Support	$50/hr	TBD	TBD	Dependent on occurrence of issues.
Expenses				
Travel	$0.30/mi	200	$60	MHT Airport 2x
Subtotal			$260 + Technical Support Fees	

6.5 Benefit Analysis

In order for the BHMS to be attractive to a customer for purchase, it must amortize itself by reducing instances of baggage jams thus saving costs incurred from jams. At MHT, the BHMS would reduce instances of baggage jams by collecting data on which aspects of bag hygiene are resulting in jams and where those jams are occurring most often. Based on this data, the BHMS provider would suggest corrective measures (e.g. bag hygiene policy changes) to the airport operators that could reduce instances of jams. Figure 11 shows the possible outcomes that can occur from a baggage jam, with green being the least costly outcome, red being the most costly outcome, and yellow falling in between.

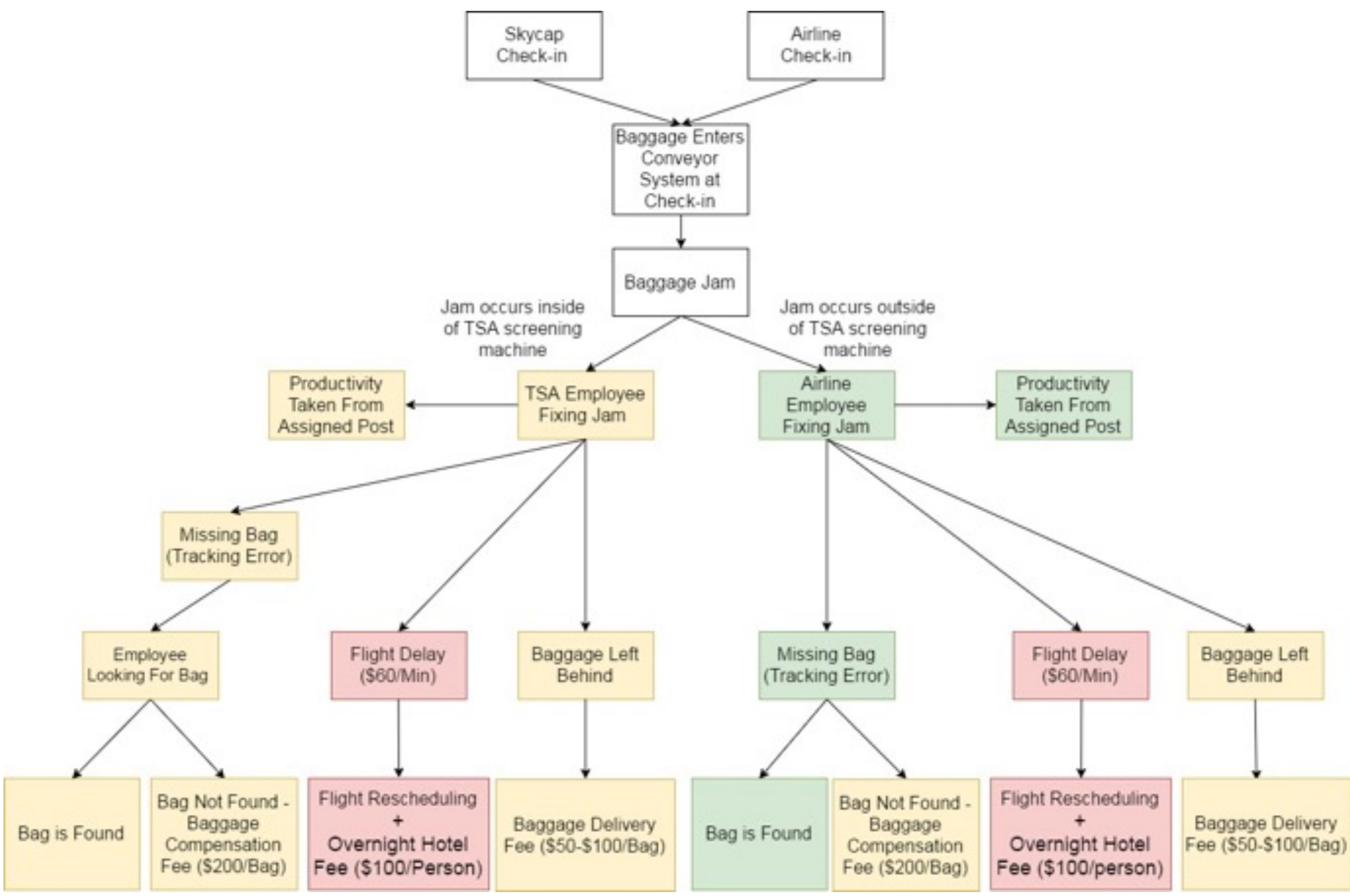

Figure 11: Possible Outcomes Resulting From a Baggage Jam

According to interviews with industry experts at MHT, the probability of each outcome is inversely proportional to its financial risk—i.e. the more costly outcomes (in red) are less likely to occur [2]. However, the red outcomes are also significantly more costly, potentially costing upwards of $100,000 USD; some associated expenses, for example, include the costs of rescheduling a flight and housing passengers in a hotel overnight. Comparatively, the green outcomes only cost tens of dollars to hundreds of dollars per occurrence but also happen much more frequently and therefore can add up in cost. Note that the left-hand path of the baggage jam model associates a higher cost with some outcomes than their counterpart outcomes on the right-hand path (e.g. "Missing Bag"). This is because a jam that occurs inside the TSA screening machine is immediately more costly than one outside the machine since it requires a shutdown of the entire BHS and other associated safety protocols [1] [2]. If the BHMS is able to prevent the occurrence of even one or two of the red outcomes, it immediately pays for itself. Similarly, if it reduces the instances of green and yellow outcomes, it pays for itself over a period of time. The exact period of time over which it pays for itself is hard to determine as the probability and cost of each outcome varies across airports and BHS's.

Also varying across airports is the party benefiting from the BHMS. At MHT, the greatest beneficiary—and therefore the potential customer—is the airline. The reason being that at MHT each airline uses a separate BHS; so if a jam occurs, the corresponding airline bears the financial consequences. This model changes at airports (generally larger airports) where airlines share a BHS and where the systems may actually converge at a certain point. In this case, the risk is split among several airlines. Nonetheless, in both scenarios the airport owners also benefit from the BHMS because a more efficient airport means more flights, more customers, and more profit. In all scenarios, the branding and reputation of the airlines and airports are also at stake and benefit from smoother performance and greater efficiency.

As described before, at MHT the BHMS would be used to suggest corrective measures that the airport operators could take to reduce instances of jams. However, this model may not be appropriate at all airports. Section 8.2 discusses a different application that the system could have.

7.0 SAFETY RISK ASSESMENT

The team knew that any solution that could be implemented in airports across the United States would have to be safe enough to adhere to strict TSA and FAA safety guidelines. One of the stated main goals of the FAA is "to provide the safest, most efficient aerospace system in the world", and as such the BHMS must increase airport operation efficiency without sacrificing the safety of millions of passengers travelling through airports. While the BHMS is inherently less risky from a safety perspective than equipment involved with say, runway incursions, the team nonetheless went through the five steps in the Safety Risk Management Process as described in FAA Advisory Circular 150/5200-37 to ensure it was up to FAA standards. This ensures that the BHMS will be able to be fully and easily integrated into an airports existing Safety Management System, as required by the FAA Safety Management System Manual.

7.1 Describing the System

The BHMS is a computer based system that can be added to an existing BHS to visually collect data on bag hygiene and allows operational managers to hold different parties (e.g.

different airlines sharing one conveyor system, different crews from one airline unloading bags) accountable for jams caused by poor bag hygiene.

7.2 Identifying the Hazards

a) *Hackers*: Since the system will be storing information about passengers' bags, the BHMS may be a target for hackers.

b) *Human Element*: If the system encourages baggage workers to exert more effort in placing the bags properly there may be possible risks associated with those behavioral changes.

c) *Equipment Failure:* The product will be installed on a conveyor belt system, and thus subject to repeated vibration and wear from the environment. This could cause premature failure.

7.3 Determining the Risk

a) *Hackers*

Since the BHMS will be taking visual footage/pictures of both passenger bags and, perhaps incidentally, other airport baggage equipment there are several risks associated with hackers:

- *Passenger information theft:* The BHMS will be taking footage/pictures of passenger baggage, which includes the label with destination on it.
- *System incapacitation:* Hackers could access and incapacitate the system through the software.

- *TSA Equipment information theft:* The TSA does not allow images of Checked Bag Screening Equipment to be taken for security purposes. It is conceivable that the BHMS could be positioned with a view of these machines and images stolen by hackers.

b) *Human Element*

- *Worker Injury*: If workers exert themselves more to get additional benefits, it is possible they may get injured more often (back problems, bag dropped on foot etc), leading to health costs, and possible litigation.

c) *Equipment Failure:*

- *Increased baggage jamming:* If there are increased baggage jams due the system being non-operational this could divert maintenance resources from other potentially more vital airport safety operations.

7.4 Assessing and Analyzing the Risk

Using the risk matrix seen in Figure 12, as found in FAA Advisory Circular 150/5200-37 [29], each risk was analyzed and given a likelihood and severity. The results are shown in Table 10.

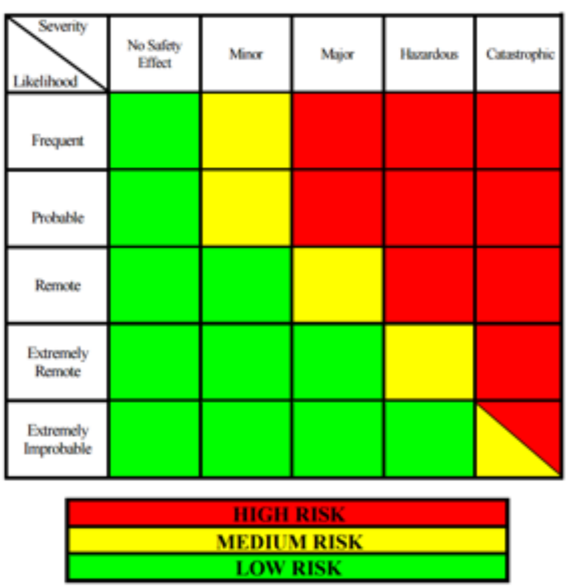

Figure 12: Risk Matrix, from FAA Advisory Circular 150/5200-37

Table 10: Likelihood and Severity of Each Risk

Risk	Likelihood	Severity
Theft of Passenger Information	Extremely Remote	Major
System Incapacitation (hackers)	Extremely Remote	Minor
TSA Equipment Information Theft	Extremely Remote	Major
Increased Worker Injury	Probable	Major
Increased Baggage Jamming (equipment failure)	Remote	Minor

7.5 Treating the Risk

Each of the risks was then treated to bring it down to an acceptable level if it was not already.

Hackers: To control the risk associated with hacking of the BHMS, the software will be continually updated to patch any discovered exploits and to take advantage of all new developments in the field of software security. Employees using the software will be given special access codes, to ensure that others without proper clearance cannot access stored data.

Worker Injury: This risk is difficult to avoid or control, so instead it will be transferred to the airlines and subcontractors of baggage handlers. If an airport decides to use the BHMS (either to gamify inbound baggage handling, or improve handling at check in) they shall get all airlines or subcontractors employing baggage workers to sign a waiver agreeing to accept all responsibility for their employees injuries during work, thereby transferring health and litigation costs away from the airport.

Increased Jamming due to Equipment Failure: This risk will be assumed by the airport or conveyor belt operator. If the BHMS fails, it will simply be as though it was never installed in the first place, no additional negatives exist. Given that the airport was functioning without the BHMS (less efficiently perhaps), the failure of the BHMS is acceptable to be assumed and not additionally controlled for.

8.0 FUTURE WORK

The team knows that there is significant work that can be done in the future to further develop and improve the Bag Hygiene Monitoring System.

8.1 Further Development of Alpha Prototype

As mentioned in the technical aspects section, there are further technical functionalities that need to be developed from the alpha prototype to the final product. The user interface in particular is significant and the team would further consult Dan Hannon (Human Factors Expert) on the most optimal design for functionality.

8.2 Other Potential Applications

In addition to the current application in MHT, the team is also confident that the existing BHMS can be modified to fit other types of applications in different airports. One of the most promising application the team was considering is gamification of the BHMS that will interact with baggage handlers in larger scale airports, specifically for inbound baggage coming off planes. With gamification, the team is aiming to tackle bad bag hygiene caused by the repetitive nature of bag handling. By implementing an incentive based game within the current baggage unloading process, this would not only motivate employees, but also make the process more involved and entertaining for the baggage handlers to practice good bag hygiene.

Along with gamification, another application is to implement the BHMS into shared conveyor systems (between different airlines) in larger airports. With this type of application, it would directly tackle the lack of accountability since the BHMS would be able to specifically pinpoint which airline/employees are responsible for the bad bag hygiene. Furthermore, through data collection, this would hold the parties accountable and not only make them more involved, but also more aware of the consequences of their actions.

8.3 Possible Business Model

Throughout the report, the team assumed for simplicity that the final product was going to be sold as a permanent solution (higher capital investment). However, the team was also considering an alternate business model where the final product itself, could be rented on a temporary basis. This type of business model would be able to capture the smaller regional airport market since the rental model would be more financially feasible for them.

Appendix A: Contact Information

Team Members

	Email
Nicholas Nopprapun	nicholas.nopprapun@gmail.com
Erick Garcia	erick.em.garcia@gmail.com
Noah Kagan	nakagan@gmail.com

Faculty Advisors

	Email
Gary Leisk	gary.leisk@tufts.edu

Appendix B: Description of Tufts University

Tufts University is a private institution founded in 1852 located at three campuses in Medford/Somerville, Grafton, and Boston. The Medford/Somerville location is considered the flagship campus that contains all the undergraduate programs, Fletcher School of Law and Diplomacy, Graduate School of Engineering, and the Graduate School of Arts and Sciences. With the majority of the Tufts population, all of the administrative offices are located in this campus.

Currently, Tufts has an undergraduate enrollment size of 5,290 undergraduate students and 5,847 graduate students. With a small population, this means that Tufts has an impressive student-faculty ratio with 67.5% of its classes with fewer than 20 students. The Tufts School of Engineering currently offers 10 different bachelor degrees. All the members of this team are pursuing a Bachelor of Science in Mechanical Engineering.

The Department of Mechanical Engineering at Tufts currently has faculty size of 25 members all specializing in different fields such as robotics/autonomous systems, material mechanics and processes, thermo-fluid systems, and product design (human factors). Many of the faculty members in the mechanical engineering department, along with their classes, are involved in a number of pioneering research studies that are making huge strides in their respective fields. This provides many undergraduate and graduate students with excellent opportunities to dive into a whole spectrum of different fields depending on their personal interests. This not only advances their skills as mechanical engineers, but also provides a solid foundation for their career paths.

Appendix C: Description of Non-University Partners

Name	Email
Christopher T. Perez	ctperez@panynj.gov
Jonathan L. Adams	jadams@flymanchester.com
Thomas J. Labrie	tom.labrie@wnco.com

Christopher T. Perez

Christopher Perez is the duty manager for the international facility in Newark Terminal B. His role as duty manager is to oversee the daily operation of the terminal for all incoming and outbound flights. In regards to the team's project, Chris Perez gave the team a comprehensive tour of the operations in Terminal B focusing specifically on the operation of baggage handling. With this tour, the team gained valuable insights on the intricacies of the baggage handling operation of a large scale airport.

Jonathan L. Adams

Jonathan L. Adams is the building maintenance supervisor in Manchester-Boston Regional Airport. His role as supervisor is to ensure all the buildings and equipment throughout the airport are operating at the most optimum level, as well as inspecting the installation of new equipment. In regards to the team's project, John Adams was an integral stakeholder (due to the focus on MHT), as he gave us a comprehensive tour of the baggage operation at MHT, the current needs and requirements for the solution, and insights on how the team's solution could be implemented within the airport.

Thomas J. Labrie

Thomas J. Labrie is the Southwest station manager at Manchester-Boston Regional Airport. His role as station manager is to oversee all Southwest ground operations within the airport. In regards to the team's project, Tom Labrie represented an integral airline stakeholder as he not only provided the team with a comprehensive overview of current Southwest operations at MHT, but also provided insights to the current needs and requirements for the solution from the perspective of the airline.

Appendix E: Evaluation of the Educational Experience

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Yes, absolutely! We had a unique hands-on opportunity to learn about the design process of a product. The process we went through identifying the most important needs for the industry experts was unlike any other academic experience we have had so far. Going from almost no knowledge about baggage systems to having a design idea that was well received by the airport operators with whom we shared it with was an incredibly eye opening and meaningful experience. The scope of the design challenge necessitated that we reach out to professors and experts in many different fields, and this taught us a lot about the interdisciplinary approach needed to design a successful product.

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

One of the challenges we faced was selecting a focus for the project itself. The competition has such a wide range of possible problems that narrowing the scope down was difficult at first. The decision to focus on baggage was made by looking at previous contest entries, as well as brainstorming about which part of airport operations impacts us most as customers. We noticed that there weren't a lot of other entries focusing on baggage, so we saw this as an area with potential for innovative solutions.

Another challenge we had later in the process was essentially the opposite: we were learning so much about the baggage process, that the amount of different factors that could affect the success of our design seemed overwhelming. We decided to take a step back, reassess which problem we were trying to solve for the competition entry, and focus our efforts on the factors we had the most control over.

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

We used a stage-gate design approach, iterating each stage multiple times before we felt confident we had the best knowledge to proceed. We began by informing ourselves of the general background of baggage operations with interviews and literature review online. Then we began to focus on identifying the most important needs for the customer we wanted to satisfy, namely the airport operators in charge of baggage. Once needs were identified, we generated several possible concepts, and then selected the one best suited to satisfy the important needs.

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

The interactions with industry experts and airport employees was the single most important and meaningful part of our entire project. We never would have had the idea to explore bag hygiene as a design focus if one of our interviewee's had not casually mentioned it, almost as an afterthought. The feedback and encouragement we got from the team at Manchester-Boston Regional Airport (MHT) was essential to the fine-tuning of our design. Working with them to determine the best possible implementation at MHT helped us further imagine the functionality of our product for many other types of airports.

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 lot about how to apply the mechanical engineering theory we have been learning in many of our classes to real-world practical solutions. Being forced to work within constraints and needs dictated by an outside customer taught us how to balance the idea of a “perfect solution” with a practical engineering solution that is good enough to satisfy most of the customer needs reasonably well. We also learned a lot about interviewing techniques, and how to approach different experts to get the most useful information from them. These skills will be important to us as we graduate and enter the workforce.

Advisor:

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

As an instructor of the capstone design course in the Mechanical Engineering Department at Tufts University, I have utilized the competition as a source of problems for the students to tackle for a few years. I have found it valuable because it provides: (1) an opportunity to tackle a real problem; (2) a wide array of problems that can challenge but also interest students of varying backgrounds; (3) access to real customers and problem environments; and (4) an incentive for students to put in a significant effort and try to develop viable solution(s) to the problem.

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

The learning experience was well-aligned with my curricular goals for the capstone design experience. It fit nicely into a stage-gate process approach, provided a real experience (with real customers/clients), had an open-ended nature, required the students to invoke knowledge they've accumulated in their undergrad career (so it's a great "capstone" experience), and challenged the students to communicate their solution to experts in the field. One aspect I particularly appreciated was the human factors aspect; the students needed to consider not just technical aspects of their solution, but how to appropriately provide interface(s) for the humans who would use/interact with their solution. I believe every undergraduate graduating with a degree in Mechanical Engineering should have some exposure to this aspect of design.

3. What challenges did the students face and overcome?

My student team started their capstone experience by selecting baggage handling as a problem area. They developed the required initial design tools to help enumerate customer needs and engineering requirements. However, after starting to visit airports and talking to baggage handling experts, they realized they were tackling the wrong problem! While this was a major challenge for them, requiring a re-think of the entire project, it was an incredibly valuable educational experience. As the project continued, the need to iterate and be customer-focused was reinforced over and over. I loved that aspect of this project.

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

I will definitely use this competition again in the future. I fully expect to present the competition in the Fall for my capstone course, but may also explore utilizing the competition in other design-related courses, such as our Machine Design course and my graduate-level Inventive Design course. With the right planning and course execution, I believe the competition can be scoped by an instructor to coincide with the curricular goals of many different courses.

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

One challenge I have is how late in the year the competition is announced. I would prefer if it could be introduced in early summer, so I am more prepared for the Fall semester. Another aspect that is a challenge is the cost content of the report. Because the competition is generally geared around solving problems for a finite number of airports, airlines, or operators, it is a challenge for students to do a solid job with this aspect of the competition. I wish there were more resources to help with this aspect.

Appendix F: List of References

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