A Modular Operation Solution to Airport Baggage Transportation

University of South Florida 2020

Team members: Zhiwei Chen (Graduate student); Xiaowei Shi (Graduate student)

Advisor: Xiaopeng Li (Associate prosessor)

Department of Civil and Environmental Engineering, University of South Florida, FL 33620, USA

Contents

Figures

Tables

Executive Summary

In this report, we present an innovative modular operation solution to the baggage transport in airports for the 2019-2020 ACRP Design Competition.

Many airport operators are searching for better solutions to further decrease the operational cost related to airport baggage transportation. Currently, the transportation of baggage between terminals and aircraft is mainly undertaken by human-driven carts with little optimization. As a result, the transportation capacity provided by the dispatched carts is not well aligned with the baggage transportation demand, resulting in an increase in operational cost and a decrease in resource utilization. To address this issue, we propose a modular operation for airport baggage transportation. Specifically, we dispatch vehicles formed by a higher number of carts and a high frequency during periods with intensive demand (peak hours). In contrast, vehicles consisting of a smaller number of carts can be dispatched during periods with relatively sparse demand using a relatively low frequency.

Based on this concept, we designed the proposed modular operational paradigm, a schedule optimization module, and the required technical details with valuable comments and suggestions from industry experts. To evaluate the proposed design, we conducted a case study with baggage demand data from the Tampa International Airport (TPA), based on which risk assessment and impact assessments were further carried out. Results show that the proposed modular system can effectively reduce the operational cost (including energy cost and ground crew salary) and increase resource utilization rates. Successful implementations of this design will set up an example for developing a modular vehicle-based operational paradigm in other transportation systems.

Problem statement and background

Baggage transportation is one of the major categories of ground handling activities and a primary contributor to the service quality and operational cost of airports. Baggage-related problems (e.g., delayed, damaged, lost baggage) rank the second among all the customer complaint categories in the United States (US Department of Transportation, 2020). The cost associated with baggage transportation, such as the energy cost, ground crew salary, and the costs related to mishandled baggage, accounts for a crucial proportion of the operational cost of airports (Meersman et al., 2011). For example, the baggage services incurred a cost of 1,127,153$ in 2019 at Tampa International Airport (TPA), and this number was projected to reach 1,420,950$ in 2020 (Tampa International Airport, 2019).

To improve the efficiency of baggage transportation, many airports have introduced Baggage Handling Systems (BHS). With BHS, the baggage transportation process can be streamlined as shown in Figure 1 (Huang et al., 2016). After being checked in or transferred from a connecting flight, the baggage is sent to an X-ray security screening machine. Once passed the security check, the baggage is sent to the main sorter to be identified and assigned with a destination. The baggage is then transported to the assigned destination, which can be either an unloading area or a buffer area. Baggage in the buffer area will have to wait for reassignment to be sent to an unloading area. In contrast, baggage in the unloading area will be collected, loaded in human-driven carts, and finally transported to the airplane by ground crews. During this entire process, the Radio Frequency Identification (RFID) technology or bar-coded baggage tags can be used to track the location of the baggage.

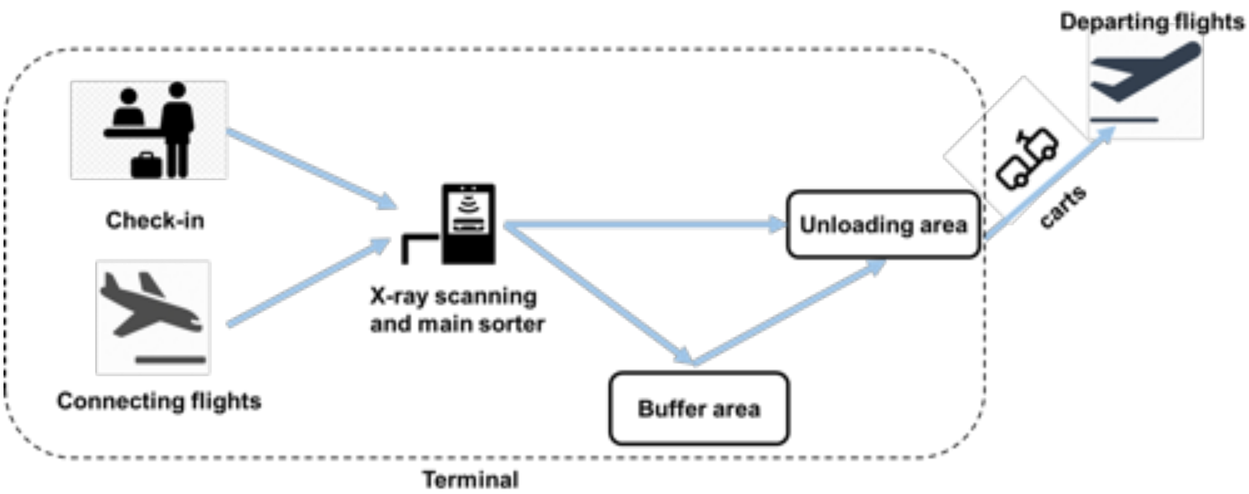


Figure 1. Streamlined baggage transportation process in airports

This automated baggage handling process has been shown to greatly alleviate the burdens on airport ground support personnel, decrease operational cost, and increase customer satisfaction because of a reduction in the number of mishandled baggage. Yet, there are still challenges faced by airport ground operators and therefore substantial potentials to achieve better performance in baggage transportation. Among these challenges, it is of airport ground operators' particular concern that the operational cost incurred by baggage transportation is still substantial. An example is that the fuel cost reached 319,912$ in TPA in 2019 (which was higher than the projected value for that year, $307,572; Tampa International Airport, 2019). Therefore, many airport operators, the case study TPA in this design included, are searching for better solutions to further decrease the operational cost related to the airport baggage transportation**.** Thus, developing a more cost-effective solution for airport baggage transportation is vital for reducing the operational cost and improving the operational efficiency for airports.

Summary of literature review

Airport baggage transportation

As described in Figure 1, baggage transportation in airports for departure flights is composed of two steps: transporting the baggage from the check-in areas to the unloading areas (within the terminals) and transporting the baggage from the terminals to the aircraft. The baggage is transported by conveyors (a part of the BHS) within the terminal. When the cumulative number of arrival baggage in the unloading areas reaches a given quantity or the time reaches the planned departure time, carts will be formed into vehicles to transport the baggage to the aircrafts. In the literature, a large number of studies have been conducted on designing the HBS systems to improve the transportation process (i.e., the first step described above). For example, Zhang et al. (2008) investigated the traceable BHS with the RFID tags and designed a distributed aviation baggage traceable application based on RFID networks. Lin et al. (2015) built a BHS simulation model by using System Modeling Language, which aims to enhance the validity of the system. Zeinaly et al. (2013) proposed a strategy for the control of BHS. Johnstone et al. (2010) studied the dynamic routing problem of the baggage handling system. Further, several studies have been carried out to optimize the assignment of airport baggage unloading zones to outgoing flights (e.g., Huang et al, 2016; Huang et al., 2018).

However, the second step of the baggage transportation process has received little attention in the state-of-the-art. To the best of our team's knowledge, no studies have been carried out on optimizing how to schedule the carts to transport baggage between the terminals and aircraft (we call this the cart scheduling problem in this report) to reach a better system performance. Without an optimized design, the ground crews transport baggage based on some unoptimized rules in practice. Yet, baggage transportation between the terminals and aircraft also plays an important role in airport operations and there are potentials to improve this process. On one hand, rapid and on-time baggage transportation guarantees that flights can depart on time and can also improve the level of service. On the other hand, the operational cost related to baggage transportation is a considerable component of the operational cost of airports. Thus, it is necessary to design a better solution for transporting the baggage between the terminals and aircraft.

Vehicle scheduling optimization

Although cart scheduling has rarely been investigated for airport baggage transportation, vehicle scheduling is an extensively studied topic in other urban transportation systems. Among them, the most relevant problems are the dial-a-ride (DAR) problem with time windows and the transit system scheduling (TSS) problem. Therefore, we offer a brief review of these two problems in the remainder of this section.

The general DAR problem investigates the dispatch of vehicles to serve a set of passengers with predefined travel origins, destinations, and service time windows with a limited vehicle fleet. Decisions include the number of vehicles dispatched, the nodes that each dispatched vehicle visits, and the sequence that each vehicle visits the selected nodes. This problem definition has been adopted by many studies with various objective functions and constraints for incorporating real-life operational considerations (Garaix et al., 2011; Häme, 2011; Masmoudi et al., 2016; Muelas et al., 2015; Paquette et al., 2013). For example, Braekers and Kovacs (2016) studied the DAR problem by considering the driver consistency constraint, aiming to reduce the number of drivers that are needed to serve all passengers. Reinhardt et al. (2013) incorporated a multi-modal operation into the traditional DAR problem, intending to minimize the waiting time for disabled passengers with synchronization between different modes. Masmoudi et al. (2017) considered that the passengers and the vehicles are both heterogeneous to make the study close to the reality.

The TSS problem can be regarded as a special (or simple) case of the DAR problem because only decisions on vehicle dispatch time are determined. In this problem, the investigated systems are usually mass urban transportation systems with a fixed number of stations where passengers arrive continuously (e.g., bus, train, subway). By determining the vehicle schedule, all customers' travel demand must be satisfied while the operators' specific objectives are achieved (Cacchiani et al., 2016; Niu and Zhou, 2013; Yang et al., 2016). For example, Barrena et al. (2014) studied the vehicle scheduling for a railway system by considering a dynamic demand environment. The objective for the research is to minimize the total waiting time for the passengers. Huang et al. (2016) investigated the train scheduling in an urban rail transit system, and they aimed to obtain an energy-efficient and service-quality-based train schedule.

However, the cart scheduling for airport baggage transportation is different from both problems. For the DAR problem, we do not need to visit several nodes successively. However, the carts must come back to the unloading areas for the next dispatch after serving an aircraft. For the TSS problem, the cart scheduling is different because there is a time constraint for the baggage transportation for each aircraft. Thus, the modeling techniques and solution algorithms proposed in these relevant studies provide valuable insights for but cannot be directly applied to our design. Substantial methodological efforts are needed to realize the proposed design.

Modular vehicle operations

Vehicle modularity is a concept with a long history in railway transportation and airport baggage transportation. The past few years have witnessed an increasing interest in introducing the modularity concepts into other urban transportation systems, such as bus systems, highway systems. Indeed, an emerging vehicle technology called modular autonomous vehicles (MAV) are being tested in several countries in the world. With this modularity concept, vehicles can adjust their capacity flexibly by assembling or dissembling identical detachable modular units according to the passenger demand. A few pioneering studies have realized this emerging technology and made attempts to propose operational design for systems based on modular operations (Chen et al., 2019a, 2019b; Dai et al., 2020; Hassold and Ceder, 2014; Mo et al., 2019)). Particularly, our team members have carried out a series of studies investigating the operational design for urban mass transportation systems with MAVs under different system settings, such as transit shuttles (Chen et al., 2019a), transit corridors with modular operation at the first station (Shi and Li., 2020), transit corridors with station-wise modular operations (Chen and Li., 2020). These studies have demonstrated that the innovative modular operations can improve system performance by increasing resource utilization rate, decreasing operational cost and reducing passenger waiting cost. Additionally, our group has been conducting experiments using scaled MAVs to demonstrate the feasibility of implementing modular operations, as shown in Figure 2. Nevertheless, modular operations have not been well studied in the context of airport baggage transportation, and their impacts on system performance are not fully understood yet. Our design aims to fill these knowledge and methodological gaps.

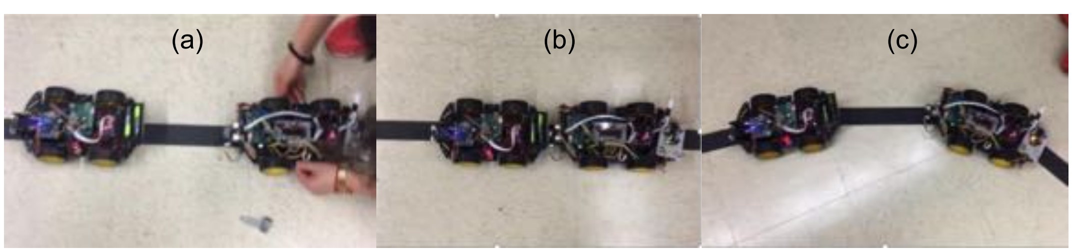


Figure 2. Scaled MAV experiments conducted in our lab.

Problem solving approach

Description of ideas

Currently, the transportation of baggage between terminals and aircraft is mostly undertaken by human-driven carts with little optimization, as shown in Figure 3(a). However, studies have found that the baggage transportation demand is time dependent (Huang et al., 2018). For instance, the number of baggage during daytime (e.g., due to a higher number of flights) is larger than that during nighttime (see Expected Impacts and Findings for a real-world example with data collected from the TPA). Without a proper schedule of cart dispatching, ground crews generally transport the baggage at a predefined time (e.g., 30 mins) before the departure of a flight, using several carts that can accommodate all the baggage. Consequently, the transportation capacity provided by the dispatched carts is not well aligned with the baggage transportation demand, resulting in an unnecessary increase in the operational cost.

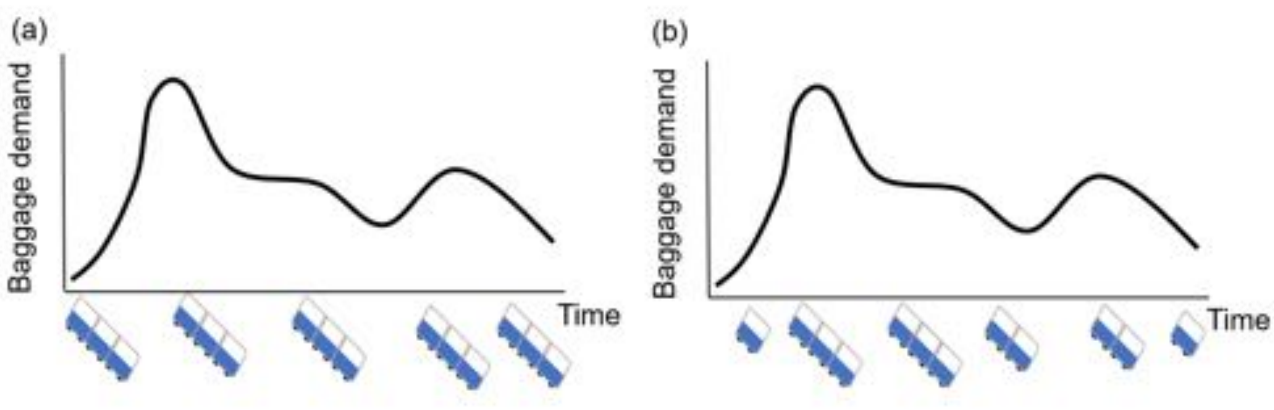


Figure 3. Airport baggage transportation paradigms. (a) The existing paradigm with fixed-capacitated vehicles and little optimization; (b) The proposed modular operation paradigm with adjustable vehicle capacity and optimization.

Additionally, our team members observe that carts used for airport baggage transportation are modular; they can be connected and disconnected to form vehicles of different capacity (or sizes). This modularity nature of the carts indicates an opportunity to introduce modular operation in the airport system, as shown in Figure 3(b). Specifically, we dispatch vehicles formed by a higher number of carts and a high frequency during periods with intensive demand (peak hours). In contrast, vehicles consisting of a smaller number of carts can be dispatched during periods with relatively sparse demand using a relatively low frequency. This modular operation concept takes advantage of the economics of scale property of the operational cost in ground handling activities and thus is expected to improve system performance (i.e., higher baggage loads, less energy wasted on hauling empty vehicles). Besides, we can apply operations research methods to properly design the dispatch frequency and capacity of the vehicles so that the vehicle capacity and baggage demand can be relatively well matched to avoid unnecessary operational cost.

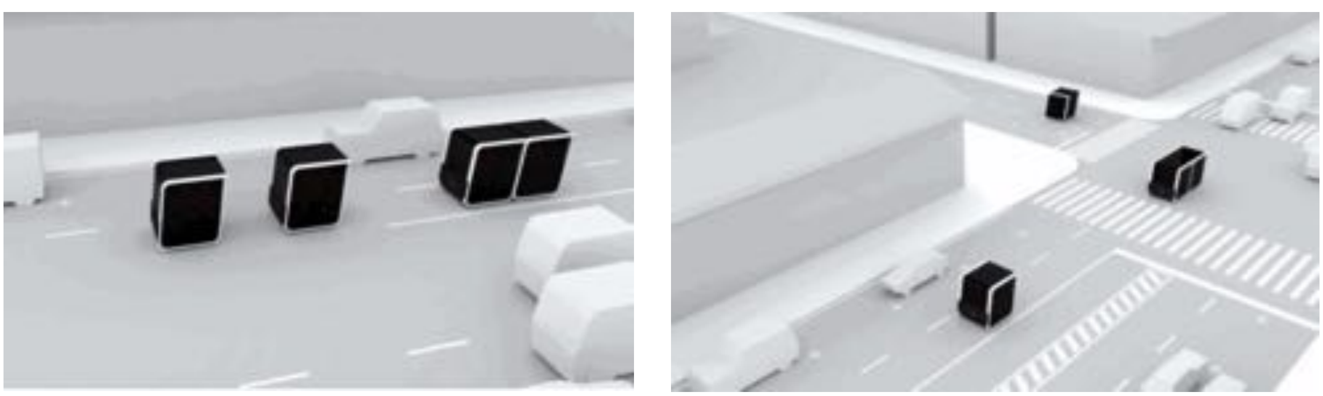


Figure 4. The emerging modular autonomous technology (Next, 2020).

Further, several for-profit companies are conducting field experiments on modular autonomous vehicles (MAV), e.g., Next Future Transportation (CNBC, 2018), Ohmio LIFT (NBR, 2018). As shown in Figure 4, the MAV concept integrates route-guidance with advanced vehicle navigation technologies and precise trajectory control with autonomous vehicle (AV) technologies to allow modular units to be flexibly connected and disconnected. When this MAV technology is mature, we can replace existing human-driven carts and ground crew with MAVs to enable an automated modular operation of the baggage transportation. This would further cut down the operational cost related to the ground crew and thus is expected to introduce more benefits to the proposed modular operational paradigm.

As far as the team members' knowledge, the proposed modular operation solution has not been seen in airport baggage transportation. Thus, we aim to design, formulate, analyze, and evaluate the potential of the proposed modular operational concept in airport baggage transportation, using the TPA as a case study. Specifically, through this design we aim to answer the following questions:

1. How can we design the modular operational paradigm so as to incorporate the modular operation into the existing operational process of airport baggage transportation?

2. With the modular operational concept, how can we formulate the baggage transportation process for airports into an optimization problem that can produce baggage transportation plans with the minimum operational cost?

3. Will this modular operational paradigm bring benefits to airport operators compared with the existing operation? If so, how much the improvement will be? Is it a feasible and practice solution to airport baggage transportation in terms of the economic perspective? What impacts will it potentially bring to the real world?

Analysis method

To answer the above questions and develop a practical framework for airport operators to design and evaluate the proposed modular operation for baggage transportation, we apply an analysis approach as summarized in Figure 5. This approach consists of three steps, i.e., modular system design, schedule optimization, and real-world case study.

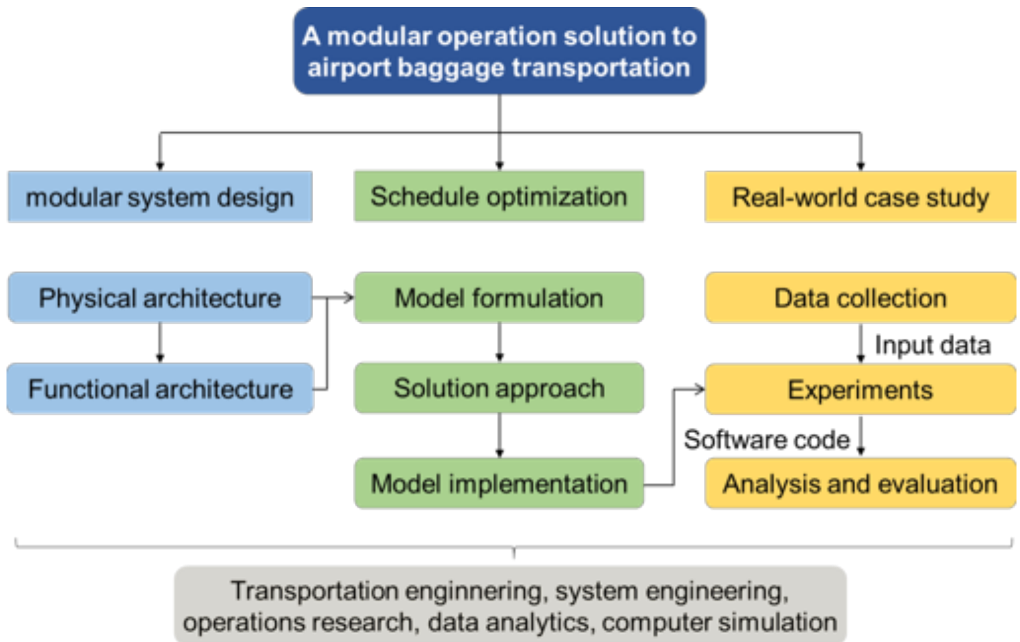


Figure 5. Framework of the analysis method.

First, we design the modular operational paradigm for airport baggage transportation, including the high-level physical and functional architectures. This design will be based on the structure of existing baggage transportation systems to avoid thorough modifications to the infrastructure. This way, the cost of the proposed design can be lowered. Particularly, we discuss the system design with the existing practice where human-driven carts are used and also a future scenario where modular autonomous vehicle technologies can be introduced into the system for better system performance. A system engineering approach will be adopted for this step.

Second, we optimize the cart schedule under the context of modular baggage transportation. This optimization necessitates an analysis of the baggage arrival process, operational constraints, stakeholder objectives, and operational cost structure. We formulate this problem into a rigorous optimization model that can be solved by commercial solvers to generate cart schedules. Real-time adjustment on the planned schedule will be conducted based on the actual baggage arrival process. This optimization model can be integrated into baggage transportation management systems to automatically generate optimized operational schedules for airports in practice. Skills on mathematical modeling, discrete optimization, computer programming and simulation are needed for this step.

Third, we collect realistic baggage demand data from the TPA and carry out a case study to analyze the applicability of the model and evaluate the benefits of this new modular operational paradigm. We feed the collected data into the optimization model to test its feasibility and validity. Results are first analyzed to evaluate the necessity and validity of the proposed solution. Then, a comparison between the proposed modular operation and the existing operation is made to assess the impact of our design. Next, a risk assessment and cost-benefit analysis are carried out to analyze the performance of the design from the economic perspective. Finally, the commercial potential and real-world impacts of the proposed design will be thoroughly discussed. Knowledge of data collection and analytics and transportation economics is required for this step.

The technical details of each step in this framework will be illustrated in the Technical aspects.

Technical aspects

Modular system design

To embrace the modular operation in airport baggage transportation, the operational process of the baggage transportation system needs to be redesigned, including the physical and functional architectures. This redesign is accomplished via a system engineering approach.

Physical architecture. Because the carts used for baggage transportation are already modular, the relevant physical infrastructure needs not to be changed substantially. Therefore, the physical structure of the system will remain almost the same as that of the existing system. Infrastructure in the system includes check-in facilities, BHS facilities, buffer and unloading areas, (human-driven) carts, ground crew, aircraft, and a baggage transportation management system, as illustrated in Figure 6. Nevertheless, to achieve a modular operation, a cart scheduling module need to be incorporated into the baggage transportation management system. This module will take as inputs the baggage arrival demand of different flights and operational cost parameters of transporting baggage with carts of different sizes. By feeding these inputs into an optimization model (see subsection Schedule optimization for details), the module will output when and how many carts should be dispatched to transport the baggage from the unloading areas to each aircraft so that the total operational cost is minimized.

Further, as mentioned previously, if the MAV technology becomes mature in the future, the existing human-driven carts and ground crew can be replaced by automated modular operation, which is expected to bring further improvement. Yet, the current design primarily focuses on the existing human-driven carts for practical purposes. The same design methodology can be adopted for future MAV applications when this technology is ready for operation in practice.

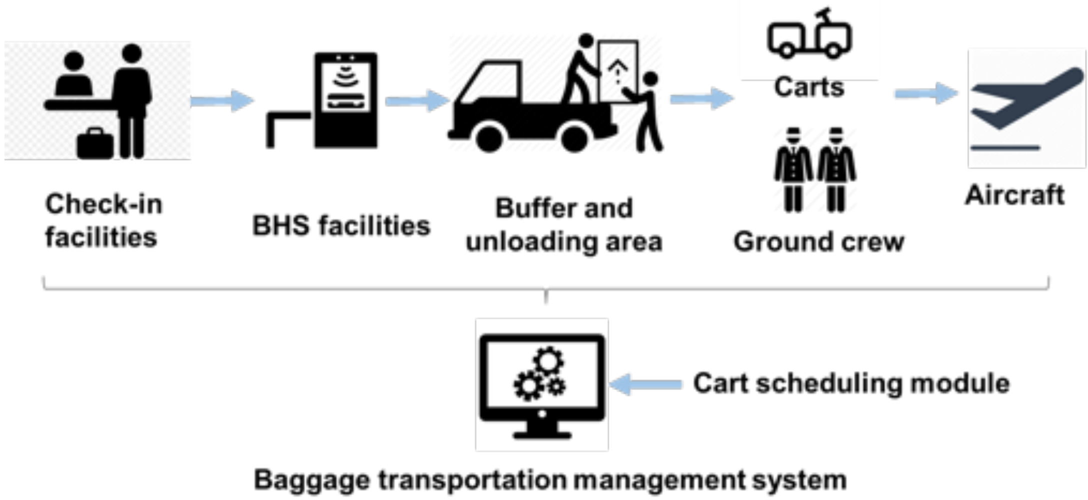


Figure 6. Physical structure of the modular baggage transportation system

Functional architecture. The modular operation requires a redesign of the functional structure of the baggage transportation system, as summarized in Figure 7. As we can see from this figure, the baggage transportation management system first acquires information on flight schedule (e.g., departure time, flight size) and customers (e.g., number of expected baggage) from the database. This information will be used to simulate the baggage arrival process. Note that at the planning stage, simulated arrival is used since we need to preplan the schedule before the actual passenger arrival. Real-time adjustment based on the actual baggage arrival information will be adopted to adjust the pre-planned schedules as illustrated below. Then the simulated passenger arrival process and other input parameters (e.g., the operational cost, fleet size, the capacity of a cart) are fed into a cart scheduling optimization model to generate pre-planned cart schedules. This is completed at least one day before the flight departure. The generated cart schedules will be stored in the system.

On the day when the flight is scheduled to depart, the check-in facilities and HBS facilities will provide information on the actual baggage arrival process for the baggage transportation management system. Meanwhile, real-time fleet size information (i.e., the number of available carts in the unloading area) is also obtained. With this, the system adjusts the pre-planned schedule to match the actual baggage demand. The real-time schedule is then sent to the ground crew to inform them of when and how many carts to be dispatched for each flight. Accordingly, the ground crews then formulate the carts into vehicles of different capacity (or size), load the baggage onto the carts, and drive the carts to the corresponding aircraft. Afterward, the baggage is loaded onto the aircraft. Finally, the empty carts are driven back to the unloading areas for the next dispatch.

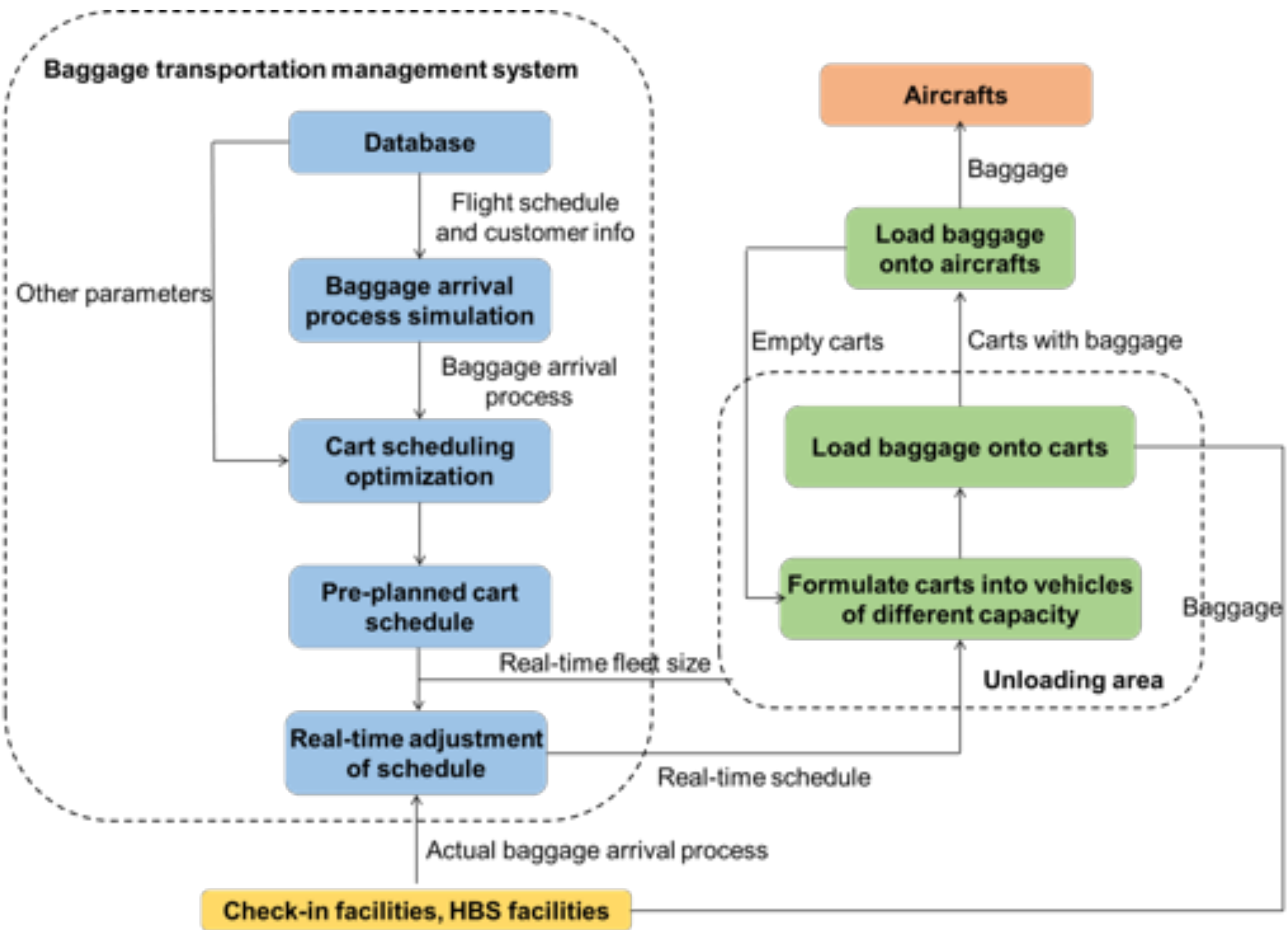


Figure 7. Functional structure of the modular baggage transportation system

Schedule optimization

To improve the performance of the modular baggage transportation system, we apply an operations research method for optimizing the cart schedules. The problem is first translated into math language. Then we formulate the problem into a rigorous discrete optimization model. Finally, the model is implemented in Visual Studio 2019 with C++ as the coding language and Gurobi (a state-of-the-art commercial solver for optimization models) as the solver.

Describing the problem in math language. We consider a time horizon (e.g., a day) divided into a set of time intervals with an equal length. Each time interval is indexed as t. Below is a summary of the input parameters of the scheduling problem.

1. The flight schedule indicating the latest time for baggage to be transported to the aircraft, denoted as d_i, for each flight i.

2. The number of baggage needed to be transported from the unloading areas to aircraft i at the beginning of time interval t, denoted by p_{it}.

3. There are V modular carts (MC) that can be dispatched to transport the baggage from the unloading area to the aircraft. These MC can be grouped into vehicles of different capacities (or sizes). We define a type-l vehicle as one consisting of l MCs. Assume the capacity of a single MC is c and thus the capacity of a type-l vehicle is lc.

4. The operational cost of dispatching a type-l vehicle, denoted as f_l, can be expressed as a concave function (to reflect the economics of scale; Chen et al., 2019a). In this design, the function we use is $f_l = C^F + C^V(lc)^\alpha$, where C^F represents the fixed operational cost regardless of the vehicle's size, C^V represents the variable operational cost dependent

on the vehicle's size, and $\alpha \leq 1$ is a power index represents the extent of the economics of scale.

5. The transportation time between the unloading area and aircraft i is e_i. The loading and unloading time of baggage destined to aircraft i is h_i.

With these inputs, we need to determine a plan to dispatch the carts to transport the baggage from the unloading areas to all aircraft before the aircraft leaves such that the operational cost is minimized. Decisions include the dispatch time, size (i.e., the number of MC units), destined aircraft, and the number of baggage transported of each vehicle. These decisions can be mathematically expressed as the following decision variables.

y_{ilt}: represents whether a type-l vehicle is dispatched to transport the baggage to aircraft i at the beginning of time interval t, which equals 1 if yes and 0 otherwise.

v_t: the number of MC remaining at the unloading areas at the beginning of time interval t

b_{it}: the number of baggage transported to aircraft i at the beginning of time interval t

For the convenience of the readers, the key notation is summarized in Table 1.

Table 1. Key notation in the optimization model.

Parameters	
t	Index of time intervals
l	Index of vehicle types; a type-l vehicle consists of l MCs
i	Index of flight
d_i	The latest time for baggage to be transported to the aircraft i.
p_{it}	Number of passengers destined to aircraft i during time interval t
c	Capacity for one MC
e_i	Travel time between the unloading area and aircraft i
h_i	The loading and unloading time of baggage destined to aircraft i
f_l	The operational cost of dispatching a vehicle with l MCs
V	Initial number of MCs available at the terminal

Table 1 (Cont.). Key notation in the optimization model.

Decision variables	
y_{ilt}	Equals if a vehicle with l MCs is dispatched to transport the baggage to aircraft i at the beginning of time interval t, and 0 otherwise.
v_t	Number of MC at the unloading areas at the beginning of time interval t
b_{it}	Number of baggage transported to aircraft i at the beginning of time interval t

Optimization model. With the above notation and variables, we formulate the cart scheduling problem into an optimization model. The model introduces two sets of constraints to describe the general operational details of airport baggage transportation and an objective function to reflect the goal of our design as follows.

1. Constraints on vehicle dispatch

These constraints are introduced to describe the vehicle dispatching process. Constraints (1) show that the number of MCs dispatched must be less than or equal to the number of MCs available in the unloading area at the terminal. Constraints (2) indicate that at most one vehicle can be dispatched for each aircraft during each time interval. Constraints (3) and (4) describe the MC circulation process in the system. Specifically, Constraints (3) set the number of available MCs in the unloading area at the beginning of the study period. Constraints (4) show that the number of available MCs at time t equals the number of available MCs at time $t-1$ minus the number of MCs dispatched at time t and plus the number of MCs that return from the aircraft. Note that for the convenience of the notation, we define $y_{ilt} = 0$ if $t \leq 0$. Constraints (5) define variables y_{ilt}, indicating that the values of y_{ilt} can be only 1 or 0. Finally, Constraints (6) require that the variables v_t must be nonnegative integers.

$$\sum_{i,l} l \cdot y_{ilt} \leq v_t, \forall t. \tag{1}$$

$$\sum_{l} y_{ilt} \leq 1, \forall i, t. \tag{2}$$

$$v_1 = V. \tag{3}$$

$$v_{t+1} = v_t - \sum_{i,l} l \cdot y_{ilt} + \sum_{i,l} l \cdot y_{il(t-2e_i-h_i)}, \forall t. \tag{4}$$

$$y_{ilt} \in \{0,1\}, \forall i, l, t. \tag{5}$$

$$v_t \in \mathbb{N}^+, \qquad \forall t. \tag{6}$$

2. Constraints on baggage movement

These constraints are imposed to describe the baggage movement between the unloading areas and aircraft. Constraints (7) and (8) indicate that the number of baggage transported to an aircraft during any time interval cannot exceed the number of baggage checked in. Constraints (9) are the capacity restriction, meaning that the number of baggage transported cannot be greater than the capacity of the vehicle dispatched. Constraints (10) are necessary to ensure that all the baggage checked-in are transported to the corresponding aircraft. That is, for each aircraft, the summation of the number of baggage transported to an aircraft over all time intervals should equal the total number of baggage checked-in for that aircraft (i.e., $\sum_{t\in\mathcal{T}} p_{it}$), which includes those transferred from connecting flights. Constraints (11) indicate that variables b_{it} must be nonnegative integers.

$$b_{i1} \leq p_{i1}, \qquad \forall i. \tag{7}$$

$$b_{it} \leq p_{it} + \sum_{t'=1}^{t-1} (p_{it'} - b_{it'}), \qquad \forall i, t. \tag{8}$$

$$b_{it} \leq c \sum_{l} l \cdot y_{ilt}, \qquad \forall i, t, \tag{9}$$

$$\sum_{t \in \{1,2,\cdots,d_i - e_i - 2h_i\}} b_{it} = \sum_{t \in \{1,2,\cdots,g_i\}} p_{it}, \qquad \forall, \tag{10}$$

$$b_{it} \in \mathbb{N}^{+}, \qquad \forall i. \tag{11}$$

3. Objective function

The objective of our design is to minimize the operational cost of the MCs while transporting the baggage to the corresponding aircraft. This is mathematically formulated as follows

$$\min_{y_{ilt}, n_i, b_{it}} \sum_{i,l,t} f_l \cdot y_{ilt} \cdot e_i. \tag{12}$$

Solution approach and model implementation. The above optimization model is a linear integer programming model. To solve it, we used a state-off-the-art commercial solver for integer program, Gurobi. We implemented the model in Visual Studio 2019 with C++ as the programming language (see Figure 8 on the next Page for a snapshot of the code).

Real-world case study

To test the feasibility and validity of the optimization model, as well as to assess the performance of the proposed modular operational paradigm, we carried out a case study with realistic baggage transportation demand data collected from the Tampa International Airport (TPA). Below we present the case study background, data collection method, and evaluation approach.

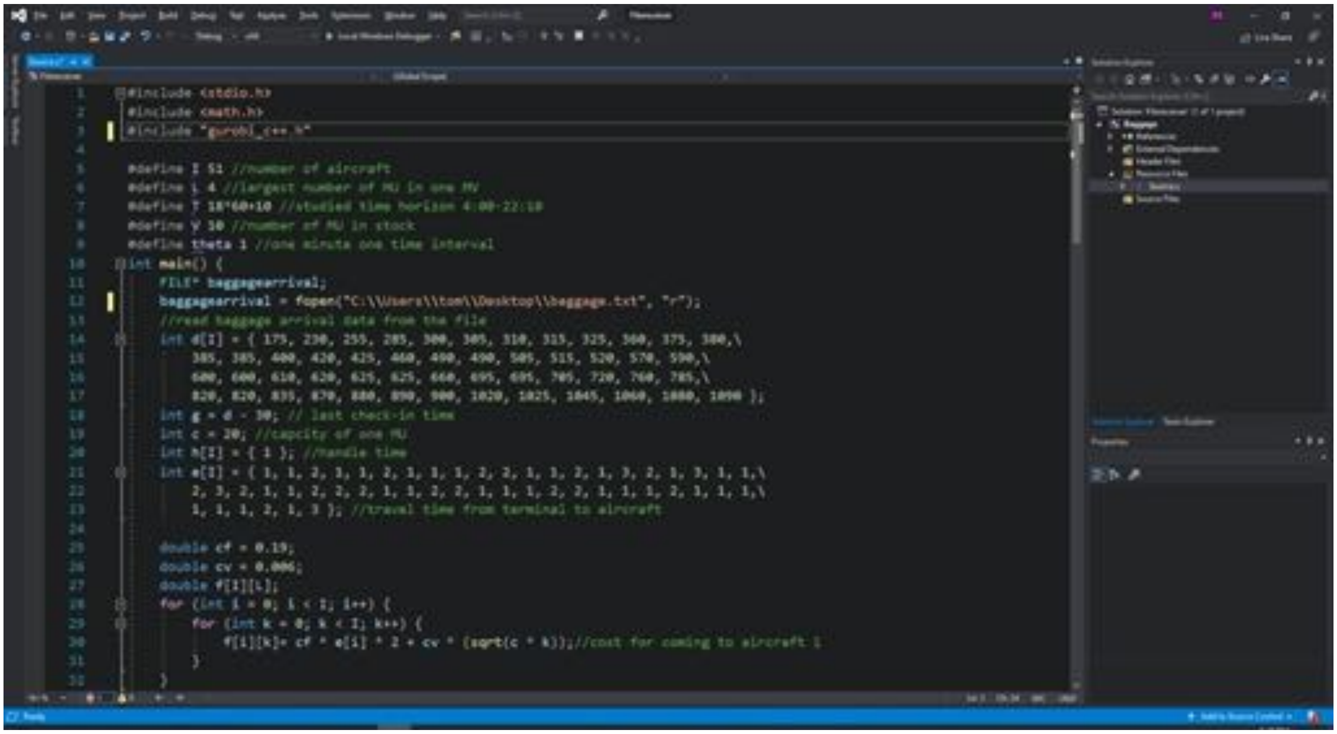


Figure 8. A snapshot of the C++ code in Visual Studio

Background. TPA is an international airport in the city of Tampa, Florida, United States. It is the 28th busiest airport by passenger movement in North America, with an average daily passenger of 58,3127 and an average checked bag of 17,728 (TPA, 2019). We selected this airport for our case study because the proximity to this airport allows us to get in touch with the airport operators and to travel there for necessary filed studies. There are six active terminals in total but only four of them were in operation during the study period (Terminals A, C, E, F). Among them, Terminal C is the largest and there was only one airline company operating when on the day we selected to collect flight schedule data. This provides an excellent testbed for studying the proposed modular operational paradigm because there are no other airline companies involved. Figure 9 presents the map of this terminal, with 16 gates scattering around the terminal.

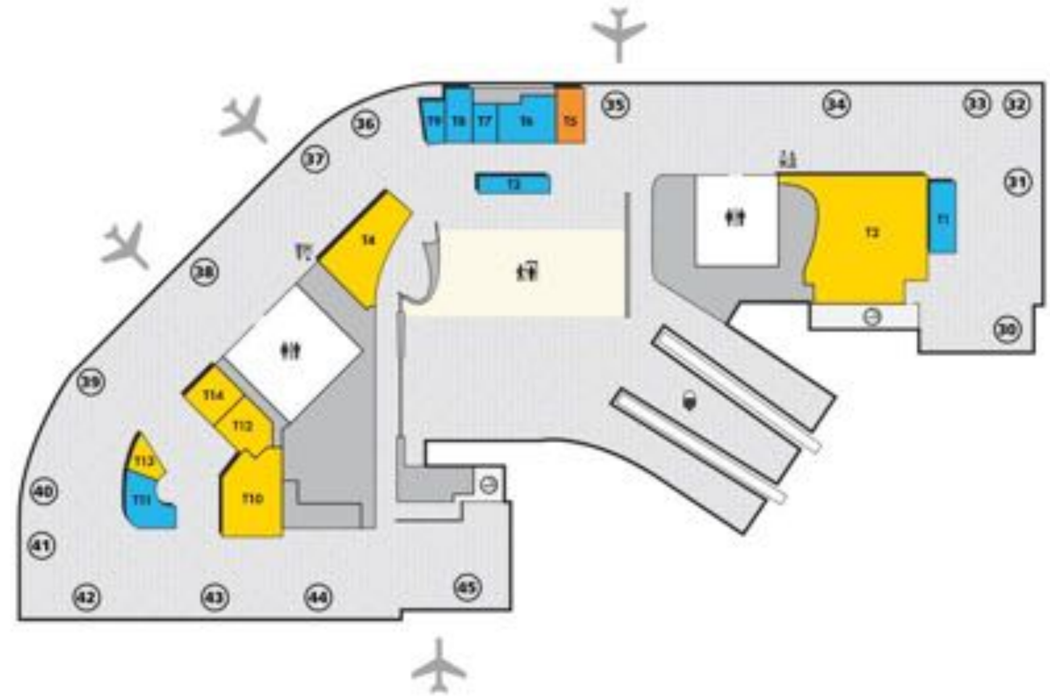


Figure 9. Map of Terminal C at TPA (Source: www.tampaairport.com)

Data collection. Three types of data are needed for this case study, including baggage arrival data, vehicle-related data, and time-relevant data. Since the actual baggage arrival information is not available at the planning stage, we used flight schedule information to simulate the baggage arrival process via the following steps:

Step 1. We collected the flight schedule for a typical weekday (April 13th, 2020) on TPA's official website, which is summarized in Table 2. As seen from this table, a total of 51 aircraft were scheduled to depart from the terminal from 06:55 am to 10:10 pm.

Step 2. The airline company at Terminal C mainly offers domestic services, and thus Boeing 737 and 757 are the most often used aircraft models. We used the capacity of these models (i.e., around 200 passengers/aircraft) to estimate the number of customers.

Step 3. Since all passengers do not necessarily travel with baggage that needs to be checked in, we introduce a parameter w to represent the probability of a passenger carrying a baggage that needs to be checked in. Multiplying the number of customers of each aircraft and w yields an estimation of the number of baggage for each aircraft.

Step 4. In the literature, the passenger arrival process at airports are observed to follow specific distributions (e.g., normal distribution, Weibull distribution, Poisson distribution, etc.). After going through the major literature, we found that the commonly used passenger arrival rate distribution is the Poisson distribution (Ashford et al., 1976). Thus, we simulated the baggage arrival process as a Poisson process.

With these steps, the baggage arrival rate with three values of w over a day were obtained, as shown in Figure 10.

The vehicle-related data are collected as follows. By referring to the parameters of standard 4-wheel baggage carts, we set the capacity for one MC (i.e., c) as 20 baggage. Additionally, the operational cost parameters (i.e., C^F, C^V, and α) were estimated based on the gas price. Thus, the value of C^F was set to \$0.19, the value of C^V was set to \$0.006, and α was set to 0.5. Besides, the initial number of available MCs at the terminal (i.e., V) was set to 10.

The time-related data are collected as follows. From TPA's official website, the latest check-in time is 30 minutes before the scheduled departure time (www.tampaairport.com). The travel time between the terminal and aircrafts (i.e., e_i) was obtained by measuring the travel distance from the terminal to each gate. Assuming that the travel speed of the MC is 20 mph, the travel time was calculated as shown in Table 3.

Evaluation approach. To evaluate the performance of the proposed design, we first analyze results from the optimization model to see if a modular operation is needed and the results are correct or not. Then, we compare the optimal objective value (i.e., the optimal operational cost computed by the optimization model presented above) from our design, and the operational cost of a case where the MCs can only be operated with a fixed capacity. Based on these results, we further carry out a risk assessment and a cost-benefit analysis (based on the current human-driven cart operation) to assess the economic effectiveness of the proposed design. Finally, the commercial potential and real-world impacts of the proposed design will be thoroughly discussed. Results of the evaluation are reported in Expected impacts and findings.

Table 2 Departure time and assigned gate for each aircraft.

Departure time	Gate	Departure time	Gate	Departure time	Gate	Departure time	Gate
6:55	C34	10:25	C36	14:00	C38	17:40	C35
7:50	C33	10:40	C33	14:10	C36	17:55	C31
8:15	C39	11:00	C44	14:20	C39	18:30	C37
8:45	C34	11:05	C37	14:25	C35	18:40	C35
9:00	C33	11:40	C35	14:25	C33	18:50	C33
9:05	C39	12:10	C44	15:00	C37	19:00	C31
9:10	C31	12:10	C32	15:35	C40	21:00	C31
9:15	C35	12:25	C33	15:35	C35	21:05	C35
9:25	C32	12:35	C36	15:45	C33	21:25	C33
10:00	C38	12:40	C43	16:00	C31	21:40	C37
10:15	C39	13:30	C37	16:40	C37	22:00	C31
10:20	C30	13:50	C31	17:05	C39	22:10	C43
10:25	C34	14:00	C34	17:40	C33		

Table 3 Travel time between the terminal and each gate.

Gate	C30	C31	C32	C33	C34	C35	C36	C37
Travel time / min	1	1	1	1	1	1	2	2
Gate	C38	C39	C40	C41	C42	C43	C44	C45
Travel time / min	2	2	2	2	3	3	3	3

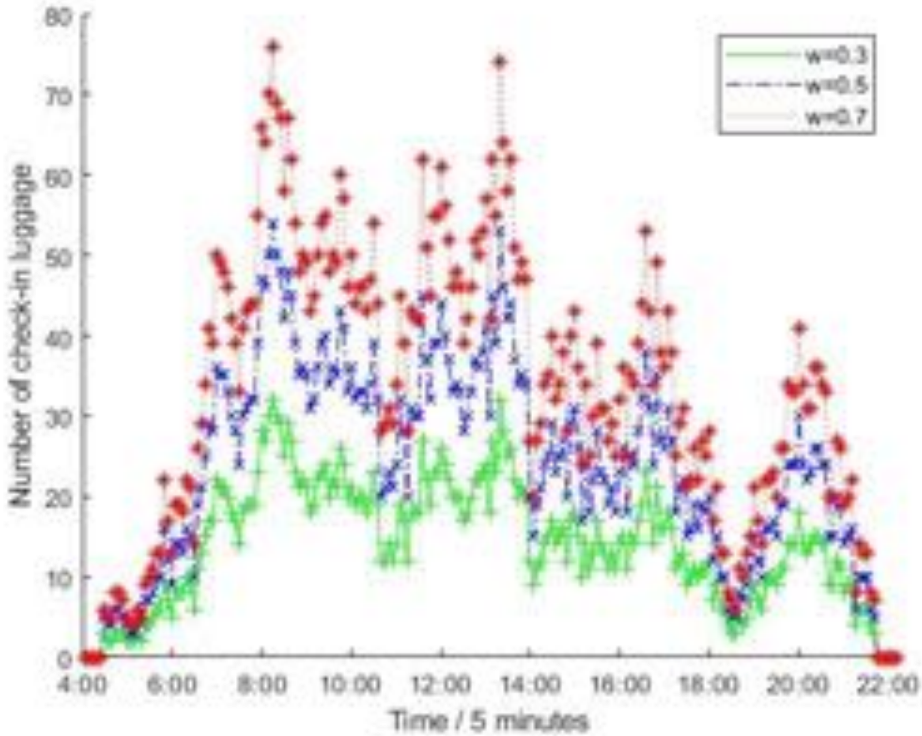


Figure 10. Simulated baggage arrival rate for all flights over a day with different values of w

Safety risk assessments

Safety risk assessment is a critical step before any design could be applied in practice. In this section, we present a comprehensive safety risk assessment for the proposed modular baggage transportation system. The assessment follows the *Introduction to Safety Management Systems for Airport Operators (FAA Advisory Circular 150/5200-37)* and the *FAA Safety Management System Manual*. The *FAA Advisory Circular 150/5200-37* recommends five steps for safety risk assessment, namely (1) describing the system, (2) identifying the hazards, (3) determining the risk, (4) assessing and analyzing the risk, and finally (5) treating the risk. To identify the level of risk, a safety risk matrix can be adopted, as shown in Figure 11. We see that the risk is evaluated from two aspects (i.e., likelihood and severity) and the level of risk is divided into three levels (i.e., low, medium, and high) based on an overall evaluation of these two aspects.

		Severity				
Likelihood		Minimal 5	Minor 4	Major 3	Hazardous 2	Catastrophic 1
	Frequent A	Low	Medium	High	High	High
	Probable B	Low	Medium	High	High	High
	Remote C	Low	Medium	Medium	High	High
	Extremely Remote D	Low	Low	Medium	Medium	High
	Extremely improbable E	Low	Low	Low	Medium	Medium / High

Figure 11. Safety Risk Matrix

Our proposed design primarily consists of operational paradigm design, model development, and algorithmic implementation. This requires changes in the airport's baggage transportation management system (i.e., software systems) but not much on the physical infrastructure at the current stage. Thus, the level of risk related to physical facilities should remain at current states as there are few changes in the physical infrastructure. Instead, most safety concerns stem from the frequent reformulation of modular carts into vehicles of different capacities and the software system itself. We summarize the identified safety hazards, risk levels, and mitigation strategies as follows.

Modular cart damage. Since modular carts need to be frequently connected and disconnected into vehicles of different sizes for operation, modular carts are likely to be damaged. This would raise safety risk during the operation, possibly leading to crashes. The risk level is identified as medium. To mitigate this safety risk, the ground crew should check the modular carts at the beginning of each operational day to identify any potential defects.

Modular cart accident. Vehicle/aircraft accidents may occur during the process of connecting and disconnecting modular carts into vehicles of different sizes. The risk level is identified as medium. The risk can be mitigated by ensuring correct communication between the ground crew and that the crews are trained properly before working on the field. Further, when autonomous carts are used in the future, this safety risk is expected to be further mitigated. Studies have shown that human errors are a key determinant in traffic accidents (Kalra and Paddock, 2016), removing human factors from the cart connection and disconnection process is thus expected to reduce the risk of resulting in an accident.

Software compatibility. *FAA Safety Management System Manual* points out that "when a system includes software and/or hardware, the safety analyses consider possible design errors and hazards they may create. The systematic design process is an integral part of detecting and eliminating design errors". The proposed cart scheduling module is possibly not completely or partially compatible with the existing baggage transportation management system. This will affect the system operation or leads to system breakdown. This risk is identified as medium. To address this hazard, extensive testing debugging and testing should be done before integrating the cart scheduling module into the airport's existing software system.

System reliability. When applying the proposed modular operational paradigm and the software module in practice, several technical issues that affect the system operation may happen, including data flow breakdown, algorithm malfunction, insufficient computation speed, and data storage failure, to name a few. These are common technical issues that will arise in large-scale commercial software and the risk level can range from low to high depends on the situation. To control the risk, a regular (e.g., monthly) maintenance on the system is needed and software engineers should be available to troubleshoot the system when needed. Data should be backed up in other resources for redundancy. High-performance computing facilities (e.g., GPU) may be used to improve the computation speed. Advanced algorithms can be developed to solve the problem if needed.

Health risks. The proposed design is expected to reduce the operational cost of the baggage transportation process. As mentioned previously, an important component of the operational cost is the energy consumption spent on moving the carts from the unloading areas to aircraft. By bringing down the energy consumption, we decrease the air pollutants and CO2 emissions. This way, we also reduce the ground crew's exposure to these substances, and thus reduce the health risk. Further, reduced CO2 indicates better air quality and contributes to mitigating climate change in the long run.

Industry interactions

In March 2020, the design team contacted the Airport Cooperative Research Program officer to ask for recommendations on appropriate airport operators and industry experts who could assist us in developing the idea and design. Sarah Pauls from the office promptly replied to our email, made a phone call to clarify our needs, and shared with us the contact information of several industry experts.

- Melissa Sabatine, Vice President, AAAE Regulatory Affairs.
- Felipe Rodriguez, Adjunct Lecturer, University of Maryland – Eastern Shore
- David Byers, President, Quadrex Aviation, LLC.
- A team working on “Baggage Handling Total Cost of Ownership”.

We got in touched with these industry experts via emails with a list of questions that we had in mind as follows.

Want to know:

We are wondering about the detailed baggage transportation procedure in airports; i.e., how baggage is transported from terminals to airplanes. Some specific questions we have in minds are:

- *How is baggage transported to different airplanes? Is baggage to different airplanes first sorted and then transported to the corresponding airplane?*
- *To transport baggage from terminals to airplanes, one vehicle with several carts will be used. Does a vehicle only transport the baggage from the terminal to one airplane or multiple airplanes? If it is multiple airplanes, how to determine the order to visit them? Also, is the number of carts in the mover changed according to the numbers of baggage to be transported?*
- *How do the ground crews arrange the baggage in the airplane?*
- *How to transport the baggage if some passengers have connecting flights?*

Further, can we get some baggage operation data from an actual airport, e.g., the number of baggage needed to be transported and the take-off time of the airplane?

Soon after the emails were sent out, we got responses from them very quickly, which provided us with the fundamentals regarding the existing operation for baggage transportation. We also figured out what sources we could utilize to acquire relevant literature to know more about the investigated problem. After this correspondence, the team realized the importance of baggage transportation, its state-of-the-practice, and an opportunity to address some of the existing challenges with the modular vehicle technologies.

As the team started to brainstorm and design the proposed solution, a deeper understanding of the airport baggage transportation process was needed. Thus, we talked over the phone with Mr. Felipe Rodriguez, who very generously provided us with abundant knowledge and his unique insights on the design. Because airport baggage transportation has not been well covered in our coursework, Mr. Felipe pointed out several advanced baggage transportation paradigms that are currently being applied in several airports. For instance, San Francisco International became the first airport in the United States to install a terminal-wide independent carrier system for baggage handling. As a result of this interaction, the team has determined the key factors that affect baggage transportation in airports and obtained a clearer picture of how to propose our design based on the existing operational paradigm.

In addition, as mentioned previously, we used Terminal C of the TPA as our case study. To determine the appropriateness of using the TPA for our case study and to learn about their existing baggage transportation operation, we reached out to Mrs. Christine Osborn, the current communications manager of TPA. She presented us the operational information on the terminal and baggage transportation operation. She also pointed out where we could obtain data that are necessary for our case study analysis, e.g., the flight schedule. This information enabled us to study the performance of the proposed operation paradigm for a real airport. Also, Mrs. Osborn was very interested in the topic proposed by us, which inspired us to continue our research. Further, during the development of our optimization model and computer simulation model, we also got in touch with Dr. Sashikanth Gurram, who is currently a data scientist in AirSage. Dr. Gurram is an expert in agent-based travel demand simulation and its application in analyzing transportation-related air pollutions. We communicated with him via emails for multiple times to talk about his experience in computer simulation (particularly the use of MATSim, a state-of-the-art microscopic travel demand simulator). The interaction with him assisted us in developing the computer simulation we needed for implementing our design.

This design cannot be accomplished without the generous assistance of the industry experts and airport operators. Their assistance has guided and influenced our decision-making process throughout the design process. Thus, we want to express our sincere gratitude to them.

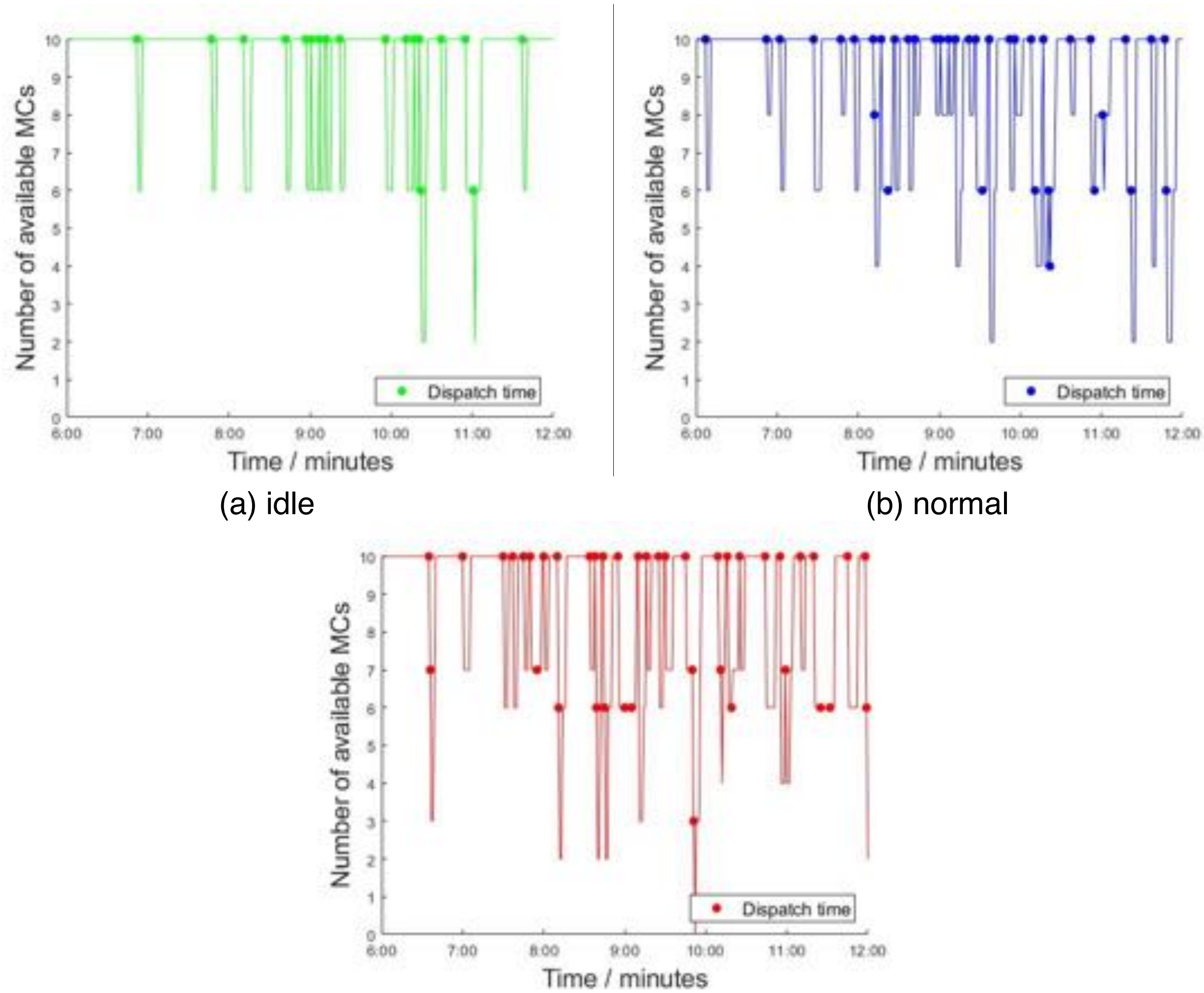
Expected impacts and findings

This section reports results from the case study to evaluate the proposed design. These include an evaluation of the necessity and validity of the proposed design, a comparison with the existing operational paradigm, a cost-benefit analysis, a discussion on the commercial potential and real-world impacts.

Necessity and validity of the proposed design. The optimal cart dispatching plans obtained from the proposed design for three different scenarios (i.e., idle, normal, busy) in the case study TPA are plotted in Figure 12, with each dot representing a vehicle dispatched to transport the baggage from the unloading areas to the aircraft. Table 4 summarizes several key indicators of the system in the optimal design for these scenarios. We can see from Figure 12 that the sizes of the dispatched vehicles vary at different dispatches, which demonstrates the necessity to introduce modular operations in airport baggage transportation. Further, we see from Table 4 that the optimized cart dispatch plans are consistent with the baggage arrival process. That is, we would like to dispatch more vehicles (and also the total number of MCs) when the system is busy while fewer MCs are needed when the system is relatively idle. Also, the operational cost is highest when the system is busy and the lowest when the system is idle. These results reveal that the proposed design is consistent with reality, and thus verify the validity of the proposed design.

Table 4. Summary of key statistics from the proposed design.

Scenario	# of dispatched vehicles	# of dispatched MCs	vehicle types used	Max. # of operating MCs	Operating cost ($/day)
Busy	102	357	{3,4}	10	$629.0
Normal	102	306	{2,4}	8	$624.3
Idle	51	204	{4}	8	$316.0



(a) idle (b) normal

(c) busy

Figure 12. modular carts dispatch plans with different simulated baggage arrival curves

Comparison with the existing operational paradigm. To understand the improvements of the proposed operational paradigm, we compare several key system outputs between the proposed modular design and the existing baggage transportation operational paradigm. The results are summarized in Table 5. It can be found that the proposed modular operation paradigm always causes a lower daily operational cost than the existing operational paradigm. Particularly, in the idle scenario, when the vehicle type is set as 1, the daily operating cost of the existing operational paradigm is almost 4 times than that of the proposed operation paradigm, which also illustrates the advantages of the modular vehicle technology. Additionally, the number of vehicles and MCs dispatched in the proposed design is not greater than those in the existing operation, which means that we do not need to purchase extra modular carts to implement the proposed design. This result confirms our statement that "the physical structure of the system will remain almost the same as that of the existing system" in the Technical aspects section. Indeed, in many of the studied cases, the numbers of MCs dispatched are lower than what is needed in the existing operation, which indicates that the proposed design can reduce the fleet size and thus the costs relevant to the vehicle fleet.

Table 5. Comparison between the existing operational paradigm and the proposed modular solution over a typical operational day

Scenario	vehicle type	Existing operational paradigm			The proposed modular solution		
		# of dispatched vehicles	# of dispatched MCs	Operating cost ($/day)	# of dispatched vehicles	# of dispatched MCs	Operating cost ($/day)
Busy	1	357	357	$2117.4	102	357	$629.0
	2	204	408	$1232.6			
	3	153	459	$937.5			
	4	102	408	$632.3			
Normal	1	306	306	$1814.9	102	306	$624.3
	2	153	306	$924.5			
	3	102	306	$625.0			
	4	102	408	$632.3			
Idle	1	204	204	$1211.0	51	204	$316.0
	2	102	204	$616.3			
	3	102	306	$625.0			
	4	51	204	$316.0			

Cost-benefit analysis. A cost-benefit analysis is provided in this section to evaluate the economic feasibility of the proposed design. The costs and benefits of the proposed system largely depend on whether it is implemented with the existing human-driven carts or the modular autonomous vehicles in the future. Since we aim to emphasize the applicability of the proposed modular design for airport operations in the real world, in this section we offer a cost-benefit analysis based on the current baggage transportation infrastructure (i.e., human-driven carts) in airports. The analysis was conducted following the guidance provided by ACRP (ACRP, 2016).

We first estimated the development cost needed to design and materialize the proposed design. The development is divided into an alpha test phase (hardware/software development) and a beta test phase (pre-production model). The alpha test phase was conducted by our team in preparation for this competition, which includes the conceptualization, operational system design, optimization model formulation, coding, and testing the model with real-world data from the TPA. This phase resulted in a prototype of the proposed modular operation solution to airport baggage transportation. Costs at this phase mainly include labor (two graduate students from our team and an advisor) and travel expenses on field tests. The beta phase will materialize our prototype to a model that will be ready to be implemented in airports. The optimization model and codes developed at the alpha phase could be applied. Thus, the work of the beta test phase will mainly be materializing the proposed prototype into an executable cart scheduling module that is ready to be integrated into the existing baggage transportation management system. Therefore, costs at this phase will mainly be incurred from labor (students, advisor, software engineers in airports), software development and testing, purchase of commercial solver and database (if necessary), and travel. The estimated costs of these two phases are summarized in Table 6 and Table 7.

Table 6 Estimated development costs of the alpha phase

Item	Rate	Quantity	Subtotal	Comments
Labor - Student	$25/h	480	$12,000	Salary for graduate assistants if they work full time
Labor - Advisor	$50/h	240	$12,000	Salary for the advisor if he works full time
Travel expenses	$50/test	5	$250	Travel expenses on field tests.
Subtotal			$24,250	/

Table 7 Estimated development costs of the beta phase

Item	Rate	Quantity	Subtotal	Comments
Labor - Student	$25/h	960	$24,000	Salary for graduate assistants if they work full time
Labor - Advisor	$50/h	480	$24,000	Salary for the advisor if he works full time
Commercial solver	50k	1	$50,000	The Gurobi solver is the state-of-the-art solver for solving the proposed scheduling problem. We use it for the academic purpose. The commercial version can be purchased from the official website.
Software development and testing	20k	1	$20,000	Development fee for the cart scheduling module
Database	50k	1	$50,000	Data purchase for storing the data necessary for the cart scheduling module
Travel expenses	$50/test	20	$1,000	Travel to airport.
Subtotal			$169,000	/

If the cart scheduling module is developed and successfully integrated into the existing airport baggage transportation system, the operations and maintenance costs should be assessed. Costs at this stage mainly incurred from the vehicle procurements (if MAVs are used in the future), vehicle operations, ground crew salary, and system maintenance cost. The estimation (based on the case study TPA system) of these cost components is summarized in Table 8.

Table 8 Estimated cost of operations.

Item	Rate	Quantity	Subtotal	Comments
Vehicle procurement	$0	0	$0	This is 0 because results from Comparison with the existing operational paradigm shows that we do not need to purchase extra modular carts for implementing the design
Operating cost	$629	1	$629	Busy scenario per day.
Crew salary	$15/h	160	$2,400	10 loaders and drivers per day.
Maintenance cost	$7,000	1	$7,000	Once a year.
Subtotal			$3,048.18	

The benefits of the proposed design include observable and unobservable benefits, as shown in Table 9. The observable benefits include the decrease in energy costs, the monetary gains due to CO2 emission reduction, and ground crew salary savings. These values were estimated based on results from the case study of the TPA system. The unobservable benefits include the increase in the level of service, as well as in the reputation of the airport.

Table 9 Estimated benefits of the proposed modular operation solution

Number	Description	Benefit estimation	Comments
Observable benefits			
1	Ground crew salary	\$15/h	The value indeed depends on the number of crews reduced. In the final benefit estimation, we did not include this item.
2	Operating cost	\$456/day	Cart procurement, fuel cost, maintenance fee of the vehicle can be reduced.
3	Monetary gain due to CO2 emissions reduction	\$26.5/day	Obtained by the fuel consumption per day.
Unobservable benefits			
1	Airport level of service	\	The value of these benefits is unmeasurable
2	Airport reputation	\	

By summing up the cost and benefit components listed in the above tables, we obtain that the total cost of implementing the proposed modular solution to airport baggage transportation is \$193,250. This would almost be a one-time cost to an airport because the software maintenance workload is relatively small. In contrast, the estimated benefit from the proposed design is \$176,112 per year without considering the unobservable benefits we mentioned. Thus, the proposed design is cost-effective. Note that this analysis only took into accounts the benefits of the reduction in CO2 emissions and the reduction in the crew salary was excluded. When the emissions of pollutants such as NOx, carbon monoxide and the crew salary are considered, the benefits of the system would be larger.

Commercial potential and real-world impacts. The proposed design is now a prototype with system design, models, and codes. To materialize it into a commercial product. Additional efforts should be made regarding the following aspects:

1. Improve the solution approach of the proposed model so that the computational resources of the cart scheduling module (solution time and process memory) can be substantially reduced, which is important for ensuring its performance in practice.

2. Based on the current prototype, the next step is to develop a sophisticated cart scheduling module that automatically determines operational plans for baggage transportation schedules for airports. This would require enormous efforts on computer programming, software testing and analysis. Further, the module should be designed in a way that it can be easily integrated into the existing baggage management systems used by airport operators.

3. We would test our product with the TPA. Feedbacks from them will be used to improve the system design.

If the proposed design is successful, it will result in the following products:

1. An innovative operational paradigm for airport baggage transportation that can be applied to many airports in the world (probably with customization). The successful application of modular operations in this particular field would set up an example for other transportation systems to embrace the emerging modular autonomous vehicle technologies.

2. A practical cart scheduling module based on the proposed modular operation that can be integrated into existing baggage transportation systems. This would offer an applicable tool that airport operators can use for their operational management. Also, it will serve as a paradigm for other transportation systems to develop decision-making tools in the era of modular transportation.

To sum up, this design will not only bring the benefits to airports as discussed in the cost-benefit analysis presented above. It will set up a framework for which other transportation systems can follow to develop a cost-effective modular vehicle-based operational paradigm, ideally motivating studies seeking to replicate our findings with other models in other contexts. It will improve the operational efficiency of these transportation systems. It is expected to save energy, reduce CO2 and traffic-related pollutants emissions, as well as decrease travel time. These benefits together will assist in mitigating several challenges that society is faced with, including energy crisis and climate change.

Appendix A: List of complete contact information

Name: Zhiwei Chen

Position: Graduate Student

Email Address: zhiweic@mail.usf.edu

Name: Xiaowei Shi

Position: Graduate Student

Email Address: xiaoweishi@mail.usf.edu

Name: Xiaopeng Li

Position: Associate Professor, Advisor

Email Address: xiaopengli@usf.edu

Appendix B: Description of university

The University of South Florida (USF) is a public research university in Tampa, Florida. It is a member institution of the State University System of Florida. Founded in 1956, USF is the fourth-largest public university in the state of Florida, with an enrollment of 50,755 as of the 2018–2019 academic year. The USF system has three institutions: USF Tampa, USF St. Petersburg and USF Sarasota-Manatee. Each institution is separately accredited by the Commission on Colleges of the Southern Association of Colleges and Schools. The university is home to 14 colleges, offering more than 80 undergraduate majors and more than 130 graduate, specialist, and doctoral-level degree programs.

USF is classified among "R1: Doctoral Universities – Very high research activity" in its 2011 ranking, the Intellectual Property Owners Association placed USF 10th among all universities worldwide in the number of US patents granted. The university has an annual budget of $1.5 billion and an annual economic impact of over $3.7 billion. In a ranking compiled by the National Science Foundation, USF ranks 43rd in the United States for total research spending among all universities, public and private.

Appendix C: Non-university partners

NA

Appendix E: Education experience from the project

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?

The ACRP University Design Competition provided a tremendous opportunity for us to apply the learned knowledge and skills in addressing real-world transportation problems. Though we have been involved in course projects in our program, this competition offered us a unique experience in solving a realistic transportation problem that requires interdisciplinary and systematic efforts. It required an application and integration of the skills that we obtained from several courses, such as system engineering, discrete optimization, and computer simulation. It also enabled us to learn about air transportation, a topic that has not been well covered in by our coursework. We were able to talk with different airport operators and industry experts through the course of developing this design, which offers insights into how transportation problems are solved in real-world transportation.

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

Two biggest challenges arose when we undertook this competition. The first challenge that we encountered is the lack of relevant literature. As mentioned previously, the coursework in our program does not cover much about air transportation and there have not been many studies on cart scheduling for airport baggage transportation. Most studies have focused on other aspects such as the design of the baggage handling system. We overcame this challenge via communication with airport operators, industry experts, and our faculty advisor. Further, time management is the other main challenge since both team members are graduate students. It was rather intensive to work on the design given our already occupied schedules in a time framework of one semester. The breakout of COVID-19 around the world made it more difficult since it completely interrupted our regular schedules and prevented us from regular in-person meetings. We were able to overcome this challenge via frequent communications and regular meetings every other Friday. Microsoft team was used for meetings when we were quarantined.

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

Since our team members have previously worked on emerging transportation technologies, we knew that the modular vehicle technology is promising in bringing tremendous benefits to transportation systems. Thus, the idea naturally came to us when we saw this competition opportunity: modular vehicle operations may also bring substantial benefits to airport baggage transportation. Next, we started to communicate with airport operators, industry experts, and our faculty advisor for their ideas and comments. The feedback from them assisted us in searching for related literature and information of the state-of-the-practice. After a thorough literature review, we found that no one has proposed a modular operation for airport transportation. Also, baggage transportation among terminals and aircraft has not attracted enough attention while it plays an important role in airport operations. Therefore, we decided to investigate this problem by using the modular vehicle technology.

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

Participation by industry in the project was very helpful and meaningful. Interacting with experts in air transportation has revealed to us the potential of the investigated problem, the sources that we should turn to for more background information, and fundamentals on the existing operational paradigms of airport baggage transportation. Particularly, since we did not have much experience in addressing any real-world transportation problems, our initial design was indeed too ideal due to the lack of consideration of several key factors in baggage transportation. The interaction with the industry experts has helped us identify these issues and come up with potential approaches to include them in our design. Interacting with industry experts certainly provided us an opportunity to learn about how a transportation engineer should think when dealing with real-world problems.

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?

This project has offered us a meaningful learning experience with knowledge and skills that can hardly be obtained from traditional classes on campuses. This is the first time that we have integrated the knowledge and skills from various courses (e.g., transportation engineering, discrete optimization, computer simulation) to address a real-world problem, which was a great “review session” for what we have learned during the past years. Besides, we learned how to perform risk assessment, cost-benefit analysis, and knowledge about airport baggage transportation, which were not covered in our courses. Finally, our skills in time management, communications, and technical writing were also improved via this competition. The knowledge and skills we obtained from this competition (particularly those from the industry experts) will surely be of great help for our future study and career path.

Faculty

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

This competition is valuable for my students. By participating in this competition, the students got an understanding of challenges in addressing transportation problems in real life. They also learned how to make a balance between their own research assignments, coursework, and the competition. Further, the interaction with the industry experts is a key educational value of this competition, which is a great example of connecting the academia and the industry. These precious experiences absolutely will have significant impacts on their future study and research.

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

The context in the competition is quite appropriate for a graduate-level course. At USF, faculties usually require students to submit a term project to demonstrate their ability to apply what they learn from the course to solve real-world problems at graduate level courses. The problem that the students had to address in this competition is an excellent example of such a term project. However, it is more challenging than a usual course project since the design must be application oriented. The students need to find the existing gaps, design the research plan, cooperate with each other, consult with industry partners, and finally solve the problem.

3. What challenges did the students face and overcome?

The biggest challenge for the students is their lack of knowledge in aviation or air transportation. Our lab focuses on establishing a set of methodologies to understand, predict, and improve smart city systems via emerging technologies (e.g., connected, automated, modular, shared, and electric vehicles). We mostly look at the highway, railway, and public transportation systems, while air transportation has been less studied. Neither of the students has taken any course about air transportation. Thus, they spent great efforts in searching for material to understand the background and the existing practice in air baggage transportation. I am glad to see that they were able to learn so much from the industry experts. Also, they did struggle in balancing this competition with all the research assignments from their graduate research assistantship going on. They did an excellent job managing their time and got this design done nicely and on time.

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

Sure. The learning experience the students gained from this competition has significant efforts on education. I am fully supportive of this type of competition since it will provide students with opportunities to learn about the industry.

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

I would suggest expanding the topic lists by also including the application of emerging technology in the air transportation system, such as the modular vehicle technology, urban air mobility.

Appendix F: References

Ashford, N., Hawkins, N., O'Leary, M., Bennetts, D., McGinity, P., 1976. Passenger Behavior and Design of Airport Terminals. Transp. Res. Rec. 18–26.

Barrena, E., Canca, D., Coelho, L.C., Laporte, G., 2014. Exact formulations and algorithm for the train timetabling problem with dynamic demand. Comput. Oper. Res. 44, 66–74.

Braekers, K., Kovacs, A.A., 2016. A multi-period dial-a-ride problem with driver consistency. Transp. Res. Part B Methodol. 94, 355–377.

Cacchiani, V., Furini, F., Kidd, M.P., 2016. Approaches to a real-world Train Timetabling Problem in a railway node. Omega (United Kingdom) 58, 97–110.

Chen, Z., Li, X., Zhou, X., 2019a. Operational design for shuttle systems with modular vehicles under oversaturated traffic: Continuous modeling method. Transp. Res. Part B Methodol.

Chen, Z., Li, X., Zhou, X., 2019b. Operational design for shuttle systems with modular vehicles under oversaturated traffic: Discrete modeling method. Transp. Res. Part B Methodol. 122, 1–19.

Chen, Z., & Li, X. (2020). Designing corridor systems with modular autonomous vehicles enabling station-wise docking. Transportation Science, Under review.

CNBC. (2018), These autonomous pods could replace the world's buses, Website: https://www.cnbc.com/video/2018/02/15/these-autonomous-pods-could-replace-the-worlds-buses.html (accessed on 10/16/2018)

Dai, Z., Cathy, X., Chen, X., Ma, X., 2020. Joint optimization of scheduling and capacity for mixed traffic with autonomous and human-driven buses : A dynamic programming approach. Transp. Res. Part C 114, 598–619.

Garaix, T., Artigues, C., Feillet, D., Josselin, D., 2011. Optimization of occupancy rate in dial-a-ride problems via linear fractional column generation. Comput. Oper. Res. 38, 1435–1442.

Häme, L., 2011. An adaptive insertion algorithm for the single-vehicle dial-a-ride problem with narrow time windows. Eur. J. Oper. Res. 209, 11–22.

Huang, E., Mital, P., Goetschalckx, M., & Wu, K. (2016). Optimal assignment of airport baggage unloading zones to outgoing flights. Transportation research part E: logistics and transportation review, 94, 110-122.

Hassold, S., Ceder, A.A., 2014. Public transport vehicle scheduling featuring multiple vehicle types. Transp. Res. Part B Methodol. 67, 129–143.

Huang, Y., Yang, L., Tang, T., Cao, F., Gao, Z., 2016. Saving energy and improving service quality: Bicriteria train scheduling in urban rail transit systems. IEEE Trans. Intell. Transp. Syst. 17, 3364–3379.

Huang, E., Liu, I., & Lin, J. T. (2018). Robust model for the assignment of outgoing flights on airport baggage unloading areas. Transportation Research Part E: Logistics and Transportation Review, 115, 110-125.

J. T. Lin, Ping-Hsi Shih, E. Huang and Chun-Chih Chiu, "Airport baggage handling system simulation modeling using SysML," 2015 International Conference on Industrial Engineering and Operations Management (IEOM), Dubai, 2015, pp. 1-10.

Kalra, N., & Paddock, S. M. (2016). Driving to safety: How many miles of driving would it take to demonstrate autonomous vehicle reliability?. Transportation Research Part A: Policy and Practice, 94, 182-193.

Masmoudi, M.A., Braekers, K., Masmoudi, M., Dammak, A., 2017. A hybrid Genetic Algorithm for the Heterogeneous Dial-A-Ride Problem. Comput. Oper. Res. 81, 1–13.

Masmoudi, M.A., Hosny, M., Braekers, K., Dammak, A., 2016. Three effective metaheuristics to solve the multi-depot multi-trip heterogeneous dial-a-ride problem. Transp. Res. Part E Logist. Transp. Rev. 96, 60–80.

Meersman, H., Pauwels, T., Struyf, E., Van de Voorde, E., & Vanelslander, T. (2011). Ground handling in a changing market. The case of Brussels Airport. Research in Transportation Business &

Management, 1(1), 128-135.

Mo, P., Yang, L., Wang, Y., Qi, J., 2019. A flexible metro train scheduling approach to minimize energy cost and passenger waiting time. Comput. Ind. Eng. 132, 412–432.

Muelas, S., LaTorre, A., Peña, J.M., 2015. A distributed VNS algorithm for optimizing dial-a-ride problems in large-scale scenarios. Transp. Res. Part C Emerg. Technol. 54, 110–130.

M. Johnstone, D. Creighton and S. Nahavandi, "Status-based Routing in Baggage Handling Systems: Searching Verses Learning," in IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 40, no. 2, pp. 189-200, March 2010.

Niu, H., Zhou, X., 2013. Optimizing urban rail timetable under time-dependent demand and oversaturated conditions. Transp. Res. Part C Emerg. Technol. 36, 212–230.

Next Future Transportation, 2020. Website: https://www.next-future-mobility.com/

NBR, (2018). NZ electric vehicle maker inks $US20m Chinese production deal. Website: https://www.nbr.co.nz/article/nz-electric-vehicle-maker-inks-us20m-chinese-production-deal-ck-p-216398

Paquette, J., Cordeau, J.F., Laporte, G., Pascoal, M.M.B., 2013. Combining multicriteria analysis and tabu search for dial-a-ride problems. Transp. Res. Part B Methodol. 52, 1–16.

Reinhardt, L.B., Clausen, T., Pisinger, D., 2013. Synchronized dial-a-ride transportation of disabled passengers at airports. Eur. J. Oper. Res. 225, 106–117.

Shi, X. & Li, X., 2020. Operations Design of Modular Vehicles on an Oversaturated Corridor with First-in-first-out Passenger Queueing. Transportation Science. Under review.

Tampa International Airport. Website: https://www.tampaairport.com/sites/default/master/files /Final%20FY2020%20Budget_All_Files_Combined_V2_8.27.19_0.pdf

US Department of Transportation. Website: https://www.transportation.gov/airconsumer/air-travel-consumer-report-archive

Yang, L., Qi, J., Li, S., Gao, Y., 2016. Collaborative optimization for train scheduling and train stop planning on high-speed railways. Omega (United Kingdom) 64, 57–76.

Y. Zeinaly, B. De Schutter and H. Hellendoorn, "A model predictive approach for baggage handling systems," 16th International IEEE Conference on Intelligent Transportation Systems (ITSC 2013), The Hague, 2013, pp. 687-693.

Zhang, T., Ouyang, Y., & He, Y. (2008). Traceable air baggage handling system based on RFID tags in the airport. Journal of Theoretical and Applied Electronic Commerce Research, 3(1), 106-115.