PEDESTRIAN BEHAVIOR AND MODELING FOR COMMUTER AIRPORT TERMINALS

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ABSTRACT

The Society of Fire Protection Engineering research roadmap has identified that new movement and anthropometric parameters reflective of today's society are essential as proper input parameters into pedestrian and even modelling. Airports, which require the use of such modelling, have not seen many publicly available contemporary studies that any practitioner (that is to say many data sets are project specific and may be proprietary) can draw upon for movement speeds to date. Hence, this study herein aims to collect and analyze people movement and behavioral data for an airport. Moving walkways in the airport corridor systems are a main feature of the study location, thus the behavior of individuals on these walkways is the primary focus of this study. Movement with and without luggage is collected and examined for 734 persons. The authors examined the recorded videos with manual and innovative kinematic tracking algorithms. Analysis determined people were moving faster in these spaces than traditional movement studies suggest, at an average pace of nearly 3 m/s inclusive of the tread speed of 0.7 m/s. The subsequent use of pedestrian modelling software for analysis followed in this study. The modeling herein was adapted through a software development kit to adapt to dynamic changes in agent movement behavior depending on barrier and technology features of the airport. Results of the modeling showed consistent overall travel times through the corridor with the observed times. Modeled travel times gave an average time of 3:59 and 4:20 for those without luggage and those with heavy luggage, respectively. The movement data results herein and limitations necessitating future data collection are invaluable for any practitioner undertaking or having interest in airport pedestrian movement studies.

INTRODUCTION AND BACKGROUND

The Society of Fire Protection Engineers (SFPE) research roadmap (SFPE, 2018) and recent SFPE demographic movement and anthropometry study (Gales et al., 2020) have identified that new movement and anthropometric parameters reflective of today's society are essential as proper input parameters into evacuation and pedestrian modeling. Human behavior data collection was a significant area of priority identified as needing some of the most attention in the SFPE roadmap. The most critical data needed was identified as demographics, specifically for vulnerable populations, anthropometry, and cultural differences. This is then followed by a need for a basis for numbers in codes and response to notification. The theme also identified required design tools. These included behavior-based models that cover cultural, pre-evacuation time, and actions other than evacuating. As the roadmap is revised, many of these areas still see a need for attention given their difficult to study nature.

The lack of human movement data can lead to infrastructure designs relying on older information and possibly unverified models. A commonly referenced work for pedestrian movement is that of John Fruin and his commuter study (Fruin, 1970, 1971). That study categorized movement speeds by density and developed different levels of service depending on these densities, these densities and correlated levels of service which are commonly referred. However, this work used still images and focused on movement around stairs. Service capabilities and level of service were also related directly to the space available instead of factors relating to the actual ability to promote flow through the space. This is not to criticize Fruin's valuable contributions, but these were reflective of the limitations of research at the time which included technology to film and analyze human movement.

While the findings from Fruin's research have usefulness today in understanding how people move, the scope of application is acknowledged as limited (SFPE, 2019). If people are moving differently depending on age, culture, location, destination, and accessibility needs then these factors need to be collected and understood. Further, a study on the use of macroscopic versus microscopic pedestrian modeling exposes the limitations of the Fruin profile or other studies of aggregated movement (Teknomo, 2006). The study points out that this macroscopic approach limits itself to suggesting that only allocating more space is the solution to improving flow. In contrast, modern technology allows for a microscopic level of modeling person movement behaviors and can be used to show that pedestrian flow can be improved through design of the space already available. This means using the Fruin levels of service as a comparison point is not fully applicable to microscopic models of individual speeds and is not included in this report, to avoid making comparisons without a proper framework of measurement.

To address the dated data, contemporary studies have been conducted to begin calibrating and validating pedestrian movement models. One such study looked at pedestrian movement at multiple locations that included London, Hong Kong, New York, Monaco, and Leeds using data collected from video cameras (Berrou et al., 2005). They suggested that their findings show that there is not a straightforward flow-density relationship. The data, though, was collected at locations serving pedestrians at rail transit stations, ports, a shopping district, and outside a stadium. Another study looked at an observed phenomenon of capacity drop due to flow exceeding critical density for model optimization (Cepolina, 2009). Experiments were completed at the University College London using volunteers between the ages of 20 and 30 years old, though, which means the results lack the influence of traveler behavior due to being in a particular environment. The experiments also relied on telling the volunteers how fast to move or using individuals among the volunteers to try to influence other's behavior. Further, a study looked at extending the capabilities of a pedestrian flow model to include a person's response to visual information (Wang et al., 2014). This was tested against observations for pedestrians in a shopping mall in Hong Kong, though, which may be biased towards pedestrians more interested in reacting and changing their actions than in a transportation facility. All these found studies lack consideration to collecting data on the behaviors and movement of people at airports.

Further in the collection of data are more studies of pedestrian behaviors within buildings. Of the types of buildings considered by contemporary researchers to date (Care homes, Hospitals (Rahouti et al., 2020) (Folk et al., 2020), Cultural Centres (Gales and Champagne, 2022), Stadia (Larsson, et al., 2020) (Young et al., 2021) (Chin et al., 2022a) (Chin et al., 2022b), and office occupancy (Rahouti et al., 2021) etc.) all have shown that previous guidance of movement speed and behavior is not reflective of contemporary demographics. In the above-mentioned studies some modeling validation exercises were also completed with new movement data. Those studies (Rahouti et al., 2020) (Folk et al., 2020) (Gales and Champagne, 2022) (Larsson et al., 2020) (Young et al., 2021) (Chin et al., 2022b) (Rahouti et al., 2021) have indicated that there are pronounced differences in movement in different building types as well.

These above recent studies are not inclusive of all infrastructure types where some have not received much research attention. To date, airports, which require the use of pedestrian modeling for planning purposes (passenger pick up etc.), in emergency evacuation, high motivation, and non-emergency conditions, have not seen many modern public studies that any practitioner can draw upon for movement speeds to date. Existing analyses can be over twenty years old (Young, 1999) and contemporary discussions are either lab based and do not necessarily capture the stimuli found in a real airport setting or are policy centered (Bateman and Majumbar, 2020). They may also be proprietary data sets which are project specific and not available to the public. It is essential that this infrastructure type be openly studied.

Of focus in airports are commuters with Luggage and this study must give consideration. Luggage has shown effects to movement behaviors in other studies relevant to transportation hubs. A study looked at defining different characteristics for pedestrians in the study based on the use of luggage, among other factors (Banerjee & Maurya, 2022). In this study it defined pedestrians with luggage requiring more space which can lead to jam densities with fewer people, a factor that can be important in areas with limited space such as a corridor. Further, it considered luggage to play an important role for walking speeds and cited walking with luggage reduced the walking speed by 3-15%. Research by the National Research Council of Canada at the prototype cabin research facility looked at plane boarding (Gwynne, et al., 2018). 35 participants went through 12 trials that included luggage as a factor. Baseline behaviors for the participants with and without luggage were collected. The study found that luggage had a notable effect on boarding performance times. (Holloway, et al., 2015) and (Watts et al., 2015) studied the effect of passengers with luggage boarding trains. The study looked at the effect of height gaps between the train and the platform which leads to at least one step up to or down from the train. They built three different rigs to test the effects of level access, one step, and two step conditions. As expected, more steps increased the boarding and alighting time. However, they found that younger people were less affected by steps and luggage where elderly people were. These studies of boarding times onto transportation modes of planes and trains show that the study of passengers with luggage can have effects on travel times for travelers throughout the transportation terminal and is an important factor to be studied.

The research approach presented in this study is motivated from a previous study published in 1999 (Young, 1999). That research considered behaviors of people at the San Francisco International Airport and Cleveland Hopkins International Airport on and off moving walkways. Their more significant observations were that they found the free-flow speeds to match that of Fruin. Recent observations in previous data collections which showed new differences from older movement profiles have indicated that this infrastructure type should be revisited with new data collection to illustrate contemporary movement speeds of demographics.

METHODOLOGY

The location of study for this research is an inter-city North American airport, with focus on the pedestrian access corridor on the landside. The other portions of the airport were not accessible at the time of the study for study (ex. security and post security). This access corridor has many features of interest making it an optimal choice for a movement study. In consultation with the airport authority, the authors were permitted existing footage taken over the course of three days from the landside terminal corridor to utilize for research purposes. The authority holds control over the landside area of the airport, which includes the curbside drop-off and pick-up, shuttle bus stop, corridor access, and the corridor itself. Their control up to the airport ends at the end of the corridor. Following this a mutual agreement to not disclose the airport location or specific features from the videos which could identify the airport was agreed upon, and ethics protocols from the authority and university department holding the research grant governed the data collection protocol of the study herein. It should be remarked that the location of the airport is in-material. The usefulness of the data presented herein is generally applicable for consideration to all airports however future work should consider a second site for confirmation or discussion of findings.

A Sketchup model based on scaled design drawings provided to the researchers by the authority of the landside airport was built. Particularly this features a corridor system for the predominate length of the terminal side. As drawings were provided and verified to be built to scale a full dimensional survey of the resulting space was not required by the authors other than various field visits to confirm measurements in drawings. Figure 1 illustrates the corridor system measuring 258.74 m from Point 2 to Point 3.

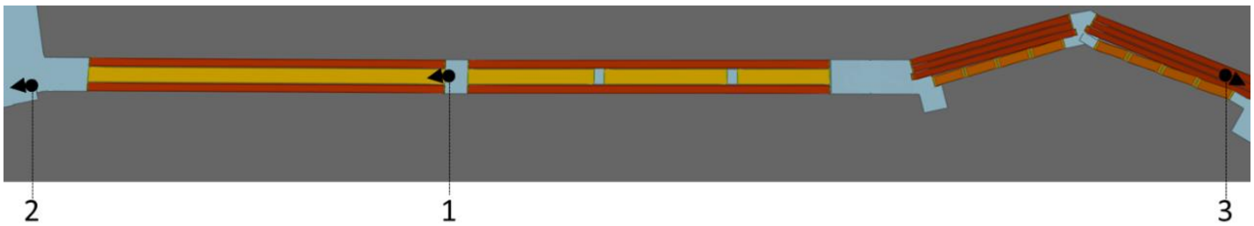

Figure 1: Computerized layout of corridor area used for study (camera locations used for the study 1, 2, and 3 are shown)

Video surveillance from permanent security cameras was collected from the corridor by the authority. The videos were then shared to provide a full and accurate source of data of pedestrian movement. Behavioral data should be noted to not incorporate characteristics of emergency evacuation though elements of high motivation evacuation stimuli are considered inherent in the data captured (see Young et al., 2021) therefore the data will be subjected to certain limitations when in use for emergency evacuation.

Population volumes and individual spot speeds were collected primarily from footage during the peak hour, showing the highest level of activity at the curbside, for the airport. The peak hour was chosen as the speeds and densities should represent some of the more critical cases of these environments. The day and peak hour that the footage was taken from was chosen by the airport authority based on prevailing maximum air traffic levels to ensure the data collected represented peak conditions.

Collection of the speeds themselves was done using a video image tracking software. This software called Kinovea, demonstrated in Figure 2 is a freeware, open-source sports kinematics software. The image provided for Kinovea is from work done studying a heritage cultural centre in which validation of Kinovea has been presented prior (Gales et al., 2022). Due to maintaining confidentiality of the airport, footage or any images used in Kinovea to the airport corridor is not provided in this paper but can be requested upon completion of appropriate screening from the authors and airport authorities. In regular use, Kinovea can track user-specified objects in video footage, in this case each person's head. The positions in the footage are converted into distances by using a measured grid imposed onto the footage – calibrated through field measurement. The data collected from Kinovea was exported to be post-processed using custom excel VBA scripts (those used in Gales et al., 2022) to determine average speeds over the course of tracking. The developed script also grouped final average speeds based on the tags manually given to the tracked objects within Kinovea. By using the frame rate of the footage and the recorded positions the travel speed of each targeted individual was calculated as a function of distance over time at each frame as an instantaneous speed. The final travel speed for each person was then calculated as the average of these instantaneous speeds. Travel speeds were collected for different demographics, classified by luggage, of pedestrians in the corridor. The travel speeds were also separated depending on if they used the moving walkways or walked on the ramp and by direction, airport departures or arrivals, in the corridor. This provided speed profiles by demographic, using the moving walkway or the ramp, and if they were walking up (departures) or down (arrivals) the incline. An assorted sample number of each demographic were collected for the spot speeds of each demographic as available based on being present. Of note the software has specific limitation in that it can only track unimpeded speeds therefore group behavior was not a focus of this study but is being considered in future research by the authorship team (see Young and Gales, 2022).

Figure 2: Kinovea tracking person movement with surveyed grid (Gales et al., 2022) (Young and Gales, 2022) Note: the airport video footage is not shown at this stage as currently non-disclosure agreements specify that footage from the surveyed days cannot be reproduced in publication.

ETHICS AND LIMITATIONS

The ethical procedure for this research is based upon a thesis dissertation research ethics protocol form at the home institution governing the research program. This incorporated institutional restrictions in the form of an agreement between the involved universities and airport studied. Restrictions included, for this time, the video observed in the study, nor the location of the airport can be reproduced in final publications or made public (this is considered a minor aspect as the results will generally apply to all airports and the revelation of the airport is not necessary). The video footage must also be stored in a non-networked drive and at conclusion returned to the airport. Beyond this autonomy was given to the researchers to study all aspects of the land side facilities in the advancement of graduate student theses which, beyond the videos provided, primarily involved information available in the public domain about the airport.

Movement speed results broken down by age and sex demographics have not been included. The lack of their presence in the reported data should not be interpreted that these factors are not important for understanding the movement behaviors in this area. The limitations of this study restricted multiple researchers from accessing the video due to confidentiality agreements with the authority. A single viewer introduces subjectivity and a bias to collecting demographics information from video footage. Future research should have the film looked at by multiple researchers to follow the procedures to reduce subjectivity as defined by (Haidet et al., 2009). In doing so, a more detailed demographics breakdown can be released with greater confidence.

DATA COLLECTION RESULTS

The corridor featured a moving walkway (people mover) which effects how pedestrians move through the space. This led to the data collection of how many people were using the moving walkway feature, the speeds at which they were moving, and separated them based on classification of luggage (Figure 3). The luggage classifications were separated based on no luggage, light luggage that was able to be carried, and luggage in rolling cases that people in the corridor pulled behind them. Analysis of the video footage resulted in the movement speed profiles presented in summary form with Tables 1 and 2 below.

Figure 3: Graphic of principle demographic (luggage users)

Sample sizes for each demographic were considered, samples of less than 50 were regarded only as pointing towards potential profiles. While there is no set threshold of samples for obtaining a statistically significant estimation of speed, this number has been chosen to warn against using profiles with less confidence from the study. The reason for collecting this data is to improve our understandings over other profiles and relying on low sample size profiles would contradict the efforts of this research.

With consideration of profiles with enough samples, these movement profiles show that speeds within this area of the corridor are higher than expected compared to traditional values. It can also be seen that luggage type and facility use has a noticeable effect on the movement speed observed. Movement speed for the speeds of those on the moving walkways includes the tread speed of the moving walkway, approximately 0.7 m/s.

The average travel time for all demographics through the corridor is presented in Table 3 below and for comparison to the results found from the model scenarios.

Speeds from the above figures used for direct comparison in the study are presented Tables 1 and 2 below. These speeds and standard deviations were used in the custom code to create the new movement profiles for use in the different movement scenarios.

Table 1: Peak Hour Vs Off Peak Speeds

Demographic		Average Spot Speed (m/s)	Standard Deviation	Sample Size
Peak hour	Roller luggage	2.96	0.64	257
	No Luggage	2.97	0.60	117
Off Peak	Roller luggage	2.73	0.67	240
	No Luggage	2.98	0.58	120

Table 2: Observed aggregate spot speeds on a moving walkway

Demographic	Average Spot Speed (m/s)	Standard Deviation	Sample Size
Roller luggage	2.85	0.66	497
No Luggage	2.97	0.59	237

Table 3: Observed averaged travel time

Actual Travel Time	Standard Deviation	Sample Size
5:22	0:40	128

These speeds, with consideration of the speed of the treads, are faster than those seen by Fruin and others. The speed given by Fruin 1.35 m/s for 1000 non-baggage-carrying pedestrians (Fruin, 1971). This is noticeably slower than what is seen for the airport corridor. The study that looked at the speeds crossing intersections, though, found an average speed of 1.63 m/s across all intersection sites and 1.42 m/s at mid-block sites (Bennett et al., 2001). While these speeds are still lower than what is seen at the study corridor, it shows that observed speeds can vary between similar activities. Both locations were looking at people crossing a street; however, they showed a difference in speed of 0.21 m/s.

Additional data about the movement characteristics of the people using the corridor were collected and have been presented in Table 4 below which may aid in defining the proportion of different journeys in modeling endeavors. These characteristics were not used for the construction of the model, instead, this data is presented to provide clarification of the use characteristics. The classification of proportion of males presented in the table should be interpreted as outward appearing physical features that were able to be identified from the camera angle. This included facial hair and build. Clothing had an influence as winter wear covered some identifying features, thus correlation of fashion choice to others identified as masculine presenting was used. This is a binary classification for physical characteristics and should not be used to define the use of airports by sex or gender. This analysis should be repeated by multiple investigators to confirm the masculine identification – though given the security nature of the study multiple investigators are not permissible at this time.

Table 4: Behavioral and other observations

Additional Data	Percent	Sample Size
People Using the Moving Walkway	93%	1665
Passing on the Left	81%	67
Proportion of Males[1]	65%	193

MODELING

As illustration to the differences of these movement profiles through the space considered modeling was performed.

Considering the layout of the corridor itself in the terminal, the entrance at the curbside is through elevators with the nearby stair (use is beyond the study scope) access being marked for emergencies. On the airport security side there are escalators, stairs, and elevators; the escalators are the main access into and out of the corridor on this side. Throughout the corridor there are moving walkways which are a primary focus of the research done for this study as they are utilized significantly more than the adjacent floor space and found in likewise infrastructure globally.

Pedestrians move differently on these moving walkways from other areas of the corridor and this difference in behavior needs to be understood so it can be properly accounted for and modeled. Once the data had been collected for this research it was brought into the working model of the corridor space. This model was built to run simulations for general movement in the corridor and has not been built specifically for emergency egress purposes. The modeling software used for this study was MassMotion 10.6 (Oasys, 2022). MassMotion is a state-of-the-art modeling software being used for other research making its use in this research a valid choice for comparison with the current standard for pedestrian modeling. MassMotion uses a social forces model to simulate agent movement behavior. The use of MassMotion was chosen primarily as regional authorities have familiarity to the software. It should be noted that alternative modeling tools and technologies may have benefits to this and other studies (Lovreglio et al., 2020).

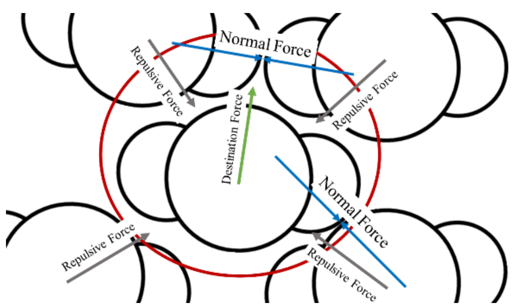

Figure 4: Basic framework of Social Forces

MassMotion has many capabilities of modeling pedestrian spaces and was able to be modified to accept the new movement behaviors as observed in the footage. In the context of this study other pedestrian movement software could be used as the focus herein is more verification as opposed to validation with the approach generally applicable to any package. Within the model, the escalators, doors, and elevators in the corridor are all features supported by MassMotion and were left as default for this study. The moving walkways were originally coded as escalators; however, for this modeling

[1] Masculine Presenting

case the behaviors of the people on the moving walkways needed to be added to the software's capabilities since this had not been an option available previously from the software in the version the authors had access. This meant giving the software the ability to determine when an agent was on a moving walkway compared to other parts of the model and, if so, giving them a new movement profile to use. This dynamic assignment of movement profiles for agents in the model was used to allow agents to act differently depending on if they were walking on floor space as opposed to the moving walkways.

While the reactionary behaviors of the agents off the moving walkways was mentioned to already be calibrated, this does not mean that the movement of the agents through the model could be considered calibrated. For this reason, full simulation runs of movement through the whole corridor needed to be run to check the speeds. This was done by creating a movement scenario of airport departure trips from the top of the elevators to the top of the escalators on the other side of the corridor. The volume of people in scenarios were able to be matched generally to the volume of people arriving at the airport and the speed profile was set to match those found in the spot speed data collection. To test different aspects of model's capabilities the following scenarios were run:

Table 5: Modeling Scenarios Considered

Scenario	Inputs	Duration	Goal
1	Departure Direction 150 people distributed randomly	15 Minutes	To verify model's ability to handle large volumes
2	Departure Direction 200 people distributed throughout and as groups arriving every five minutes Roller luggage only	1 hour	To verify modeled condition of pedestrians with roller luggage at peak hour conditions for the departure direction
3	Departure Direction 200 people distributed throughout and as groups arriving every five minutes No luggage only	1 hour	To verify modeled condition of pedestrians with no luggage peak hour conditions for the departure direction

Table 6: Results of Corridor Modeling

	Total Travel Time		
Scenario	Average Travel Time	Standard Deviation	Comment
1	4:18	0:43	
2	4:36	2:51	
2*	4:20	0:46	*Scenario 2 results with outliers/agents not following realistic movements removed
3	3:59	0:26	

DISCUSSION AND PRELIMINARY CONCLUSIONS

The total travel times across the corridor length are all faster in the models than that found when measuring the actual travel time through the corridor, as was presented in Table 3. This difference in total travel time could be explained from how the data was collected. The data collected for the movement of people were of two categories, spot speeds and total travel time. By using the spot speeds for the desired speeds throughout the corridor in the model this assumes that the speeds are independent of where they are in the corridor. However, as can be seen, it was found during the modeling efforts that the total travel times were shorter than those found by examining the recorded footage. This suggests an assumption that the location of spot speeds is biased towards an area where speeds are higher than the average travel speed throughout the corridor or that there may be delays of movement that are not being accounted for by the model. However, these differences aside, the model is showing that it responds to different inputs correctly. The scenario modeling people with luggage compared to the scenario of those without luggage showed a noticeable difference in total travel time of 21 seconds (comparing scenario 2* to scenario 3). The model also showed a higher standard deviation in times for those with luggage compared to those without. These differences agree with the slower travel time and higher standard deviation in speeds found for travelers with luggage.

Further, the model was able to be expanded to include agent specific movement speeds while on the people movers instead of assigning all agents the same static speed. This gave more realistic observations of behavior of travelers on the people movers.

The results of this research can be used to understand the implications of human behaviors in the corridor for general movements that may with limitations be considered beyond these stimuli. The data collection shows that movement speeds in this corridor, and potentially other similar areas, are higher than traditional movement speeds. Movement speeds of 2.85 m/s and 2.97 m/s were found for pedestrians with roller luggage and no luggage, respectively, on a moving walkway with a tread speed of approximately 0.7 m/s, inclusive. This, however, does mean the travel times in the corridor could be more sensitive to situations of higher densities. Further studies should explore these relationships.

The research also showed that it is possible to model behaviors dynamically based on transportation features. Agent travel behaviors were able to be adjusted to try to move at different speeds depending on walking on regular floor or the moving walkways and done in a way that each agent had a unique travel behavior for the regular floor space and moving walkway. While the total travel times in the model scenarios were found to be around one minute faster than the observed 5:22 minute average travel times, expected differences between scenarios were observed to reflect the expected outcome by showing a 21 second difference in travel time between the two demographics. Calculating the average travel times of the model to match that of the observed times is an effort of validating the whole of MassMotion which is outside the scope of this study. This study aimed instead to verify that the capabilities of the model could be improved to reflect a change in travel time due to change in demographic and use of the moving walkways as the goal was to show general modeling framework capabilities over that of just MassMotion. This means the method of dynamic behavior assignment in models can be used to give answers as to how the travel time should be expected to change if features of the corridor, or other areas of interest, are changed or if the demographic of users shifts. Further work, however, is needed to expand the capabilities for the model to capture realistic general movement. The airport scene is still missing critical data on human behaviors before a fully validated model can be built that matches the real-world conditions with confidence. These areas include traveler fatigue and group behaviors.

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