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FINAL REPORT

ANALYSIS OF SAFETY CONCERNS FOR AUTOMATED SMALL VEHICLE TRANSPORTATION ON A UNIVERSITY CAMPUS

PRT Consulting, Inc.

April 2007

KANSAS DEPARTMENT OF TRANSPORTATION

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16 Abstract

This study focuses on the safety and security of automated small vehicle transit (ASVT) in a university setting. ASVT uses small driverless vehicles operating on dedicated guideways to efficiently transport passengers to their destinations. A previous research project found that such a system that interlinks activity centers with peripheral parking could significantly enhance mobility on a university campus. This study is part of a series of second-phase research to investigate implementation issues related to ASVT-type technology.

Safety data was gathered for the 30-year old Morgantown PRT system at West Virginia University and for surface transportation on the Kansas State University (KSU) campus. Where applicable, this data was used to calibrate the ASVT system ratings. It was also used to help determine which of the aspects rating undesirable or worse warranted additional mitigating measures.

The study concludes that there is no aspect of ASVT that poses any significant security or safety issues that have not been successfully mitigated in other forms of public transit. Furthermore, the inherent nature of ASVT in which passengers are aggregated in small groups rather than large groups provides significant threat deterrence when compared to traditional transit. Additionally, using an ASVT concept as a shuttle between peripheral parking and central facilities in combination with restricted vehicle access to central facilities significantly decreases the threat exposure for vehicle-born explosive devices.

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Final Report

Prepared by

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THE KANSAS DEPARTMENT OF TRANSPORTATION
TOPEKA, KANSAS

April 2007

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Table of Contents

Executive Summary iii

Chapter 1 1

1.1 ASVT Overview 1

1.2 Safety and security 3

Chapter 2 5

Chapter 3 9

3.1 Threat Quantification 9

3.2 Safety Threats 9

3.3 Safety Threat Quantification 14

3.4 Security Threats 19

3.5 Security Threat Quantification 20

Chapter 4 23

4.1 Safety Threats 25

4.2 Security Threats 28

Chapter 5 31

Chapter 6 34

6.1 Safety Threats 36

6.2 Security Threats 45

Chapter 7 51

Chapter 8 57

Chapter 9 59

References 62

List of Tables

Table 1. Threat Values 9

Table 2: Vulnerability Values 24

Table 3: Threats and vulnerabilities (no mitigating measures) 32

Table 4: Revised threats and vulnerabilities (std. mitigating measures) 49

Table 5: KSU safety and security incidents and accidents 53

Table 6: Morgantown PRT safety and security incidents and accidents 54

Table 7: KSU/Morgantown accident/incident comparison 56

Executive Summary

This study focuses on the safety and security of automated small vehicle transit (ASVT) in a university setting. ASVT uses small driverless vehicles operating on dedicated guideways to efficiently transport passengers to their destinations. A previous research project found that such a system that interlinks activity centers with peripheral parking could significantly enhance mobility on a university campus. This study is part of a series of second-phase research to investigate implementation issues related to ASVT-type technology.

Safety issues result from accidental causes and security issues result from deliberate causes but the effects are similar and both were analyzed in terms of threats (or hazards) and vulnerabilities. Threats are the causes of safety/security incidents and are assessed in terms of severity or consequence while vulnerabilities are a measure of the probability of occurrence. The threats and vulnerabilities were rated in accordance with ASCE's Automated People Mover Standards.

Initial baseline ratings ignored standard mitigating measures (akin to analyzing road safety while ignoring seat belts, markings, signs and traffic signals) and, as expected, indicated numerous areas requiring mitigation. When re-evaluated after consideration of standard mitigation measures, all aspects specific to an ASVT system received ratings of possibly acceptable or better. Those aspects receiving ratings of undesirable or worse were all aspects (such as stairways and elevators) very similar to those currently in existence.

Safety data was gathered for the 30-year old Morgantown PRT system at West Virginia University and for surface transportation on the Kansas State University (KSU) campus. Where applicable, this data was used to calibrate the ASVT system ratings. It was also used to help determine which of the aspects rating undesirable or worse warranted additional mitigating measures.

The study concludes that there is no aspect of ASVT that poses any significant security or safety issues that have not been successfully mitigated in other forms of public transit. Furthermore, the inherent nature of ASVT in which passengers are aggregated in small groups rather than large groups provides significant threat deterrence when compared to traditional transit. Additionally, using an ASVT concept as a shuttle between peripheral parking and central facilities in combination with restricted vehicle access to central facilities significantly decreases the threat exposure for vehicle-born explosive devices.

Chapter 1
Introduction and Background

Phase I of the research project studied the potential mobility benefits that Automated Small Vehicle Transit (ASVT) technology brings to linking activity centers and parking within a university campus. Phase II investigates several implementation issues. This portion of the Phase II study is focused on the potential safety and security concerns that could be associated with such a system. Before discussing safety and security, a brief description of what is meant by ASVT is appropriate.

1.1 ASVT Overview

For this project ASVT is assumed to be a system that uses small (up to 20 passenger) driverless vehicles operating on dedicated guideways at speeds up to 30 m.p.h. The guideways could be elevated or at grade and would be interconnected to form a network providing, in some instances, alternative routes between an origin and a destination. The stations could also be elevated or at grade. Most stations would be off line which permits vehicles to bypass the station without slowing or stopping.

If the system is confined to very small vehicles (say six or less passengers) it could operate only in on-demand mode with non-stop origin to destination service like a true personal rapid transit (PRT) system. However, if the system has larger vehicles it will likely operate in additional modes such as scheduled and circulation. The difference between scheduled and

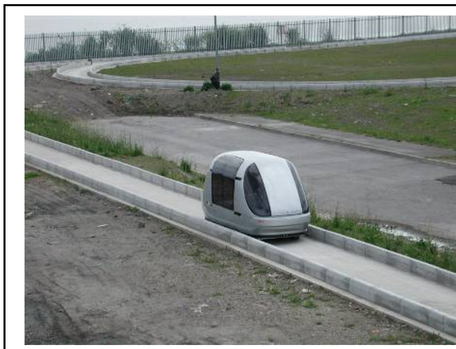

Figure 1: ULTra's at-grade open guideway.

circulation mode is that although both will send vehicles on trips based on a fixed schedule, circulation mode will have each vehicle stop at each station it comes to whereas scheduled mode will have the ability to bypass stations and provide express service. An automated system with these types of operating modes and larger vehicles is typically called group rapid transit (GRT).

Some ASVT systems have open guideways where the vehicles (called transportation pods or T-Pods) have rubber tires running on pavement. The T-Pods steer themselves and continually update their position relative to the guideway sidewalls and other fixed items. Other systems have the cab riding on a chassis with wheels enclosed by the guideway (this is known as “captive bogey” – see Figure 3). Yet others have the T-Pod suspended from a guideway. Due to switching problems the latter type is not thought to be viable and will not be considered in this study.

Figure 2: ULTra’s elevated open guideway

The unique aspects of ASVT are that it is completely automated, vehicles are capable of providing direct origin-to-destination service for small groups of people, vehicles can bypass intermediate stations, and the system operates on its

Figure 3: Postech’s captive-bogey guideway

own dedicated guideway. Terms such as “Personal Rapid Transit” and “Group Rapid Transit” bear resemblance to the ASVT concept, but are typically more narrowly defined. These systems can be considered subsets of ASVT, and the general findings for ASVT are valid for such systems bearing like operational characteristics.

1.2 Safety and security

Safety and security issues can be addressed from three distinct vantage points. The first category, referred to as *system safety*, encompasses dangers presented to the traveling public as a result of the operation and/or operational failures of the transport system itself. The second aspect, termed *system security*, refers to deliberate malicious attempts to harm people using the system or to use the system as an instrument to harm the public. Since 9/11, public sector infrastructure, particularly in the transportation sector, has received additional security scrutiny as it relates to vulnerability to terrorists. The third aspect of safety and security, termed *personal security*, refers to the safety and protection of passengers from each other. This aspect may be more critical on university campuses in which individual and small group ridership encompasses a majority of trips than at an airport where the vast majority of movement is in large volumes of passengers.

> This study is intended to investigate safety and security of ASVT on any university campus. However, in order to provide some focus and concrete examples, historical accident data from the Kansas State University (KSU) campus was used as a baseline for the safety and security of existing campus surface transportation systems. **KSU Administration is in no way involved in this study and absolutely has no intent or plans to build an ASVT system on the KSU campus.**

In order to consider the potential safety and security of a system it is necessary to first consider all of the potential threats to the system. Safety threats (or hazards) are the causes of accidents such as an icy guideway which could cause a vehicle to skid and crash. Security threats are the deliberate causes of undesirable events such as the threat of a mugging.

Once the threats have been quantified, the system can be examined to determine its vulnerability to a particular threat. A consideration of the combined threat and vulnerability then leads to the need for mitigating the vulnerability. Mitigation measures need to be identified if the system has a high vulnerability to a threat that has a high likelihood of occurring.

Chapter 2
Methodology

This study took the same approach to security and safety. Events that cause security breaches are typically called threats while those that cause safety issues are called hazards. Since the same analysis methodology applies to both within this report, they are analyzed in tandem and generally referred to as “threats”.

The most applicable methodology for quantifying the threats and vulnerabilities associated with an ASVT system was that contained in the ASCE Automated People Mover (APM) Standards (1). APM systems have historically consisted of a few relatively large automated vehicles traveling on a guideway and carrying large volumes of people. The overall size and complexity of these systems is sufficiently similar to that of the postulated ASVT university campus system that the ASCE methodology seems quite appropriate.

Some aspects of the APM standards may need to be revisited as ASVT systems become popular and grow in size. The mean time between events (MTBE) used is based on system operating hours. This may not be appropriate for large ASVT systems with numerous vehicles for which a more appropriate MTBE could be based on operating hours per ten or one hundred vehicles. Consideration might also need to be given to ASVT’s inherent operating characteristic of transporting people in small groups which limits exposure to a minimal number of people compared to the hundreds of people that could be carried in an APM train.

The study commenced with a postulation of the major safety and security threats that could be of concern to a campus ASVT system. Each threat was then quantified by giving it a severity rating based on the safety ratings provided in the ASCE Automated People Mover Standards (1). These ratings provide a standard measure of the severity of the consequences of any given threat.

The vulnerability of the proposed ASVT system to each threat was then estimated. Vulnerability estimates were obtained using both the ASCE Automated People Mover Standards and available data from West Virginia University Personal Rapid Transit System and safety and security statistics for a conventional university transportation system. These ratings provide a measure of the statistical likelihood of any given threat occurring.

The overall system safety and security metric was then derived for each threat by combining the threat severity and the vulnerability rating. The overall ratings were then categorized as Unacceptable, Undesirable, Possibly Acceptable or Acceptable, again in accordance with the ASCE Automated People Mover Standards (1).

Although the above methodology is standard procedure for many types of automated people movers, this is the first (known) attempt to apply such methodology to proposed ASVT system concepts. The author has made every effort to justify the ratings by using information and historical data from operational systems. However, since the concept has yet to be deployed in a modern context, additional analysis and/or operational experience may provide additional data upon which to base the ratings.

The overall ratings were initially evaluated without what is considered standard safety and security mitigating measures for ASVT systems in order to establish a comparative baseline. This could be likened to investigating road safety in the absence of seat belts, highway markings, signs and traffic signals. For ASVT standard measures include devices such as critical system redundancy, fire protection and video (CCTV) surveillance. A description of standard mitigating measures derived from literature and operational experience of like systems is outlined and the safety and security analysis adjusted accordingly. Extraordinary (beyond standard) mitigating measures are recommended and discussed for any threat that possesses an unacceptable risk after application of standard mitigating measures.

Historical safety and security data from a conventional university campus (KSU) and from the Morgantown West Virginia University Personal Rapid Transit (PRT) was used extensively in this study. This historical data was used to develop ratings for the postulated ASVT system, provide insight into comparative system safety between conventional modes and ASVT, and assess the impact of mitigating measures.

The Project Steering Committee provided input into the study by participating in a focus group meeting and providing final editorial review of the report. At the focus group meeting the author presented postulated threats and ratings and the committee then brainstormed potential additional threats and discussed appropriate ratings and mitigation measures for all of the threats.

Chapter 3
Threat postulation

3.1 Threat Quantification

The ASCE Automated People Mover Standards (1) quantify the severity of a threat using a rating of I through IV a shown in Table 1.

Table 1. Threat Values

Rating	Effect
I Catastrophic	Death, system loss, or severe environmental damage
II Critical	Severe injury, severe occupational illness, major system or environmental damage
III Marginal	Minor injury, minor occupational illness, or minor system or environmental damage
IV Negligible	Less than minor injury, occupational illness or less than minor system or environmental damage

Determining whether a given threat could cause only minor injury or severe injury or even death was accomplished by considering each threat and the types of effects that could result. Sometimes the ratings were fairly obvious at other times they were not. In the latter instance data from similar threats at Morgantown or on the KSU campus were reviewed to assist with the rating determination.

3.2 Safety Threats

ASVT systems provide an inherent level of immunity to several safety threats due to dedicated guideways that minimize the exposure of pedestrians and manually-operated vehicles to the system. In addition, most ASVT systems have no crossing guideways (except

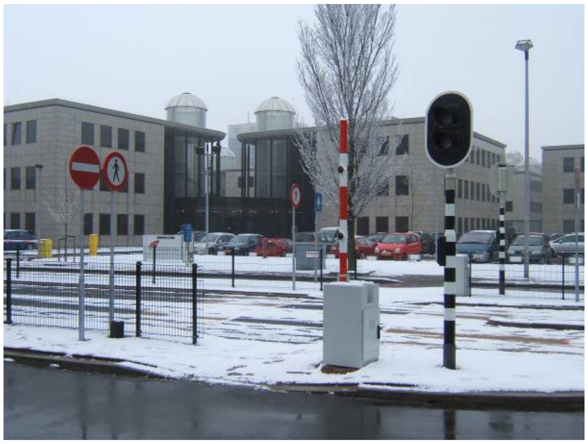

Figure 4: 2getthere's controlled pedestrian crossing at Rivium office park.

possibly at very low speeds in stations), only merges and diverges. Guideways are typically uni-directional any time the T-Pods travel at moderate to high speed and head-on collisions are therefore not possible. The safety of these systems is illustrated by the Morgantown PRT system. This ASVT system has completed 110 million injury-free passenger miles (regular transit would have injured over a hundred passengers in that many miles).

Figure 5: 2getthere's controlled pedestrian crossing at Rivium office park.

A Holland Company, 2getthere has been operating ASVT systems locally for about nine years. Some of their systems allow pedestrian and vehicle crossings and others allow for bi-directional movement, all at low-speed sections of the system. While they have had an accident, they have not injured any passengers. A comprehensive database of incidents was not available for this study. The pedestrian and vehicle crossings take the form of modified railroad crossings. Cross-bucks protect the intersection location, prohibiting either pedestrians or vehicles from crossing the ASVT guideway while in use. At the appropriate time (either on a timer or when a pedestrian or vehicle is sensed) the ASVT system yields the right-of-way and raises the cross-bucks to allow pedestrians and/or vehicles to cross the guideway. The operation of these points of crossing are low-speed, low capacity and completely computer controlled as part of the ASVT operating system.

The bi-directional use of guideways in the 2getthere system is evidenced in two configurations. The first (depicted in Figure 6) is a bridge crossing an existing highway. A single lane is used to limit infrastructure cost. The ASVT master control system provides, in essence, an invisible traffic light system for the ASVT vehicles. If the bridge is in use by another vehicle, an approaching vehicle will wait at one end until cleared to cross by the control system.

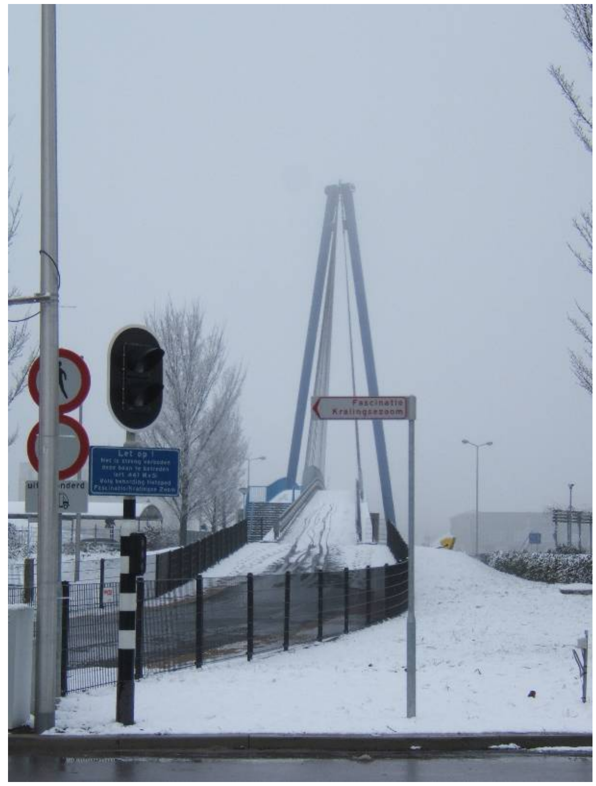

Figure 6: 2getthere's one-lane bridge crossing a major highway.

The second use of bi-directional guideway is arguably nothing more than a pinched-loop configuration. However, since 2getthere uses magnetic guidance or "magnetic rail" that is invisible, the pinched loop configuration appears to provide opportunities for head-on collisions. Although 2getthere offers no physical barriers (see Figure 7.) to prevent head-on collisions, multiple safety and control system failures are required for such an event to be possible.

In simple ASVT layouts that limit vehicle interaction to merges and diverges, without standard mitigating measures, T-Pod to T-Pod physical contact would be limited to either glancing-force or rear-end collisions. A rear-end collision at speed or a T-Pod being knocked off the guideway could cause serious injury or even death. In more complicated layouts such as the 2getthere bi-directional guideways described above, head-on collisions are physically possible, though multiple control system failures would need to occur. The author believes that the high intrinsic safety of physically-separated one-way guideways limited to merges and diverges and preventing any pedestrian interaction, may be necessary for all but low-speed, low volume applications while also serving to enhance public confidence in system safety. However, no historical operating system data is available to confirm this. The technology behind the 2getthere system has a significant history of industrial cargo-movement applications, but people-moving applications are just emerging and provide insufficient operating history. The capital costs savings related to bi-directional guideways and guideway crossings may or may not prove beneficial in the long run. The following analysis assumes that any bi-directional guideways or pedestrian interaction is only allowed at low speeds, limiting the severity of head-to-head collisions to that expected for higher speed glancing, or rear-end contact. Within this study, guideway crossing safety is similarly assumed to be

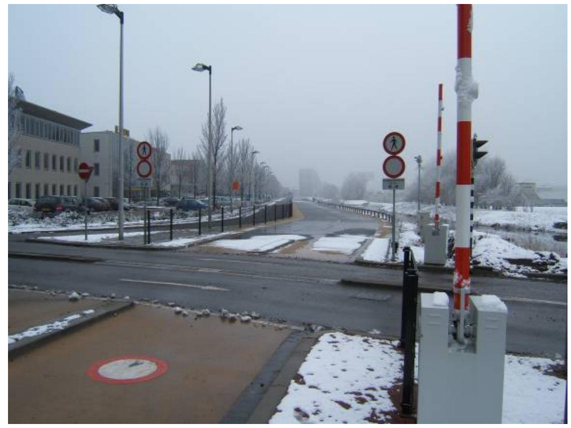

Figure 7: 2getthere's two-lane guideway with no physical barrier between lanes.

a subset of obstacle avoidance. Further analysis may be needed as operating system data becomes available relative to these assumptions.

3.3 Safety Threat Quantification

Accidents Between T-Pods

Control System Failure

Accidents between T-Pods could be caused by failure of the control system. The control system is a computerized system serving to instruct each T-pod in terms of its required location, speed, acceleration, deceleration and destination. Control systems are typically either synchronous or asynchronous. A synchronous system provides a simpler form of control wherein imaginary slots travel along the main guideways at fixed time intervals (headways) and predetermined speeds. When a T-Pod needs to join the main guideway from a station, the control system assigns an open slot to it. If a synchronous system's capacity is exceeded, the system will keep running smoothly but the number of passengers waiting in the stations will increase as will the wait times.

An asynchronous system adjusts the speed of T-Pods on the main guideway and/or on the merging guideway to open up slots for merging vehicles. This form of control is more complex but may offer higher capacity in systems that have numerous (probably more than ten) merges. If an asynchronous system's capacity is exceeded, gridlock could occur on the guideways.

Control system failure could lead to loss of T-Pod separation (headway) resulting in rear-end collisions or side-on collisions. A rear-end collision with a speed differential of 30mph or a side-on collision causing a T-Pod to leave an elevated guideway could result in death.

Threat rating = I

Navigation System Failure

The navigation system ensures that each T-Pod is in the location ordered by the control system and operating in accordance with the required parameters. If a T-Pod thinks it is in a different position to where it actually is, the accidents described above could occur. Failure of the steering system for open guideway systems is considered a navigation system failure. Failure of a switch for a captive bogey system is considered a navigation system failure.

Threat rating = I

Guideway/T-Pod Interface Failure

In an open guideway system this is where the rubber hits the road. An accident such as those described above could occur should there be insufficient friction between the tires and the guideway surface. Contributing factors to interface failures include smooth tires, smooth guideway surface, and wet, snowy or icy conditions. Other factors include failure of the T-Pod suspension system (including axles, bearings, etc.) or tires (blowout).

In a captured bogey system this type of failure could be caused by the bogey (or parts of it) jamming in the guideway.

The above-mentioned types of failure could theoretically result in a T-Pod coming to an instantaneous (brick wall) stop causing a hazard to the following T-Pod(s).

The guideway could fail completely (collapse).

Threat rating = I

Single T-Pod Accidents

Accidents involving only one T-Pod could be caused by navigation system failures or by guideway/T-Pod interface failures. These accidents also include the T-pod catching alight.

Threat rating = I

T-Pod/Foreign Object Accidents

Inanimate Object on Guideway

This threat mostly involves objects such as branches or whole trees falling on the guideway from above. However it could also include objects such as balls thrown from below. At-grade portions of the guideway could potentially be subject to an automobile or truck crashing through the sidewalls onto the guideway.

Threat rating = I

Animate Object on Guideway

This threat involves animals or humans accessing the guideway and being hit by one or more T-Pods. It is more likely to be an issue with at-grade portions of the guideway.

Threat rating = I

T-Pod/Passenger Accidents

T-Pod Door Accidents

This threat involves a door closing on or otherwise injuring a passenger. It also involves accidents that could result from the opening of doors while the T-Pod is in motion. These accidents seem unlikely to result in death.

Threat rating = II

T-Pod Furniture Accidents

These are accidents that could result from passenger interaction with T-Pod furniture such as fold-up seats or fire extinguishers. These accidents seem unlikely to cause serious injury or death.

Threat rating = III

Station/Passenger Accidents

Platform Accidents

The most serious threat here is the potential danger of a passenger inadvertently entering the guideway from a station and being struck by a T-Pod which would be traveling slowly at that point. Another possibility would be for portion of a passenger's body (say an arm) to protrude into the guideway and be struck by a T-Pod.

Platform threats include slip/fall accidents. These accidents seem unlikely to result in death.

Threat rating = II

Stairway Accidents

Stairway accidents include slip/fall events but are expected to be no different than for stairways in other environments. These accidents seem unlikely to result in death.

Threat rating = II

Elevator Accidents

Elevator accidents include accidents involving the doors and other systems but are expected to be no different than for elevators in other environments. Since a station elevator will rise less than twenty feet, these accidents seem unlikely to result in death.

Threat rating = II

Maintenance Facility Accidents

These accidents include those typical of work on heavy equipment involving jacks and power tools. They also include the facility catching alight.

Threat rating = I

3.4 Security Threats

Security threats imply a deliberate attempt to harm passengers or to use the system as means to harm the public. While these attempts are considered unlikely as discussed in the next section, the purpose of this section is to consider the potential results of security attacks (system security).

Personal security is defined as the safety and protection of passengers from each other or third parties loitering in the vicinity of the system.

The ASCE APM standards are focused on safety and their techniques have been adapted herein to also apply to security. While this adaptation seems viable, it results in focusing solely on security within the bounds of the transportation system. This is adequate for the purposes of this study but it must be pointed out that ASVT-enabled facility-wide security enhancements could be implemented as briefly described below.

Improvised explosive devices carried by vehicles are a potential security threat to large buildings such as airport terminals, government offices and possibly university campus facilities. Automobiles can be kept away from such buildings by providing remote parking lots served by shuttle buses. However, the buses themselves can be put to nefarious use and busloads of passengers can be difficult to process. Serving remote parking lots with an ASVT system minimizes the risk because it would be very difficult to divert an automated vehicle for the purpose of loading it with explosives. In addition, by providing a few points of access or a screening stop prior to arriving at the facility, an ASVT system could facilitate the implementation of security screening. The smaller the ASVT T-Pods used, the more the system would provide a steady stream of traffic thereby further facilitating passenger processing. Such concepts for inter-facility safety and security call for a broader analysis.

Security threats are rated in the same way as safety threats.

3.5 Security Threat Quantification

Any deliberate security attack could result in death and all of the security threats have been rated I.

System Security

<u>Attacks on the Control System</u>

The control system could be attacked in an attempt to disrupt service or even to cause T-Pods to crash.

Threat rating = I

Attacks on T-Pods

These attacks could range from attempts to disable specific T-Pods to attacks from a distance using military weapons.

Threat rating = I

Attacks on Guideways

Bombs could be placed on guideways or guideway columns in an attempt to bring a portion of the guideway down. A truck could collide with a guideway column with the same intent.

Threat rating = I

Attacks on Stations

Bombs could be placed in stations in an attempt to shut a station down and/or injure and kill passengers.

Threat rating = I

Attacks on Maintenance Facility

Bombs could be placed in the maintenance facility in an attempt to shut the system down and/or injure and kill workers.

Threat rating = I

Personal Security

Attacks in T-Pods

People could attack each other in T-Pods for reasons of theft, sexual assault or intent to maim or kill.

Threat rating = I

Attacks in Stations

People could attack each other in stations for reasons of theft, sexual assault, intent to maim or kill or simply to be next in line.

Threat rating = I

Threat ratings are summarized in Table 3.

Chapter 4
Vulnerability Assessment (Without Mitigating Measures)

This section addresses the vulnerability of the ASVT system to the postulated threats. For each threat it considers how vulnerable the system may be. This initial analysis is undertaken assuming that the system includes no mitigating measures. This could be likened to investigating road safety in the absence of seat belts, markings, signs and traffic signals. The intent is to first identify where mitigating measures are needed. Following sections address the vulnerability with standard mitigating measures in place and the need for extraordinary mitigating measures.

Each vulnerability is quantified and given a rating of A though E in accordance with the following table derived from the ASCE Automated People Mover Standards (1). Safety ratings take account of how frequently the threat is likely to present itself. Security ratings consider both how easy it would be to carry out the threat and the anticipated likelihood of it being carried out (again, if there were no mitigating measures in effect). The two differ in that safety hazards are assumed to be independent random events. The potential for a safety threat to present itself is not diminished by mitigating measures. For instance a crash avoidance system on a T-Pod does not diminish the frequency of a deer appearing on the track – it only diminishes the consequences of the event. On the other hand, mitigating measures may diminish the probability of security threats. CCTV or other surveillance may deter a perpetrator from initiating an event as well as diminish its consequences, should it occur.

The ASCE Automated People Mover Standards (1) measure frequencies in terms of system operating hours and (curiously) do not differentiate between small and large systems. For this study the ASVT system was assumed to be one system operating 24/7 as was the entire campus. For a larger system it may be more appropriate to base the frequency on, say, the number of operating hours per 10 or 100 T-Pods.

The ratings of A through E are each defined by a fairly large range of system operating hours (somewhat larger than the author would have chosen but probably not inappropriate for this study). In most cases it was fairly obvious which rating to apply. For example an event that was likely to occur about once a year clearly has a rating of "B

Probable" (more often than every 41 days but less than every 11 years).

Table 2: Vulnerability Values

Rating	**Frequency**
A Frequent	Mean time between events (MTBE) < 1,000 operating hours (41 days)
B Probable	1,000 < MTBE < 100,000 operating hours (11 years)
C Occasional	100,000 < MTBE < 1,000,000 operating hours (114 years)
D Remote	1,000,000 < MTBE < 100,000,000 operating hours (11,400 years)
E Improbable	MTBE > 100,000,000 operating hours (11,400 years)

4.1 Safety Threats

Accidents Between T-Pods

<u>Control System Failure</u>

Industrial computers should not (but could) fail more often than once a year. They certainly should not fail more than nine times (every 1,000 operating hours) in a year. They have been rated “B”. This rating could have been refined by further research into computer reliability but later portions of the study did not reveal sensitivity to computer reliability.

Vulnerability rating = B

<u>Navigation System Failure</u>

Navigation systems are also computer-reliant.

Vulnerability rating = B

<u>Guideway/T-Pod Interface Failure</u>

Snow and ice are frequent occurrences in Kansas during the winter months and could occur more than nine times in one year (once every 41 days).

Vulnerability rating = A

Single T-Pod Accidents

These could result from any of the above threats

Vulnerability rating = A

T-Pod/Foreign Object Accidents

Inanimate Object on Guideway

This could conceivably occur more frequently than once a year.

Vulnerability rating = B

Animate Object on Guideway

This could conceivably occur more frequently than once a year.

Vulnerability rating = B

T-Pod/Passenger Accidents

T-Pod Door Accidents

These could conceivably occur more frequently than once a year.

Vulnerability rating = B

T-Pod Furniture Accidents

These accidents seem unlikely to occur.

Vulnerability rating = C

Station/Passenger Accidents

Platform Accidents

These accidents could occur approximately annually.

Vulnerability rating = B

Stairway Accidents

These accidents could occur approximately annually.

Vulnerability rating = B

Elevator Accidents

These accidents are likely to occur at longer intervals than once every eleven years.

Vulnerability rating = C

Maintenance facility Accidents

These accidents could occur approximately annually.

Vulnerability rating = B

4.2 Security Threats

Conventional transit systems (automated or not) move people in large groups. Crowds gather at stations and the vehicles themselves are often crowded. Thus buses, trains and aircraft have formed attractive terrorist targets. ASVT on the other hand is designed to move the same total volume of people continuously in small groups like water through a hose instead of by the bucketful. The small vehicles, guideways and stations of an ASVT system are therefore the antithesis of a likely terrorist target.

Rather than being like conventional transit in its operating characteristics, ASVT is much more akin to automobiles and perhaps even elevators and escalators. These forms of transportation have not typically been popular terrorist targets. However automobiles have been used to deliver explosive devices. ASVT vehicles could be put to the same purpose in a situation where, for example, there was an ASVT station inside a crowded building. This type of situation is unlikely to occur on a university campus.

The perhaps more likely security threat for an ASVT system as compared to conventional transit is the threat to personal security. This is defined as the safety and protection of passengers from each other or third parties loitering in the vicinity of the system.

System Security

<u>Attacks on the Control System</u>

The control system would not be linked into outside networks and would be difficult to hack or modify without extensive inside knowledge

Vulnerability rating = E

Attacks on T-Pods

The return on effort for such an attack would seem to be very low.

Vulnerability rating = D

Attacks on Guideways

The return on effort for such an attack would seem to be very low.

Vulnerability rating = D

Attacks on Stations

The return on effort for such an attack would seem to be quite low.

Vulnerability rating = D

Attacks on Maintenance Facility

Such an attack could close the system for an extended period

Vulnerability rating = C

Personal Security

Attacks in T-Pods

These attacks can be expected to take place at the same rate as in other campus transportation modes (see Tables 5 and 6.)

Vulnerability rating = B

Attacks in Stations

These attacks can be expected to take place at the same rate as in other campus transportation modes (see Tables 5 and 6.)

Vulnerability rating = C

Vulnerability ratings are summarized in Table 3.

Chapter 5
Threat/Vulnerability Analysis

Having rated the threats and vulnerabilities, we can now consider how they interact. Table 3 provides the consolidated information. In determining the overall ratings consideration was given to the possibility of a threat having a different threat rating associated with a different vulnerability rating resulting in a higher overall rating. In other words if a threat had a very low likelihood of causing death but a high likelihood of causing severe injury, the combination resulting in the worst overall rating was used.

Table 3: Threats and vulnerabilities (no mitigating measures)

Threat	Threat Rating	Vuln. Rating	Overall Rating		
Safety Threats			Unacceptable	Undesirable	Possibly Acceptable
Accidents Between T-Pods					
Control System Failure	I	B	●		
Navigation System Failure	I	B	●		
Guideway/T-Pod Interface Failure	I	A	●		
Single T-Pod Accidents	I	A	●		
T-Pod/Foreign Object Accidents					
Inanimate Object on Guideway	I	B	●		
Animate Object on Guideway	I	B	●		
T-Pod/Passenger Accidents					
T-Pod Door Accidents	II	B	●		
T-Pod Furniture Accidents	III	C			●
Station/Passenger Accidents					
Platform Accidents	II	B	●		
Stairway Accidents	II	B	●		
Elevator Accidents	II	C		●	
Maintenance Facility Accidents	I	C	●		
Security Threats					
System Security					
Attacks on the Control System	I	E			●
Attacks on T-Pods	I	D		●	
Attacks on Guideways	I	D		●	
Attacks on Stations	I	D		●	
Attacks on Maintenance Facility	I	C	●		
Personal Security					
Attacks in T-Pods	I	B	●		
Attacks in Stations	I	C	●		

ACSE's Automated People Mover Standards indicates that that ratings IA, IIA, IIIA, IB, IIB and IC are unacceptable; IIIB, IIC and ID are undesirable; IVA, IVB, IIIC, IID, IIID, IE and IIE may be acceptable; IIIE, IVC, IVD and IVE are acceptable. On this basis only T-Pod furniture accidents and attacks on the control system may be acceptable and all of the other threats need mitigating.

An ASVT system designed and constructed without any mitigating measures would provide an unsatisfactory level of safety and security as indicated by the high number of unacceptable and undesirable overall ratings in Table 3. Current ASVT concept systems call for standard mitigation measures typically found in other automated transportation modes. These mitigation measures are discussed in the following section and remove most, if not all, of the unacceptable and undesirable safety and security threats and vulnerabilities.

Chapter 6
Standard Mitigating Measures

This section describes standard mitigating measures for each of the postulated threats. A mitigating measure is considered standard if referenced in 21st Century Personal Rapid Transit by Ray MacDonald (2), if more than one ASVT vendor so indicates in their literature and/or if it is considered standard in the automated people mover industry.

Having described the mitigating measures, this section also reassesses the threat and vulnerability ratings for each threat with the measures in place. These new ratings are then used to evaluate the need for extraordinary mitigation measures.

The Morgantown ASVT system incorporates many of the standard mitigating measures. Its effectiveness in mitigating the different threats has been considered in arriving at new ratings.

Standard mitigating measures include:

- Guideway sidewalls or bogey captive in guideway
- T-Pods are crashworthy with energy-absorbing body design
- Seatbelts are available
- A minimum safe headway is maintained between T-Pods
- An autonomous vehicle protection system senses large objects in path
- Computing redundancy is maintained

- Control/navigation systems follow fail-safe design principles (see reference (2) for details)
    - Intrinsic fail-safe design or
        - Checked-redundancy
        - N-Version programming
        - Diversity and self-checking
        - Numerical assurance
- Snow and ice mitigation measures
- Severe weather mitigation measures
- Structures designed for appropriate wind/earthquake/impact loads
- Fire resistant materials used
- Fire extinguishers supplied
- Door interlocks and object sensing
- Furniture padded with no pinch points
- Station CCTV with proactive monitoring
- Stations, stairways, elevators and maintenance facilities must meet building and safety codes
- Control systems secured with controlled access
- Maintenance facility secured with limited access.

The impacts of these standard mitigating measures are discussed in more detail below.

6.1 Safety Threats

Basic safety measures include having the bogey captive in the guideway or, on open guideway systems, having guideway sidewalls to prevent T-Pods from leaving the guideway in the event of an accident. T-Pods will be crash worthy with energy-absorbing body design and optional seatbelts for passengers. These measures coupled with the low operating speeds and the use of redundant, failsafe control systems should suffice to all but eliminate the possibility of T-Pod accidents causing death.

Accidents Between T-Pods

Regardless of which of the below failures causes a potential accident between T-Pods, each T-Pod must be equipped with a fully autonomous automatic vehicle protection system (AVPS) that can sense obstacles such as another T-Pod and also possibly sense smaller objects such as human beings in the path of the T-Pod and cause it to stop before reaching the obstacle. This raises the question of minimum safe headway (time between vehicles).

> *Minimum Safe Headway.* The minimum safe headway can be conservatively calculated for open-guideway systems (captive-bogey systems with linear induction motors are expected to have better braking performance) to be two seconds based on the following:
>
> Assuming a maximum trip length of 3 miles (4.8 km), a 25 mph (40 kph) operating speed will give a satisfactory maximum trip time of seven minutes.

Assume that a T-Pod can only slow down at a rate equivalent to that used by 90% of automobile drivers enabling them to keep control on wet surfaces. This rate is 11.2 ft/sec/sec (3.4 m/sec/sec) for automobiles (3). A stop from 25 mph (40 kph) will take 72.8 feet (22.1 m) (including a 13 foot (4 m) allowance for T-Pod length). At a two-second headway the nose-to-nose distance between T-Pods is 73.2 feet (22.3 m). Thus, if the first T-Pod instantaneously stopped (referred to as a brick-wall stop), the second T-Pod could stop without hitting it assuming near instantaneous reaction time by the control system and/or the AVPS. In conditions where available friction was less than sufficient to achieve the required deceleration rate, the operating speeds and/or headways should be adjusted accordingly. At a minimum headway of two seconds and an average occupancy of 1.5, guideway theoretical maximum capacity would be 2,700 passengers per hour per direction which should be sufficient to accommodate the approximately 10,000 daily person miles anticipated for a university campus system (4).

The AVPS must also take appropriate action in the event of:

- Movement without a movement command
- Overspeed
- Overtraveling beyond the end of the guideway
- Lost communication signal
- Unscheduled door opening

The revised ratings discussed below and shown in Table 4 all take the AVPS into account.

Control System Failure

The control system must be fully redundant in all aspects including computing and communications.

If redundancy is lost fail-safe design must cause the system to automatically revert to a safe operating speed (walking speed) and all T-Pods must cease operation upon reaching their destination stations (unless it is necessary for an empty T-Pod to depart a station to make room for an arriving T-Pod). System operation must then be halted until full redundancy is restored.

The system controlling merges will need to be more complex for an asynchronous control system than a synchronous control system but the same fail-safe design principles will apply. There is no reason to believe that the principles described in ASCE's Automated People Mover Standards (2) cannot be successfully applied to ASVT control systems.

Assume the control system has dual redundancy and a computer fails once every thousand hours (about every 41 days). The chance of the second computer also failing in the one hour needed to shut the system down is 1 in 1,000. Therefore the chance of both computers failing is 1 in 1,000,000 hours. If the chance of the AVPS failing is also

1/1,000, the chance of a control system failure causing an accident between T-Pods is 1 in 1,000,000,000 hours (a rating of E).

Revised threat rating = II

Revised vulnerability rating = E

<u>Navigation System Failure</u>

The navigation system must be fully redundant in all aspects including computing and communications. If redundancy is lost the system must automatically cause the affected T-Pod to come to a halt and rescue procedures to be initiated.

Navigation systems for open-guideway systems will be more complex than for captured-bogey systems but, again, the same fail-safe design principles will apply.

Chance of failure causing an accident between T-Pods is similar to that for control system failure

Revised threat rating = II

Revised vulnerability rating = E

<u>Guideway/T-Pod Interface Failure</u>

Captive bogey systems are said to be highly resistant to snow and ice. While this has yet to be proven, the positive acceleration/deceleration control provided by their linear induction motors negates the effect of snow and ice (friction reducers) and therefore provides a level of immunity from such threats.

Snow and ice mitigation measures for open guideway systems include heating the guideway, applying anti- and de-icing chemicals and sweeping the guideway with T-Pod mounted brushes. Morgantown has successfully mitigated snow and ice using the first two techniques.

An additional measure is to close the system or adjust operating characteristics such as headway and speed when conditions are conducive to snow and ice. Other transportation systems will likely be operating at reduced capacity during these times and reducing the capacity of the ASVT system should have little negative impact.

Some systems are proposing completely enclosed guideways to render them mostly immune from weather events. This fairly expensive solution may prove worthwhile for installations with frequent severe weather conditions.

The system should be closed to operations in the event of severe weather events such as severe thunderstorms and tornados.

Standard structural design will result in guideways being sufficiently resistant to collapse under normally-anticipated weather and earthquake conditions. Guideway column bases must be designed to withstand impact from vehicles or trucks.

The above measures should greatly reduce the severity of injuries while also reducing the likelihood of accidents.

Revised threat rating = III

Revised vulnerability rating = C

Single T-Pod Accidents

In addition to the above measures, T-Pods must be constructed of fire-resistant materials and the passenger compartment should be separated from the remainder of the vehicle with fire-proof materials. Each T-Pod must contain an accessible fully-charged fire extinguisher.

Revised threat rating = III

Revised vulnerability rating = C

T-Pod/Foreign Object Accidents

<u>Inanimate Object on Guideway</u>

This could occur approximately once every 2,000 to 10,000 hours (2 months to about a year). Assuming a frequency of once every 5,000 hours (7 months based on good maintenance, trimming of tree branches etc. that is subject to occasional failures) and assuming the AVPS fails once every thousand hours, the probability of this type of accident is 1 in 5,000,000 hours.

Revised threat rating = II

Revised vulnerability rating = D

Animate Object on Guideway

The concern here is that a person enters the guideway and is killed by a T-Pod. The vulnerability would be lower than that for inanimate objects since the person will likely take avoiding action. If the person's avoiding action is unsuccessful once every hundred times, the probability of this type of accident is 1 in 500,000,000 hours.

Morgantown initially had problems with animals (mostly dogs) on the tracks. However no incidents with animals lead to human injuries. They indicate that animate and inanimate objects on the guideway are not presently a problem. This is partial justification for the frequencies assumed here.

Threat rating = I (a person on the guideway, rather than a passenger could be killed)

Revised vulnerability rating = E

T-Pod/Passenger Accidents

T-Pod Door Accidents

Doors must be designed so as not to apply harmful pressure on an object preventing closure. Door control protection interlocks must be provided to prevent doors opening unless the T-Pod is stationary and correctly aligned with the platform.

Revised threat rating = III

Revised vulnerability rating = C

<u>T-Pod Furniture Accidents</u>

Furniture must be adequately padded with no sharp edges. Moving parts must be designed to avoid pinch points.

Threat rating = III

Vulnerability rating = C

Station/Passenger Accidents

<u>Platform Accidents</u>

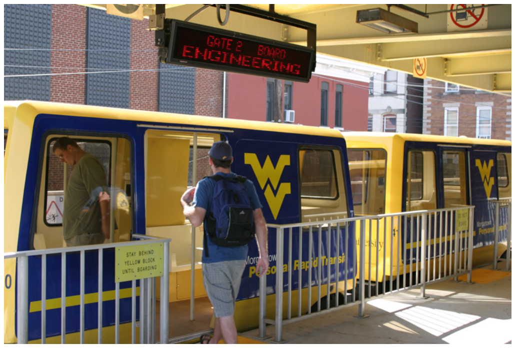

Figure 8: Morgantown station platform. Note the absence of platform doors.

Stations should be provided with CCTV cameras monitored in the control room. Operators should quickly alert passengers to potentially unsafe behavior such as standing too close to the guideway. Intelligent video scene interpretation software can be used to alert operators to such behaviors and increase the likelihood of a warning being delivered. Passengers will soon realize that they are being closely watched. Such frequent warnings have resulted in exemplary student behavior when using the Morgantown system.

Station surfaces should be textured to minimize slip and fall accidents.

Morgantown has operated for thirty years without an accident between a passenger and a vehicle. However, there have been two minor-injury platform accidents.

Threat rating = III

Revised vulnerability rating = C

<u>Stairway Accidents</u>

Stairways must comply with standard safety requirements. They should be provided with handrails and their surfaces should be textured to minimize slip and fall accidents.

Morgantown data suggest a rating of IIIC while KSU data suggest IIB.

Threat rating = II

Vulnerability rating = C

<u>Elevator Accidents</u>

Elevators must comply with standard safety requirements. System elevators are anticipated to have a maximum drop of about 16 feet.

Morgantown data suggest a rating of IVC while KSU data suggest IB.

Revised threat rating = II

Vulnerability rating = C

Maintenance facility Accidents

Maintenance facilities must comply with standard safety requirements for such facilities.

Morgantown data suggest a rating of IVC while KSU data suggest IVB to IVD. The automobile repair industry where there are annually about 954,000 workers and 86 fatalities (5) has a rating of IC for a ten-person repair facility.

Threat rating = II

Vulnerability rating = C

6.2 Security Threats

System Security

Attacks on the Control System

The control system should be kept inside a secure facility with access being limited to approved personnel who have undergone suitable background checks. It should be further protected by a system of frequently-changed passwords.

Revised threat rating = II

Vulnerability rating = E

Attacks on T-Pods

These are not usually mitigated against.

Threat rating = I

Vulnerability rating = D

Attacks on Guideways

These are not usually mitigated against.

Threat rating = I

Vulnerability rating = D

Attacks on Stations

These are not usually mitigated against.

Threat rating = I

Vulnerability rating = D

Attacks on Maintenance Facility

The maintenance facility should be secured with access limited to approved personnel who have undergone suitable background checks. The vulnerability is rated higher because more system damage could be done here making it a more likely target particularly if it incorporates the control facility and/or the power supply/distribution system.

Threat rating = I

Vulnerability rating = C

Personal Security

Attacks in T-Pods

The use of proactive CCTV monitoring of stations along with system monitoring of T-Pods will soon make passengers realize that the system is closely monitored and therefore the last place to break the law. Morgantown initially had a problem with passengers removing and discharging fire extinguishers in the vehicles. They hooked up a sensor informing them if a fire extinguisher is removed from its holder. When the sensor alarms they immediately ask the occupants “Are you on fire?” This type of proactive monitoring has resulted in users overestimating the extent to which they are monitored while using the system.

If the ASVT is a true PRT system there should be no need to unwillingly share a ride. Vehicles should be equipped with a panic button to cause a stop at the next station.

If the ASVT is a GRT system shared rides will be more common and it may be desirable to modify the operating characteristics in off peak periods (particularly at night). The Morgantown system stops at every station late at night so that a passenger not wishing to remain in the company of another passenger has frequent opportunities to exit the vehicle. The Morgantown system has experienced 2 attacks in vehicles in 30 years.

Both of these were sexual harassment only and actual attacks did not occur. KSU reported no personal attacks in transportation systems.

Threat rating = III

Vulnerability rating = C

Attacks in Stations

Since the stations will be under CCTV monitoring, attacks here are considered less likely than in the T-Pods themselves. The Morgantown system has experienced no attacks in stations in 30 years. KSU reported no personal attacks in transportation systems.

Threat rating = III

Revised vulnerability rating = C

Table 4: Revised threats and vulnerabilities (std. mitigating measures)

Threat	Threat Rating	Vulnerability Rating	Overall Rating		
Safety Threats			Unacceptable	Undesirable	Possibly Acceptable
Accidents Between T-Pods					
Control System Failure	II	E			●
Navigation System Failure	II	E			●
Guideway/T-Pod Interface Failure	III	C			●
Single T-Pod Accidents	III	C			●
T-Pod/Foreign Object Accidents					
Inanimate Object on Guideway	II	D			●
Animate Object on Guideway	I	E			●
T-Pod/Passenger Accidents					
T-Pod Door Accidents	III	C			●
T-Pod Furniture Accidents	III	C			●
Station/Passenger Accidents					
Platform Accidents	III	C			●
Stairway Accidents	II	C		●	
Elevator Accidents	II	C		●	
Maintenance Facility Accidents	II	C		●	
Security Threats					
System Security					
Attacks on the Control System	II	E			●
Attacks on T-Pods	I	D		●	
Attacks on Guideways	I	D		●	
Attacks on Stations	I	D		●	
Attacks on Maintenance Facility	I	C	●		
Personal Security					
Attacks in T-Pods	III	C			●
Attacks in Stations	III	C			●

Table 4 indicates that, despite standard mitigating measures, one threat (attacks on the maintenance facility) still provides an unacceptable risk. An additional six threats rank as undesirable. Three of these are safety threats (elevator and stair accidents as well as maintenance facility accidents) and three are security threats (attacks on T-Pods, guideways and stations).

It is significant to note that no unacceptable safety threats remain. All of the undesirable safety threats pertain to portions of the ASVT system that are not unique to ASVT. Stairway, elevator and maintenance facility accidents would be no different than those currently experienced on these types of facilities.

One unacceptable and three undesirable security threats remain. Again, these all pertain to portions of the ASVT system that are not unique to ASVT or have close parallels in conventional transit. Attacks on T-Pods, guideways, stations and maintenance facilities would not be significantly different than attacks on cars, bridges, bus stops and repair/maintenance shops.

This study shows that the unique aspects of the ASVT system do not pose unacceptable or undesirable safety or security threats.

Before considering the practicality of further mitigating the above 7 threats, it is important to put them in context of the threats that have been experienced on the KSU and Morgantown campuses as documented in the following section.

Chapter 7
Campus Safety and Security Incidents and Accidents

This section tabulates the results of research into safety and security incidents and accidents on the KSU campus in the five year period 2001 to 2005 and Morgantown PRT system safety and security incidents and accidents over the thirty-year period 1975 to 2005. The tabulations are designed to categorize the incidents and accidents in such a way as to allow the assignment of threat and vulnerability ratings to each threat using the same criteria presented in Tables 1 and 2.

KSU safety and security data was obtained from information provided by the following agencies and departments:

- KSU Department of Public Safety
- KSU Police Department
- Kansas Department of Transportation

The KSU data was available for period 2001 to 2005 inclusive (unless otherwise noted). This was sufficient to rate those threats for which a number of accidents occurred. If few or no accidents occurred in the five-year period, it was not possible to estimate the mean accident rate with confidence. For example, the fatality within the pedestrian/elevator category was maintenance-related. This single fatal accident during the five year period cannot be accurately extrapolated over a longer period of time. Table 5 includes ratings for accidents with few events but they are clearly distinguished from those with a satisfactory confidence level.

Morgantown ASVT safety and security data was provided by the staff of the Morgantown PRT System and covered the 30 years from October 1975 to May 2006 (approximately 175,000 to 200,000 hours of operation). There were some undocumented negligible injury events involving objects on the guideway. The two attacks in T-Pods both involved sexual harassment only with no physical attack.

Table 5: KSU safety and security incidents and accidents

Threat	**No. of fatal events**	**No. of serious injury events**	**No. of minor injury events**	**No. of negligible injury events**	**Overall rating**			
Safety	**I**	**II**	**III**	**IV**	**Unacceptable**	**Undesirable**	**Possibly Acceptable**	**Acceptable**
Pedestrian ('00 – '05)	0	10	217	36	●			
Pedestrian/bicycle	0	0	0	0				-
Pedestrian/motorcycle	0	0	0	0				-
Pedestrian/car	0	1	1	1	-			
Pedestrian/bus	0	0	0	0				-
Pedestrian/stairs[1] ('03 – '05)	0	3	39	14	●			
Pedestrian/elevator	1[2]	1[3]	1	0	-			
Bicycle	0	0	7	1		●		
Bicycle/bicycle	0	0	0	0				-
Bicycle/motorcycle	0	0	0	0				-
Bicycle/car	0	0	5	3		●		
Bicycle/bus	0	0	0	0				-
Motorcycle	0	0	2	0		-		
Motorcycle/motorcycle	0	0	0	0				-
Motorcycle/car	0	0	1	1		-		
Motorcycle/bus	0	0	0	0				-
Car	1	0	2	1	-			
Car/car	0	1	10	19	●			
Car/bus	0	0	0	0				-
Bus	0	0	0	0				-
Bus/bus	0	0	0	0				-
Bus maintenance facility	0	0	0	0				-
Security								
Terrorist attacks	0	0	0	0				-
Personal assaults (outdoor)	0	0	0	0				-
Totals	**2**	**16**	**284**	**76**				

[1] May duplicate some data from "Pedestrian '00 - '05".
[2] Maintenance accident.
[3] Medical problem (passenger passed out)

Table 6: Morgantown PRT safety and security incidents and accidents

Threat	**No. of fatal events**	**No. of serious injury events**	**No. of minor injury events**	**No. of negligible injury events**	**Overall rating**			
Safety	**I**	**II**	**III**	**IV**	**Unacceptable**	**Undesirable**	**Possibly Acceptable**	**Acceptable**
Accidents Between T-Pods								
Control System Failure	0	0	0	0				●
Navigation System Failure	0	0	0	0				●
Guideway/T-Pod Interface Failure	0	0	0	5[4]			●	
Single T-Pod Accidents	0	0	0	0				●
T-Pod/Foreign Object Accidents								
Inanimate Object on Guideway	0	0	0	0[5]			●	
Animate Object on Guideway	0	0	0	0[6]			●	
T-Pod/Passenger Accidents								
T-Pod Door Accidents	0	0	1	0			●	
T-Pod Furniture Accidents	0	0	0	0				●
Station/Passenger Accidents								
Platform Accidents	0	0	2	3		●		
Stairway Accidents	0	0	1	0			●	
Elevator Accidents	0	0	0	0				●

[4] Ice on vehicle steerage linkages
[5] Undocumented incidents of objects damaging low-mounted communications antenna
[6] Undocumented incidents of T-Pods hitting dogs in 1970's and 1980's prior to leash law

Threat	No. of fatal events	No. of serious injury events	No. of minor injury events	No. of negligible injury events	Overall rating			
Safety	**I**	**II**	**III**	**IV**	**Unacceptable**	**Undesirable**	**Possibly Acceptable**	**Acceptable**
Maintenance Facility Accidents	0	0	0	1				●
Security								
System Security								
Attacks on the Control System	0	0	0	0				●
Attacks on T-Pods	0	0	0	0				●
Attacks on Guideways	0	0	0	0				●
Attacks on Stations	0	0	0	0				●
Attacks on Maintenance Facility	0	0	0	0				●
Personal Security								
Attacks in T-Pods	0	0	0	2[7]			●	
Attacks in Stations	0	0	0	0				●
Totals	**0**	**0**	**4**	**11**				

Comparing all surface transportation modes at KSU and ASVT at Morgantown, the total number of events is 378 at KSU and 15 at Morgantown. However the KSU data represents a much shorter time period (5 years vs. 30) but daily passenger miles about 2.5 times higher(4). Factoring the Morgantown data to reflect these differences results in 378 KSU events compared to 6 Morgantown events (a ratio of 63 to one). If the negligible injury events (which do not affect safety) and the fatal events (for which there is little data) are ignored, the ratio becomes 176 to one. These results imply that ASVT is more than an order of magnitude safer than conventional surface transportation.

[7] Sexual harassment only

Table 7: KSU/Morgantown accident/incident comparison

	No. of fatal events	No. of serious injury events	No. of minor injury events	No. of negligible injury events	Total for all events
	I	II	III	IV	
KSU	2	16	284	76	378
Morgantown	0	0	4	11	15
Morgantown (factored)[8]	0	0	2	4	6

Although economic benefits are beyond the scope of this paper, the data in the above chart can easily be converted to financial impact using statistical data describing costs for various degrees of injury. Council (7) reports the average comprehensive cost per crash involving a single vehicle and a pedestrian when the speed limit is less than 45 mph and someone is killed or seriously injured is $747,904. Avoiding eighteen such crashes could thus save about $13 million over 30 years. This is a significant factor but the accuracy of the data leading to this result is such that it should be considered in terms of its order of magnitude only.

[8] See previous page for discussion.

Chapter 8
Possible Extraordinary Mitigating Measures

At the beginning of this study it was postulated that additional extraordinary mitigating measures may be needed to change ratings of unacceptable or undesirable to possibly acceptable. However it became apparent that the ASCE ratings anticipate a much higher level of safety than is currently experienced with conventional transportation systems. It seems unreasonable to propose extraordinary mitigation measures for stairway, elevator and maintenance facility accidents when these are anticipated to be no more frequent than are currently experienced on similar campus facilities which are accepted as being reasonably safe.

The threat of security attacks on T-Pods, guideways and stations rated undesirable. This is similar to the rating for campus bicycle and motorcycle accidents but better than the rating for campus pedestrian and car accidents. The likelihood of these attacks occurring is considered remote but they rate undesirable because an attack could quite likely cause death. Little can reasonably be done to harden T-Pods, guideways and stations against terrorist attacks and the fact that the rating is better than that for campus pedestrian and car accidents indicates it should be accepted as is.

The one threat that rated unacceptable was attacks on the maintenance facility. This rating resulted from the combination of the fact that such an attack could cause death with the fact that an attack on the maintenance facility could render the system unserviceable for an extended period of time. In considering mitigation measures for this threat it should be remembered that the rating is the same as for campus pedestrian and car accidents.

Standard mitigating measures for the maintenance facility include securing the facility and limiting access to approved personnel who have undergone suitable background checks. Additional measures can (and should) be incorporated in the system design at little or no extra cost. These include:

- Providing a suitable distance between the maintenance facility and any main guideway
- Providing a separate facility for empty T-Pod storage
- Providing a separate facility for the control room and computers
- Providing redundancy so that the system can keep operating (with a temporary maintenance facility) in the event the maintenance facility is destroyed.

CCTV monitoring of passengers inside T-Pods may become a standard mitigating measure in ASVT systems. It is already becoming more commonplace in bus and train systems. The Morgantown data suggest it is not necessary from a personal security standpoint.

Chapter 9
Conclusions and Recommendations

The focus of this study was to determine if Automated Small Vehicle Transit (ASVT) implementations contained any significant safety or security concerns. As part of a second phase of research that investigates implementation issues of ASVT on University campuses, this study uses the methodology established within the ASCE Automated People Mover Standards applied within a university context. This methodology rates the likelihood of events that may produce injuries or fatalities into one of four categories: unacceptable, undesirable, possibly acceptable, and acceptable. The analysis indicated that an implementation of ASVT using standard mitigating measures received ratings of possibly acceptable or better. Items receiving ratings of 'undesirable' or worse within the analysis were related to system components such as stairways and elevators which are common to any system in existence. The safety and security concerns that are unique to an automated transit system have been shown to be successfully mitigated in other deployments. The aspect of ASVT that makes it unique from other automated transit, that of shuttling passengers in small groups, adds the additional personal security concerns at stations and within vehicles. Morgantown has successfully demonstrated operational procedures and passenger monitoring practices to mitigate the enhanced personal security threat. No aspects of ASVT present an unacceptable safety or security threat.

Safety data compiled for the 30-year old Morgantown PRT system at West Virginia University (WVU), an example of a 1970's ASVT system design, provides additional evidence of the relative safety of such systems. The data from Morgantown and from five-years of KSU surface transportation system were used to calibrate the ASVT system ratings. A comparison of the incident rate between these two data sets exemplifies the increased level of safety available in automated systems. The data suggests that the safety of university transportation systems may be increased when augmented with ASVT. By reducing the percentage of manual travel, particularly automotive, the overall injury rate may be significantly reduced. Historical safety data from WVU's surface transportation system (similar in scope to the KSU data) would provide another opportunity to test this hypothesis.

The methodology used to assess safety and security is restricted to intra-system issues. Enhancement or degradations in safety and security to the facility or complex as a result of implementing an ASVT system is not captured in the methodology. The operating characteristics of ASVT suggest several facility wide enhancements. Aggregating passengers in small groups rather than large groups provides significant threat deterrence when compared to traditional transit. When operating as a horizontal shuttle between peripheral parking and central facilities, ASVT significantly decreases the threat exposure to vehicle-borne explosives by enabling full access control to central facilities. These and other security enhancements need to be analyzed in a facility-wide security study.

This study has developed a methodology for rating the safety and security of a generalized ASVT system that could be used in a more rigorous analysis of a specific system prior to implementation for a particular application. The results indicate that a modern ASVT system should be approximately as safe as the Morgantown PRT system which is itself much safer than conventional surface transportation. Those portions of the system unique to automated guideway systems will be much safer than those portions such as platforms, stairs and elevators, common to conventional systems.

The authors hope that this analysis will serve as the basis for future work to perform security assessments not only within the context of a university campus, but also in other applications where safety and security is of utmost concern such as airports, military installations, and government office parks.

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