Report No. UMTA-IT-06-0135-77-6

ASSESSMENT OF THE UMI TYPE II TOURISTER AGT SYSTEM AT KING'S DOMINION

SRI INTERNATIONAL
MENLO PARK, CALIFORNIA 94025

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA •

December 1977

Final Report

Prepared for

U.S. Department of Transportation
Urban Mass Transportation Administration
Office of Technology Development & Deployment
Office of Socio-Economic and Special Projects
Washington, D.C. 20590

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-IT-06-0135-77-6		

4. Title and Subtitle	5. Report Date
Assessment of the UMI Type II Tourister AGT System at King's Dominion	December 1977
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
A. M. Yen, C. Henderson, M. Sakasita, M. Roddin, W. Siddiqee	SRI Project 5949
9. Performing Organization Name and Address	10. Work Unit No.
SRI International 333 Ravenswood Avenue Menlo Park, California 94025	11. Contract or Grant No. DOT-UT-70034
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	
U.S. Department of Transportation Urban Mass Transportation Administration 400 Seventh Street, S.W. Washington, D.C. 20590	Final Report
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This final report describes and assesses the Universal Mobility Inc. (UMI) automated guideway transit system at King's Dominion Amusement Park near Richmond, Virginia. The information and data presented in the report were collected by the authors through surveys of technical literature; formal site visits; interviews with operators, management, and engineering personnel; and a visit to the system manufacturer.

A draft of this report, which is one of six site reports, has been reviewed by site personnel and the system manufacturer, according to the policy of the study's sponsor, the Urban Mass Transportation Administration (UMTA).

The purpose of the site reports is to provide a uniformly documented presentation of automated guideway transit installations for UMTA's Automated Guideway Transit Socio-Economic Research Program and for use by other research groups and interested parties.

17. Key Words	18. Distribution Statement
Universal Mobility, Inc. (UMI) Automated Guideway System King's Dominion Amusement Park	Available to the Public Through the National Technical Information Service, Springfield, Virginia 22161.

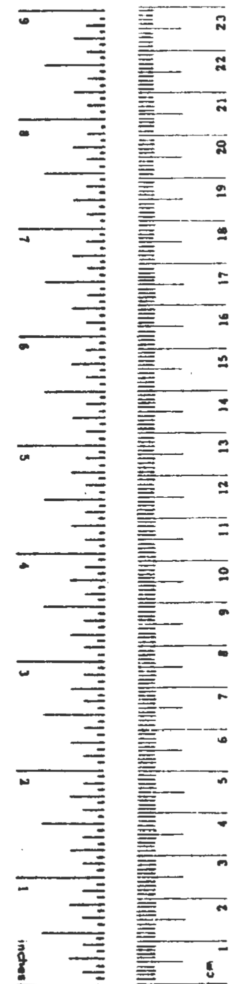
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-69)

METRIC CONVERSION FACTORS

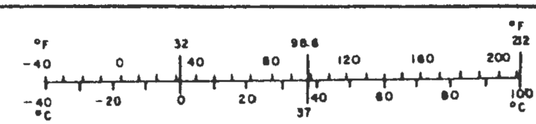
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

This project was conducted by the staff of SRI International's Transportation and Industrial Systems Center under the directorship of Dr. R. S. Ratner. Specifically, the work was completed in the Public Transportation Department directed by Mr. Joel Norman. Dr. Waheed Siddiqee, manager of the Transportation Systems Evaluation Program and supervisor of the project, coordinated the overall planning and policy level activities associated with the project.

Dr. A. M. Yen was the project leader and leader of Task 1, engineering-related data. Dr. M. Sakasita was the leader of Task 2, system economics and operational performance data. Mr. Marc Roddin and Ms. Nancy David shared the effort of Task 3, public perception. Mr. Clark Henderson was the leader of Task 4, the development process study. He also planned and monitored the special task effort for analysis of detailed cost data with the assistance of Dr. Sakasita.

Dr. R. Cronin, Mr. A. Hungerbuhler, and Mr. Steve Procter contributed to the project in an overall manner. Consultants to the project included Messrs. J. Barraza of DeLeuw, Cather (cost engineer); W. Flueckiger of GRC (cost analyst); J. W. Hall (guideway analyst); and F. T. MacInerney (mechanical engineer). The authors would also like to acknowledge Marjorie Cutler for her editing effort and various professionals and secretaries for their contributions to the project and the manuscript.

ACKNOWLEDGMENTS

The SRI assessment team would like to extend its gratitude to the many parties without whose cooperation this report would not have been possible. Among those who have given us their assistance are the staffs of King's Dominion and Universal Mobility, Inc.

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1 EXECUTIVE SUMMARY

1.1 Summary Description

This report contains the findings of an assessment of Universal Mobility Inc.'s (UMI) automated guideway transit (AGT) system used for passenger transport through the Lion Country Safari at King's Dominion Amusement Park near Richmond, Virginia.

SRI International conducted this assessment as part of an assessment program sponsored by the Urban Mass Transportation Administration (UMTA). The purpose of the program is to gain an in-depth understanding of the performance, capabilities, and limitations of the AGT systems at King's Dominion, Sea-Tac, Fairlane Town Center, Tampa International Airport, Houston Intercontinental Airport, and WALT DISNEY WORLD.

In assessing the AGT system at King's Dominion and the systems at the other five sites, the objectives were to:

- Obtain factual engineering and operational data.
- Obtain descriptive economic, system performance, and user perception data.
- Review the design, development, and implementation process.

The findings are intended to establish the state of the art of AGT systems for ultimate use in planning, evaluating, producing, and deploying future AGT systems.

King's Dominion is an amusement park with a number of rides and attractions. One of the attractions is the Lion Country Safari, which can be seen by riding the Type II Tourister train built by UMI. The trains are automatically controlled, enclosed, air-conditioned units that operate on a primarily at-grade, approximately 10,900 ft guideway. A possible total of six trains can operate on the loop in an unscheduled automatic mode. Each train can accommodate 96 passengers (all seated). The maximum operating speed of the Type II Tourister is 6.5 mph at King's Dominion, but the train has achieved speeds in excess of 15 mph at other installations.

The UMI system parallels an existing road and replaces the use of automobiles for viewing the animals. The decision to purchase an AGT system for the site was influenced by the amusement park operators' desire to reduce risks to patrons who sometimes rolled down auto windows or got out of their cars. The system was purchased after a series of meetings between various suppliers and the amusement park operators. It was installed as part of a more general expansion at the previously existing Lion Country Safari site. The UMI system was opened in April 1975.

1.2 General Findings

The UMI system can be characterized as having a relatively low technological level but an overall design that fulfills the site requirements in a straightforward and economical manner.

The vehicles themselves are a standard fibreglass sandwich design. A train is made up of eight passenger vehicles and one passengerless lead vehicle, which houses controls and air-conditioning equipment. Each vehicle shares a bogie with another car, and the entire train is permanently coupled. The design provides economy and flexibility.

One of the interesting features of the UMI system is its command and control electronics. The heart of the control system is the "autopilot." The autopilot is a European design which, according to UMI, has been licensed for use in the Western Hemisphere. The autopilot controls train speed by detecting the presence of leading trains. Each train transmits a signal through a signal rail and accomplishes the control by detecting the difference in return signal. The system, which has carried millions of passengers during the past several years at approximately 15 different installations, appears to be safe and effective.

The acquisition process for the UMI trains is an interesting contrast to the usual public procurement. The site owner and several companies negotiated informally for several months before a contract was drawn and signed. The formal bid and the evaluation process were not rigorously followed since only private firms were involved in the acquisition.

1.3 Outline of the Report

The report contains seven major sections and a comprehensive information checklist attached as Appendix A.

The background of the project, including a brief description of the UMTA program that provided the funding for this study, is given in Section 2, as is the method of approach used in the assessment.

The engineering system description and assessment is given in Section 3, which contains all major engineering subsystems including site-specific subjects. Tables summarizing the engineering description are provided whenever appropriate.

Section 4 addresses the subjects of operation, maintenance and reliability, and passenger-oriented system performance. The description of operations is standard, using such terms as capacity and headways. The study of maintenance and reliability centers around the maintenance policy practiced by the site operator whose professional goal is to maintain the system so as to accomplish high availability. For uniform reference, however, calculations in this report have been made for mean time between failure (MTBF) and mean time to restore (MTTR).

Systems economics, including capital; operations and maintenance costs, are the subject of Section 5, which includes an examination of the data, escalation, and equivalent annual cost.

The development history of the system is examined in detail in Section 6, which includes all major events that led to the present AGT system. Many system features, such as guideway type and vehicle subsystem, are predetermined in an early stage in the development process. These features have numerous impacts on all subsequent designs.

A comprehensive checklist with standard AGT assessment measurements and units appears in Appendix A and provides a convenient means of access to all system information for the reader.

2 INTRODUCTION

2.1 Background of the AGT Socio-Economic Research Program

In 1975 several Federal research programs in new transit systems were integrated to form a consolidated technology program--the Automated Guideway Transit (AGT) Program.

There are several programs within the general AGT Program: the Advanced GRT Program; the Automated Guideway Transit Technology (AGTT) Program for advancing all key aspects of AGT technologies; the AGT Applications Program for actual deployment projects, such as the Downtown People Mover (DPM); and the AGT Socio-Economic Research Program, which sponsors the assessment activities. The total AGT program is structured so that its elements complement and support each other for maximum achievement of program goals.

The AGT Socio-Economic Research Program had a modest beginning in 1973, when a macrolevel analysis of urban transportation with AGT emphasis was carried out. Beginning in 1974 the first of a series of AGT system assessments was initiated, namely the assessment of AIRTRANS system at Dallas/Fort Worth Regional Airport. Qualification guidelines for capital assistance funding of AGT systems were formulated.[1] An assessment of the Jetrail system at Love Field in Dallas, Texas was also conducted. The assessments of AIRTRANS, Jetrail and Cabintaxi/Cabinlift systems in W. Germany have been completed and published.[2,5,6] An assessment of the Morgantown system is underway.

In 1975 the program was significantly enlarged. Major research efforts were initiated in AGT system needs and market analyses, R&D delivery improvements, and socio-economic analyses of AGT systems including public perception, financial and institutional impediments to urban AGT system emplacements, and an expansion of the AGT assessment programs to include domestic airports, commercial sites and foreign sites.

An independent report on AGT systems was prepared by the Office of Technology Assessment (OTA) in June 1975 at the request of Congress.[3] This report, which was commissioned to provide the Senate Appropriations Committee with some background and status of AGT systems, has in part underscored the need for an ACT Socio-Economic Research Program.

During the 1976 Senate Appropriations Hearings, a new program area entitled "Social and Economic Research in AGT" and an appropriate level of funding were recommended. The Senate referenced the OTA report stating that the

> "finding of the OTA report is that social and economic research is needed on AGT systems. The Committee recommends providing $2 million for such research to be used to study the comparative advantages of AGT systems over other forms of mass transportation, evaluation of performance and cost experience of existing AGT systems, assessment of the market potential for urban application of AGT, and simulation and experimentation with existing AGT systems to determine what can be learned about the human response to them."

The goals of the AGT Socio-Economic Research Program are to:

- Determine the particular types of urban applications for which AGT systems are most appropriate.
- Identify and examine the institutional, social, economic, environmental, land use, and performance considerations associated with urban implementation of AGT and evaluate the acceptability of these characteristics by the various impact groups affected.
- Ascertain the capability of AGT systems to meet the mobility needs and the socio-economic requirements of the urban environment by a comparison of the performance and socio-economic characteristics of AGT and other transportation systems.
- Ascertain the nature and magnitude of the potential national market for the classes of automated guideway transit systems (SLT, GRT, and PRT) on a preliminary scale.
- Identify and assess policy options and financing mechanisms necessary to achieve significant implementation of AGT systems if warranted.
- Determine further research, development, and demonstration requirements for AGT system technology.
- Establish a central repository of current information on AGT socio-economic and performance characteristics and regularly disseminate this information to interested audiences in formats most useful to each.

Information obtained through this program will be valuable to local governments in undertaking their local alternatives analysis process, a recent UMTA requirement in seeking capital assistance funds. Furthermore, this Program will develop information to determine the domain of AGT in the hierarchy of urban public transportation and assess its merits and demerits associated with implementation in U.S. urban areas.

The AGT Socio-Economic Research Program is structured around several basic research activities, as follows:

- Generic Alternatives Analyses--This activity is to examine the relative merits and demerits of AGT systems in comparison to other forms of urban transportation.
- Assessments--The studies under this activity are concerned with the operating experience of existing AGT systems.
- Costs--Under this activity, detailed costs and economic studies are conducted for AGT systems.
- Markets--Under this activity, studies are conducted to estimate the market potential of AGT systems.
- Communications--This activity is concerned with disseminating information about AGT systems to all interested parties and receiving local expressions of views about AGT.

The work presented in this report was performed under the AGT Assessments activity.

2.2 Discussion of the AGT Assessments Activity

The UMTA AGT Socio-Economic Research Program defines the goal of the AGT Assessments as follows:

> These Assessments collect, aggregate, and uniformly present the performance and associated socio-economic characteristics from experience to date with AGT installations operating in public service, as well as document the implementation history and learning experiences of each major AGT deployment. The operational, economic, environmental, and passenger response data on all existing domestic and foreign AGT systems will be organized into a central inventory of AGT information for use in conducting the Generic Alternatives Analysis activity, the Markets activity, other activities of this research Program, and by other research groups and interested parties external to this program requiring such data.

To accomplish the above noted goal, several AGT assessment projects were initiated in 1975 for assessing existing domestic and foreign AGT systems and the Morgantown Personal Rapid Transit Demonstration Project.

This site report is one of several for the domestic AGT system assessment. The emphasis of the effort in conducting the assessment was in four major areas:

- Technology-related data--The performance of vehicle subsystems, steering, switching, propulsion, suspension, command and control, guideway, and power distributions are assessed, and the engineering system as a whole is reviewed. Many innovative designs are used in the engineering of the AGT systems. Assessments are based on the functions that an automated system must perform, its effectiveness, and its ability to be deployed in other environments.
- System economics and performance--The effectiveness of the AGT system is assessed by its throughput and layout parameters. System economics, capital, and operations and maintenance cost data are obtained and reviewed. Maintainability, from maintenance strategies and procedures to crew training, is thoroughly examined. Reliability, as a consequence of both maintenance and design, is assessed. Mean time between failure (MTBF) and mean time to restore (MTTR) are calculated wherever appropriate.
- Public response and acceptance--This subject is assessed both subjectively and objectively. Assessments by both owners and operators are obtained, and user perceptions are observed and recorded. An attempt is made to distinguish between the specified and actual comfort for passengers.
- System development process--The systems assessed represent the first generation of deployed AGT systems. The conception, design, development, procurement, testing, and acceptance of these systems vary greatly. In this task we review the entire development process and the relationship of the participants at each site to develop findings that will be applicable to planning and producing future AGT systems.

The rest of this report presents detailed discussions in these four areas.

3 TECHNICAL DESCRIPTION AND SUBSYSTEM ASSESSMENT

3.1 System Description

The UMI System installed at King's Dominion Amusement Park near Richmond, Virginia, is an unscheduled, loop-type system. The route is primarily at grade with one short elevated section. The system opened in April 1975 and operates for 6-1/2 months per year from April to October.

The UMI system ferries passengers through an animal enclosure called Lion Country Safari. The trains are enclosed and air-conditioned; each has an operator on board. The operator's primary function is to describe the animals and ensure that the train does not collide with animals. A fare of $1.50 is charged in addition to the overall gate fee for entrance to the amusement park.

The approximate guideway alignment at King's Dominion is shown in Figure 3-1. The guideway parallels an existing road that was used previously to allow visitors to drive through the animal enclosure. There is one station for both boarding and exiting. The 10,900 ft guideway itself is constructed of steel I-beams supported by concrete footings for the at-grade sections and by steel pillars in the short elevated section. The entire structure is made of limited-rust steel and requires no paint. There are no provisions for snow removal because the park is closed during the winter.

The train itself is made up of nine vehicles: one passengerless lead vehicle, which contains all controls and air-conditioning equipment, and eight passenger vehicles that carry 12 passengers each. The vehicles are permanently coupled on shared bogies. The bodies are fiberglass, and the trains run on rubber wheels. Figure 3-2 shows a train on the guideway.

The maximum design speed of the system is in excess of 15 mph. The operating maximum speed is 6.5 mph as required by specific application (amusement ride). The line capacity with all six trains operating is 1,800 passengers/hr. Other characteristics of the UMI Type II Tourister are summarized in Table 3-1. More detailed characteristics are given in Appendix A.

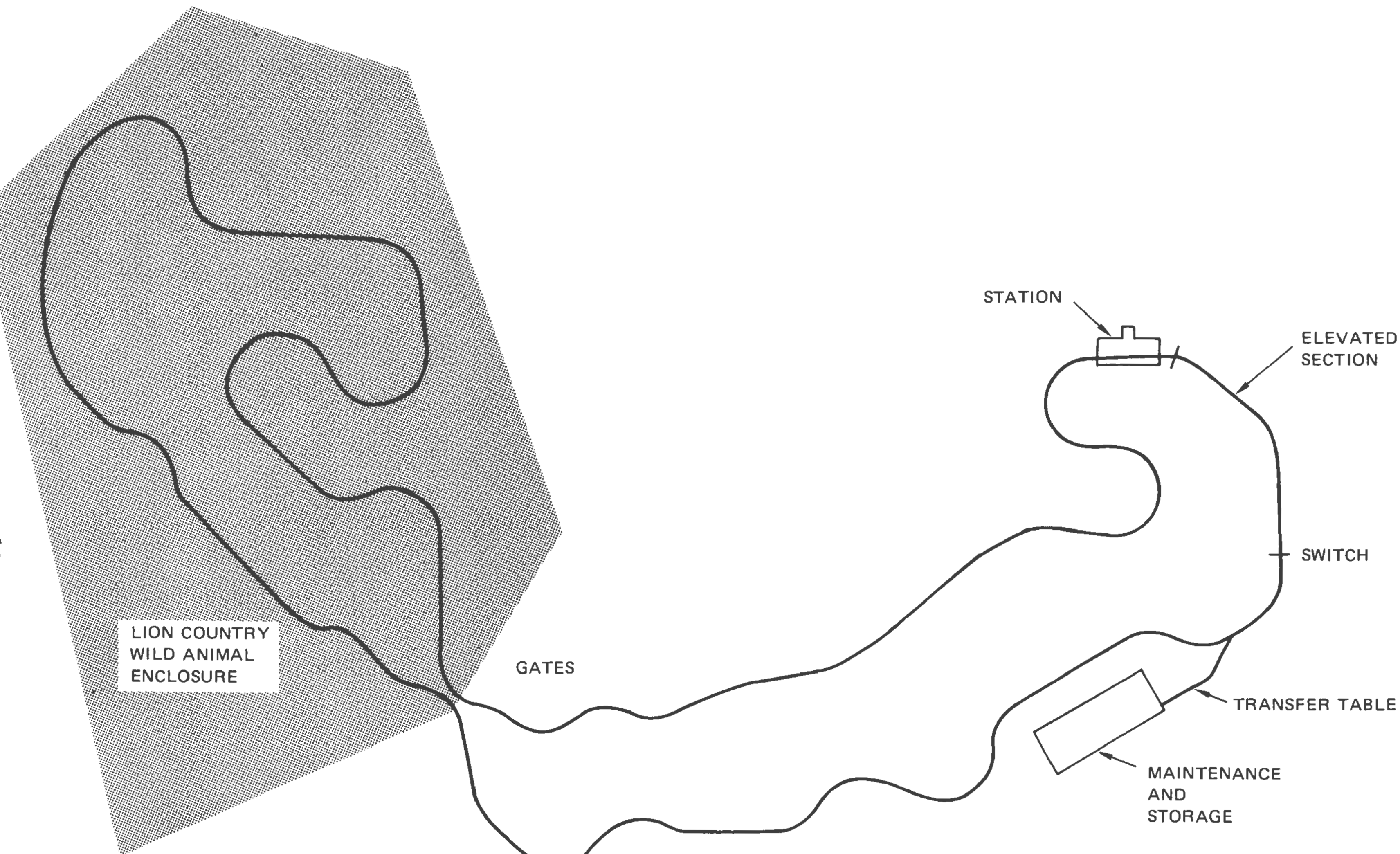

FIGURE 3-1 APPROXIMATE GUIDEWAY ALIGNMENT: KING'S DOMINION
(not to scale)

FIGURE 3-2 UMI TYPE II TOURISTER ON GUIDEWAY: KING'S DOMINION

Table 3-1

UMI SYSTEM CHARACTERISTICS: KING'S DOMINION

Manufacturer	Universal Mobility Incorporated
Date	April 29, 1975
Vehicle	
Capacity	12 seated (no standing permitted)
Max. speed	In excess of 15 mph (design); 6.5 mph operating
Headway	3.75-22.5 min (225-1350 sec)
Number	6 trains, 6 lead vehicles, 48 passenger vehicles
Type of Operation	Trains only: 8 passenger-type vehicles and 1 leader vehicle
Command and Control	
Type	Onboard Autopilot and signal rail
Management policies	Station attendant dispatches trains
Modes	Automatic loop; manual
Guideway	
Length	Approximately 10,900 ft
Type	At-grade w/elevated sec. of 550 ft
Material	Corten (limited-rust) steel
Routing	Single-lane loop
Stations	
Number	1
Platforms	1 entry, 1 exit
Berths	1
Operating conditions	
Weather	Rain
Trip speed (maximum)	6.5 mph
Capacity (maximum)	1,800 passengers/hr
Capacity (average)	Unknown

3.2 Vehicle Subsystem

3.2.1 Description of Vehicle and Performance Parameters

UMI has several vehicle designs in operation in about 15 installations in North America and Europe. UMI is currently designing a larger vehicle called the Unimobil Transporter as a candidate for larger, higher speed installations.[4] The vehicle description presented in this section covers the present installation at King's Dominion. Table 3-2 lists the subsystem parameters.

Table 3-2

UMI VEHICLE SUBSYSTEM PARAMETERS: KING'S DOMINION

	UMI Type II Tourister
Size (length × width × height; in ft)	12.17 × 6.0 × 7.4
Weight (empty)(lb)	1,900
Capacity (lb)	3,500
Total Floor Area (ft^2)	56 (approximate)
Vehicle Interior Volume (ft^3)	336 (approximate)
Operating speed (mph)	6.5
Acceleration (mph/sec)	2
Deceleration	
Service (mph/sec)	2
Emergency (mph/sec)	4.4
Jerk Limits	
Acceleration (mph/sec^2)	2
Deceleration (mph/sec^2)	2
Maximum train length (number of vehicles)	9

The Type II Tourister has a steel frame. The superstructure is made of a fiberglass sandwich with stainless steel mullions and some integrated wood components, which gives a very stiff structure with reasonable weight. Interior and exterior shell pieces present completely finished surfaces to the system users.

3.2.2 Braking

Service braking on the Type II Tourister is regenerative electrical braking. Back-up friction brakes, spring applied with air hold-off, are provided. The spring-applied emergency or parking brakes are set at about 150% of motor torque so that a vehicle can be held against an erroneous motor thrust command.

3.2.3 Minor Subsystems

3.2.3.1 Doors

Individual vehicles have two sliding doors per side. The door opening is 19 in. wide. The manually actuated doors are air operated with electrical limit switches to detect open situations. The limit switch arrangement was installed by personnel at King's Dominion.

3.2.3.2 Heating, Ventilating, and Air-Conditioning

Each train has a Chrysler Air-temp air-conditioner with 26,000 Btu/hr cooling and separate electrical hot water heater.

3.2.3.3 Passenger Environment

Large windows are provided around the perimeter of each vehicle, including in the doors. Vehicles accommodate 12 people in two compartments per vehicle. Contour bench seats are positioned laterally across the vehicle; half the seats face the rear. The vehicle interiors are fully described in Section 4.5.

3.3 Command, Control, and Communications

The UMI command, control, and communications system (CC&CS) is a vehicle-borne control system designed to separate trains safely. The system uses basic electric circuit designs and employs proven electronic components. It uses an analog computer based autopilot, one on each train. The control system basically provides train-to-train speed control. There is no sector or central control per se, because there is no need for such controls in the various UMI installations, that is, amusement parks or exhibitions. The control system's function is mainly to provide vehicle protection, speed control on corners, and station stops.

The discussion below is as complete and accurate as presently possible. The reader should note, however, that the material presented has been pieced together from conversations and limited, shop-type, maintenance diagrams. Circuit diagrams and engineering drawings of the system were not provided. UMI considers its control system a proprietary piece of equipment and is adverse to describing it in any detail.

3.3.1 Vehicle Protection

The primary function of the CC&CS at King's Dominion is train protection. The system performs speed regulation proportional to the distance between the lead and trailing trains. This is accomplished through contact with a signal rail by all trains. The details of the signal rail are covered in Section 3.3.4.

Each train transmits a 28 V, 60 Hz signal. The signal rail is segmented through the use of insulated joints and bridging diodes (and perhaps an impedance element) that are installed in series every 25 ft to 30 ft. The signal is thus transmitted in only one direction, and the signal rail becomes a series of impedance constants. The lead train has a passive grounding shoe which shorts the signal rail to ground (see Figure 3-4). The resulting voltage drop is proportional to the number of impedance elements (diodes) between the lead and follower train.

The onboard control unit, which detects the voltage drop, consists of an Autopilot, a regulator, a pair of tachometers, and other circuit components (see Figure 3-3). The Autopilot functions as a summing circuit that sends appropriate command signals to the regulator based on the feedback from tachometers and control-line voltages.

The signal rail impedance element has a value of approximately 1 Ohm at 60 Hz. Therefore, as the signal line voltage drop decreases (decreasing impedance units coupled), the Autopilot produces decreasing speed commands for the regulator.

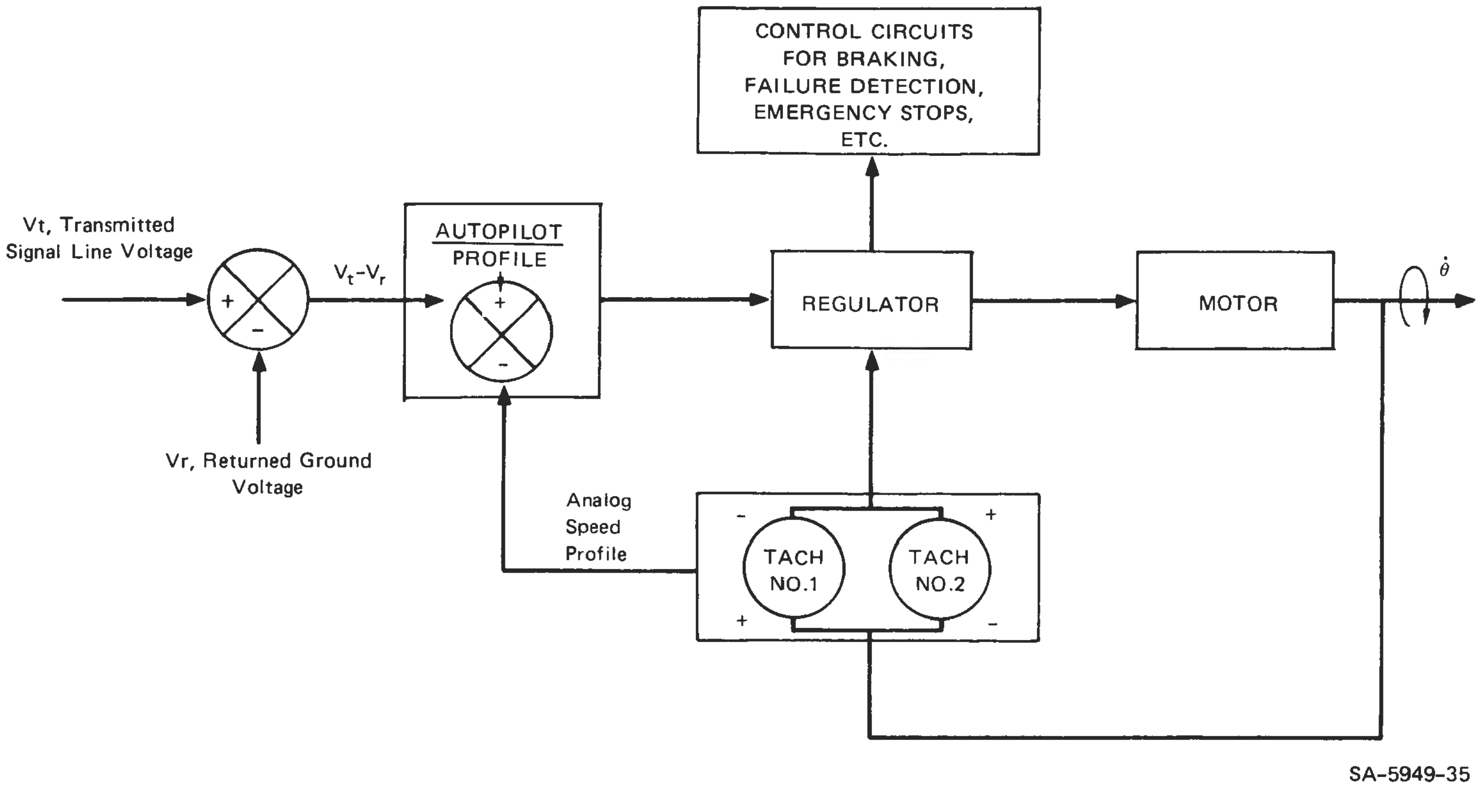

FIGURE 3-3 UMI ONBOARD VEHICLE CONTROL UNIT (Approximated): KING'S DOMINION

The nominal correspondence of speed and line voltage is shown below.

Signal Line Voltage (drop)	Speed Commands (mph)
28 V	15
26 V	13
24 V	~10
⋮	⋮
6 V	0 (service braking)

Since the maximum speed at King's Dominion is 6.7 mph, we assume that the commands are scaled appropriately for the site.

The Autopilot is an analog computer that compares the signal line voltage drop continuously with the analog-tachometer readings. Based on the comparison, the Autopilot gives a digital command to the regulator.

The variable resistors in the Autopilot that set the reference level can also be used to adjust or preset the desired deceleration profile.

Analog computers with precision resistor pots and summing functions are known to require readjustment frequently. However, this is not the case with the Autopilot, which represents the result of a well-conceived and trouble-free design. Once set, the Autopilot performs several self-checking functions and requires little adjustment.

As can be seen above, as distance decreases between lead and following trains, the Autopilot will slow the following train. At King's Dominion this occurs at about 240 ft. By the time the trains are 150 ft apart (approximately 10 impedance elements apart), they are traveling at essentially zero speed. The emergency friction brakes will be applied by virtue of a zero speed reading of the tachometers.

3.3.2 Operational Controls

The other main function of the UMI control system at King's Dominion is station stopping, which is accomplished through electronically imitating the effects of a lead train. The signal rail in the station area is wired with impedance elements and shuntings which simulate various distances of imaginary leading train positions. Therefore, station entrance speed may be selected by the distances between these shuntings to achieve the desired deceleration profile.

A "0 mph" command always appears in the last stage to enable the vehicle to coast with its momentum until a zero speed tachometer signal applies the friction brakes to bring the train to a full stop.

The shuntings on the signal rail in the station area provide enough speed degradation steps for a smooth stop at the station with error around 6 in. The total station approach takes 3-4 sec to complete after the vehicle enters the station control area.

3.3.3 Central Control

The UMI automatic control system at King's Dominion serves only to separate vehicles to a safe distance and adjust speed accordingly if it drops below that distance. However, there is no regulation of vehicle headways if the distances between vehicles are above this safe distance to start with. In other words, there would be no central distribution control per se in a large network. Bunching becomes a natural consequence of such control systems.

The distribution of vehicles in the King's Dominion loop is currently controlled by the station operator who dispatches the vehicles at a predetermined interval. This appears to be adequate for the application at King's Dominion to prevent bunching. The primary responsibilities of the narrator/operator are conducting the tour, activating vehicle doors at station stops, and performing minimal interface with control equipment to avoid hitting animals on the track.

3.3.4 Data Link

The communication system is made up of the segmented signal rail and grounding rail. All communication is accomplished via contact shoes, except operator's voice communication, which is accomplished through a radio link.

The signal arrangement is shown in Figure 3-4, where each train is equipped with front and rear contacting shoes. The 28 V ac, 60 Hz signal is sent by the contact (S_1) in the front car of the trailing train. It is transmitted forward along the signal rail until it reaches the pair of grounding shoes at the rear of the leading train.

The impedance at each impedance/diode unit is approximately 0.5-1 Ohm resonant frequency. These units are permanently attached to the signal rail at distances determined by the operating speed in the area.

Open circuit failure of diodes may cause serious error in predicting vehicle distance. Therefore, an extra contact shoe is mounted immediately in front of the transmitting shoe so that a detection of failure can be made when the leading vehicle comes across the impedance/diode unit. Detection of such a failure will cause an emergency stop until manual take-over.

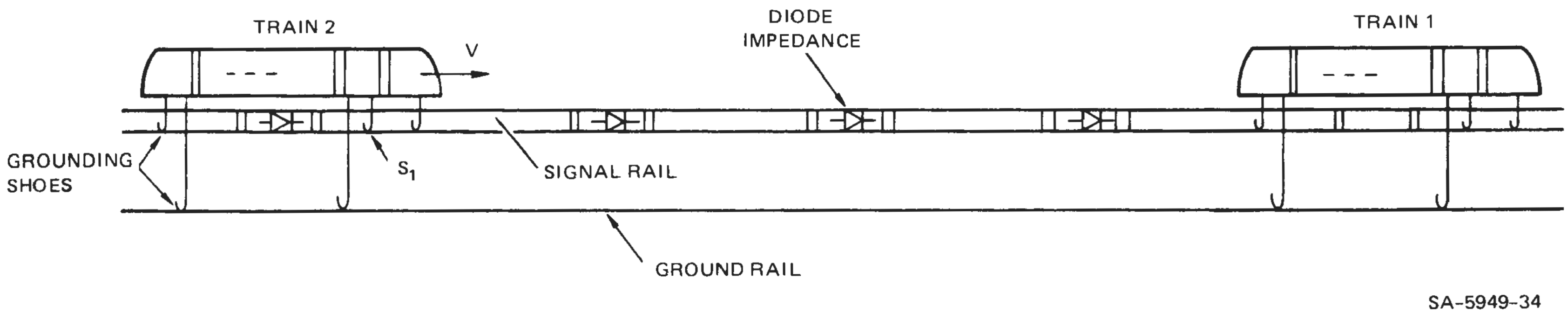

FIGURE 3-4 UMI SIGNAL RAIL CONTACTS: KING'S DOMINION

3.3.5 Comments on CC&CS

The UMI proximity control may be regarded as a type of fixed block control. The control scheme is simple and uses essentially standard components and subsystems.

The CC&CS system at King's Dominion has been demonstrated to operate in excess of 15 mph maximum. It is yet to be demonstrated that the analog devices, including the tachometers, can be effectively accurate in speeds higher than 15 mph.

Unlike most AGT systems, the UMI system at King's Dominion does not have a separate and independent program stop control at the station. It does not require the usual station/vehicle alignment because the speed of UMI vehicles is low, and there is ample time to complete a precision stop similar to that of a normal line stop.

So far, the UMI CC&CS at King's Dominion has demonstrated satisfactory performance. Because the design of the system is based on proven technology, the reliability of the system is high and the costs of the system can be kept low.

3.4 Steering

The UMI vehicle steering system is a basic single-axle/four-guidewheel system. The original design of the steering system placed the guidewheels inboard of and below the load-carrying wheels, bearing outward against the webs of guideway beams. A more recent design places the guidewheels outboard and below the load-carrying wheels, bearing inward against the guideway I-beam or box beam webs. The latter arrangement has been adopted to allow a torsionally stiffer guideway beam than was possible with the inboard wheel arrangement. The original UMI steering system design is used at King's Dominion. The guidewheels are inboard since the stronger beam was not necessary for a predominantly at-grade guideway. The top plate of the guidebeams extends over the webs as a means of making the vehicle captive to the guideway. Auxiliary steel guidewheels are positioned under the overhanging flanges restraining the vehicle from overturning in strong crosswinds. The auxiliary guidewheels have a small amount of positive clearance.

The nine-car train has ten bogies in all. The eight intermediate bogies are each shared by two cars.

3.5 Switching

A motor driven transfer table and hydraulic switch are installed at King's Dominion (see Figures 3-5 and 3-6). The switch is a segment substitution switch that translates a curved or tangent segment laterally to the proper alignment. The operating time is 20 sec, although a 6-14 sec version will be available from UMI. The switch connects the loop to a spur leading to the maintenance and storage area. The transfer table is used to move trains to storage tracks in the maintenance area.

3.6 Propulsion

The propulsion system is made up of a converter/controller, propulsion motors, a belt drive, and differential. The eight shared bogies are driven on each train. The bogies at the front and rear of the train are not powered. The converter/controller used at King's Dominion is a half-wave silicon controlled rectifier (SCR) design that converts Delta-connected 440 V ac line voltage to dc. UMI also has used full-wave thyristor controllers, but these are not installed at King's Dominion.

The eight drive motors are a standard design built by Asea of Sweden. The motors have the following characteristics:

Type	Series wound dc
Nominal voltage	240 V dc
Number of poles	2
Horsepower	7.5
Rpm	2,000

FIGURE 3-5 TRANSFER TABLE AND MAINTENANCE AREA — KING'S DOMINION

FIGURE 3-6 HYDRAULIC SWITCH AT KING'S DOMINION

UMI has used Brown-Boverie motors on some other installations and claims to have designed bogies that are driven by motors built in the United States.

Each drive motor is mounted above the bogie differential and drives the differential input pulley through three V-belts. The overall reduction from motor to wheel at King's Dominion is 20 to 1.

3.7 Power Distribution

The power distribution system at King's Dominion has two main transformers providing 480 V 3-phase ac to the power rails. There are five feeders, each with its own circuit breaker. The power rails are divided into five segments. Bridging switches between adjacent segments can provide power to a segment in the event of the failure of its feeders. Lightning arrestors were added to the transformers after the power distribution system proved vulnerable to lightning.

3.8 Suspension

The design does not have a secondary suspension system because the slow operating speeds do not require it.

3.9 Guideway

3.9.1 General

The AGT system at King's Dominion is a loop system that carries park visitors on a scenic tour wholly within a natural environment animal park. It consists of trains of vehicles operating on approximately 10,900 ft of guideway, most of which is at grade. Passenger loading and unloading is accomplished at a ground-level station, which also provides shelter for the long queues of passengers that build up. Guideway design and on-site supervision were furnished by the system supplier, Universal Mobility, Inc. of Salt Lake City, Utah. However, detailed guideway design was site adapted to a considerable degree by the King's Dominion organization, which served as its own general contractor. The UMI vehicle, coupled with the use and layout of the system, results in a guideway with minimal visual impact upon the public. As a result, little attention has been paid to aesthetics. The guideway, while quite unobtrusive at grade, is somewhat awkward in its elevated portions.

3.9.2 Geometrics

The layout of the guideway at King's Dominion was designed to minimize elevated guideway. As a result, only 550 ft are elevated. Typical vertical curves are 300 ft radius with maximum upgrade of 6% and maximum downgrade of 8%. In contrast to the profile geometry, the plan geometry of the King's Dominion AGT system is quite complex. Approximately 5,761 ft of guideway are curved using horizontal curves of various radii (100 ft radius minimum). Total width of the guideway is 29 inches. The running surface consists of two modified T sections each 8 inches wide. The at grade section of the guideway is actually about 10 inches above ground.

3.9.3 Guideway Structure

Design criteria for the guideway are not available; however, the weight and length of the vehicle suggest a uniform line load of 1 kip/ft (1,500 kg/m). This is a typical value for AGT guideways. The lack of superelevation suggests that centrifugal forces are minimum. Short spans and light loads make possible a relatively light guideway structure.

Guideway beams are structural rolled shapes of corten steel, supported at grade by footings at 27 ft on center and in elevated sections by steel columns at a maximum spacing of 60 ft. The steel guideway beams provide support, guidance, and containment for the vehicle, which runs on the top flange. In addition, the beams provide enclosed mounting surfaces for the power and command and control systems.

3.9.4 Environmental Considerations

Since the AGT system at King's Dominion does not operate during the winter, there is no operational experience under ice and snow conditions, and no provision has been made for snow removal. Rain is not a problem because the structure does not trap water.

3.9.5 Construction

King's Dominion officials report that they encountered considerable difficulties with fabrication and delivery of the steel guideway. Guideway construction began in October 1973, but the steel for the guideway was not delivered until December 1974, a delay of 14 months. Once the steel was delivered, however, the guideway structure was completed in only 2 months.

3.10 Station

The passenger station at King's Dominion is a covered area open on all sides. The passengers are directed to the boarding area by movable gates. This enables the station to hold a maximum number of passengers in an orderly fashion for boarding. The boarding area itself has rails defining the vehicle boarding area. Attendants direct passengers into the vehicle boarding areas until the available space on the train is filled. The passenger deboarding area is on the opposite side of the guideway and is uncovered. After passengers exit, they are directed down a ramp, beneath the guideway, and back to the main park area.

4 SYSTEM OPERATIONAL PERFORMANCE

4.1 Operational Characteristics

4.1.1 System Parameters

The system operates a total of six trains, each consisting of nine coupled vehicles. The number of trains operated varies depending on the number of park patrons. Each train has a capacity of 96 seated passengers. No standees are permitted.

The round-trip time of the system varies from 20 min to 25 min, including 1-7 min of dwell time. The line capacity of the system, which was calculated from this round-trip time, is between 1,380 and 1,730 passengers/hr. The maximum speed capability of the vehicle is in excess of 15 mph. The average operational speed, which includes the stop at the station, varies from 5.0 mph to 6.2 mph. This was calculated for 10,899 ft of guideway length and 20-25 min of one round-trip time.

The system operational time varies from 10 hr to 12 hr/day, depending on the season. The system is operational throughout the summer season and on weekends in spring and fall. In 1976, the system was operated for 133 days.

The system has an operator in the lead car, which does not carry any passengers. The operator functions mainly as a tour guide giving information on the animals in the park that passengers observe from the train. The operator opens and closes the train doors at the station. After the operator has closed the doors, the train starts and runs automatically, but the operator can run the train in a manual mode under some conditions.

The dwell time varies from 1 to 7 min, averaging 3 min. Trains are held at the station until they are filled. Thus, dwell times increase when demand is low. The mean headway varies depending on the number of trains in the system. Theoretically, the number of trains in the system could vary from 1 to 18.* The calculated mean headway can vary from 3.75 min under six-train operation to 22.5 min under one-train operation.

4.2 System Performance

The total hours of operation of each train are recorded periodically. The total vehicle hours of travel (VHT) in 1976 was roughly estimated by SRI from the train operation record to have been 38,000. The vehicle miles of travel (VMT) of the system was estimated using an average speed of 6 mph. The estimated VMT in 1976 was thus approximately 228,000 (25,330# VMT were for lead vehicle and 202,670 VMT for passenger vehicle).

The energy consumption in 1976 is estimated by the operator to have been 399,000 kWh.

According to the King's Dominion management, the total number of fee-paying riders was 872,700 in 1976. The system also carries a small number of school children who do not pay a fee in the off-season. The passenger miles of travel in 1976 was estimated from this patronage and the guideway length of 10,899 ft to have been 1.801 million. The vehicle load factor of 0.74 was obtained by dividing the passenger miles of travel with the product of VMT of passenger vehicles and vehicle capacity.

4.2.1 Degree of Automation and System Productivity

The degree of automation and system productivity measures are employee-to-vehicle ratio, system man hours-to-VMT ratio (degree of automation), vehicle productivity and labor productivity (system productivity).

The employee-to-vehicle ratio depicts the number of employees needed to operate and maintain one vehicle in operation. The number of employees needed for maintenance is equivalent to 3.1 people, based on three full-time maintenance staff and 10% of the maintenance supervisor's time. The number of people needed to operate the system varies from 5 to 14, depending on the number of trains being operated (tourguides, platform guards, ticket sellers, etc.). The average total number of employees who are engaged in the operations and maintenance of the system

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*That is, the loop is long enough to accommodate 18 trains.

#This is also the total train miles travelled (TMT).

is equivalent to 14. The average number of vehicles operated daily in 1976 is roughly estimated from the information provided by the operator to have been 25 ($\approx$2.8 trains during operating hours). This estimation is based on the VMT and total operational hours of the system in 1976. Thus the employee-to-vehicle ratio is 0.56. Because the station specifications did not call for automatic operation, a large number of employees are required to direct patrons to loading stalls to keep families and groups together, and to function in a public relations capacity. This means that an average 0.56 persons are employed to operate the vehicle, or 5 people are employed to operate a nine-vehicle train.

The system man-hour-to-VHT ratio was 0.60 in 1976. This means that, on an average, 0.6 man-hours were needed to operate a vehicle for 1 hr, or, 5.4 man-hours were needed to operate a nine-vehicle train for 1 hr.

The vehicle productivity, (the ratio of annual patronage to the annual VHT) is estimated to have been 23 passengers per vehicle hour in 1976.

The labor productivity, (the ratio of annual place miles of travel to the annual total man-hours) was 120 place miles per man hour in 1976.

4.2.2 Comparison of System Performance with System Specifications and Employees' Assessment

The operational performance requirements listed in the system specifications are dispatch interval, round-trip time, system capacity, average operating speed, and maximum speed. The specified requirements and the existing performance levels are compared in Table 4-1. The table shows that the system's operational performance meets or exceeds the specifications.

The operator is pleased with the system performance. Capacity is exceeded only when park attendance exceeds 30,000. The vehicle operation is simple, and the station operation is very satisfactory. The yard operation is efficient, and trains can be taken on or off the system in about five minutes.

Table 4-1

SPECIFIED REQUIREMENTS AND EXISTING OPERATION:
UMI, KING'S DOMINION

	Specified Requirements	Existing Operation	Discrepancies
Dispatch interval (peak period)	3.2 min	3.3 min ~ 4.2	Close to specified values
Round-trip time	22 min	20-25 min	Close to specified values
System capacity	1,200 passengers/hr	1,380 passengers/hr ~ 1,730 passengers/hr	Satisfies specification
Average operating speed	5.0-6.2 mph	5.0-6.2 mph	Satisfies specification
Maximum speed (design)	In excess of 15 mph	In excess of 15 mph	Satisfies specification

4.3 System Assurance

4.3.1 Maintenance Strategy

The maintenance program of the King's Dominion UMI system is conducted in-house by the King's Dominion's maintenance staff. Presently three maintenance personnel and one supervisor maintain the system.

The maintenance strategy adopted at King's Dominion is scheduled. This includes a regular checkup and repair of equipment. The maintenance work is done at the off-line maintenance yard designed for this purpose. The scheduled maintenance program includes four maintenance classes: daily, weekly, monthly, and semiannually.

Failures are detected by an operator on board the vehicle. When a failure occurs, the operator reports the failure by radio to the communication center, which is based at the station. The staff at the communication center reports the failure to the maintenance and operation supervisors. The maintenance supervisor dispatches a maintenance staff to the failure site to investigate the nature of failure. The failure may be fixed on site if possible. When an on-site fix is not feasible, there are two alternatives. One is to push the stalled train by another train, and the other is to evacuate passengers from the stalled train. The maintenance staff reports that push-mode recovery is chosen whenever it is feasible. Some further information on maintenance is given in Section 5.2.1.

4.3.2 Record Keeping

Both operation and maintenance records are kept. The operation record includes duration and classification of each downtime.

The maintenance record includes all the repairs and maintenance work performed on each train. A maintenance book is kept for each train and includes cumulative train operation hours.

4.3.3 Failure Characteristics

The failure statistics show relatively few failures resulting in system shutdown. In 1976 there were only 15 system shutdowns due to component failure. The net operating time in 1976 was 1,447 hr, so that the system MTBF was 96.5 hr. It is possible that minor failures that do not result in system shutdown occur more often. Such failures would not appear in the failure records.

4.3.4 System Reliability and Maintainability

Table 4-2 shows the failure statistics for 1976 as obtained from the King's Dominion operation and maintenance records. Note that the subsystem classifications are rather broad.

Table 4-2

NUMBER OF FAILURES AND DOWNTIME:
UMI, KING'S DOMINION

Failure Type	Number of Failures	Downtime (hr)	MTBF*	MTTR† (hr)
Mechanical	10	8.0	144.7	0.8
Electrical	2	0.22	723.5	0.11
Counter (station)	1	1.0	144.7	1.0
Gate (entrance to wild animal enclosure)	1	0.5	144.7	0.5
Unclassified	1	1.0	144.7	1.0
Total	15	10.72		

*Mean time between failures.
†Mean time to restore.

The system average MTTR is 48 min; substantial delays result when a failure occurs.

4.3.5 System Availability

The traditional availability was calculated from the total downtime caused by system failures and the total system operation hours in 1976. The available data indicate that the net system operation hours in 1976 was 1,447, and the total downtime of the system caused by failures was 10.7 hr. The traditional system availability is estimated to be:

$$\text{Availability} = \frac{1{,}447 \text{ hr}}{1{,}447 \text{ hr} + 10.7 \text{ hr}} = 0.993$$

4.3.6 Maintenance Facility

The maintenance facility of the system is located at the end of the spur track. The maintenance yard, 150 ft wide and 250 ft long, contains a transfer table, five storage tracks, and a maintenance shed. The maintenance shed, 150 ft long and 24 ft wide, contains spare parts, an overhead hoist, a depressed pit working area, and lubricators.

4.3.7 Training

On-the-job training is offered by a supervisor of the King's Dominion system. Employees are instructed on system operation and on the narration to be given during the tour.

4.3.8 Comparison of Achieved System Assurance with System Specifications and Employees' Assessment

The only document specifying system performance is the UMI-King's Dominion contract. It is reported that the contract does not contain specifications regarding reliability, maintainability, and availability of the system.

The maintenance staff reports that system reliability and maintainability are high. According to the maintenance staff the most troublesome elements of the system are the vehicle doors, which require frequent adjustment for proper operation.

4.4 Human Interface

Because of the large number of attendants at the Lion Country Safari, there is little need for signs. The only signs are those that read "do not lean on doors." These are posted on the exit doors for each car. A public address system is used in the vehicle while it is in motion so the train operator can describe the animals the passengers are observing.

Before entering the lions' cage, passengers are warned not to stand up and not to tap on the glass. Two speakers are mounted on the ceiling of each car.

Each car has an emergency call switch that passengers can use to communicate with the train operator. Located on the right rear of each vehicle 44.5 in. above the bottom of the seat, the unit contains a lever that must be pushed down and held down by the passenger while the train operator is simultaneously holding down a similar switch on the console. Passengers are directed to speak loudly. Almost all uses of the emergency communications system are false alarms.

4.5 Comfort and Convenience

Ride quality at King's Dominion is quite good. Trains move at only about 6 mph, and acceleration and deceleration are very smooth. Jerk is almost imperceptible. Performance on grades (this is one of the AGT system studied that has a significant change in grade) and curves is comparable to that on straight track sections.

The King's Dominion AGT system is designed to accommodate seated passengers only. Each car has two compartments. Each compartment has its own entry door, exit door, and a pair of hard, white, plastic three-passenger benches facing each other, 19.5 in. apart. The benches are 56 in. wide, 17 in. above the floor, and have concave bottoms 17 in. deep. The backs of the two benches in the center are 15 in. high. The benches are not particularly comfortable, which is significant since the 18 min trip at King's Dominion is the longest of any AGT installation in the United States.

The vehicles are comfortably air-conditioned or heated according to the weather. They are not illuminated because the large plastic picture windows let in ample sunlight, and at night the animal area is brightly illuminated in the vicinity of the guideway.

Only as many passengers are allowed to board the train as there are seats to accommodate them, guaranteeing everyone a seat. With all six trains in operation, the system can accommodate a maximum of 1,800 passengers/hr. This hourly demand is not usually exceeded, except on days when attendance at the amusement park is more than 30,000.

Vehicle-related interior noise is 75 dBA. The announcements and background music create a noise level of 88-92 dBA and 84 dBA, respectively.

The King's Dominion AGT is extremely simple to use. When a train arrives at the station, the doors are aligned with perpendicular fenced-in, queuing areas, one for each compartment. Passengers are directed to the various lines by an attendant, and all of the passengers are in place before the train arrives. The exit doors on the left side of the train open first and a few seconds later the right doors are opened, allowing new passengers to enter. This simultaneous loading and unloading sequence from different doors is the same procedure that is used at Tampa and Fairlane, and it greatly improves passenger flow by preventing conflicts.

Wheelchairs cannot be accommodated on the vehicle, except for very small ones designed for children. When a wheelchaired passenger wishes to ride the system, the ticket taker is alerted. The passenger is then escorted on the exit ramp to the exit platform so that the wheelchair can be positioned immediately adjacent to the door and the passenger is assisted in entering the vehicle. The vehicle exit doors are kept open for a longer period than the entry doors.

There are always a minimum of three attendants at the station when a train is loading, so any passengers with special problems can be accommodated readily.

The Safari Monorail at King's Dominion has a highly styled, modernistic appearance. The styling is, perhaps, more appropriate for Walt Disney's Tomorrowland than a wild animal park. The silver-colored cars with their dark tinted windows are attractive.

The interiors have a number of hard, smooth surfaces. The addition of fabrics or textured panels would add warmth.

The typeface used in graphic presentations appears to be stenciled. It is awkward to read and blocky in appearance. This, however, has probably been done intentionally to imitate the type of graphics which would be used in a Jungle or Safari setting.

4.6 Safety and Security

King's Dominion has a good safety record. The system has experienced only two incidents in its three years of operation. Each incident was the result of a train operator's error, and operational procedures have been established to avoid repetition of the errors.

The first incident involved a handicapped passenger. The passenger had boarded the vehicle from her wheelchair at the exit platform, according to standard operating procedures. Before closing the doors, the operator checked the entry platform to make sure that all of the passengers had cleared the door, but neglected to inspect the exit platform, since normally all passengers have exited the vehicle long before passengers are fully loaded. The doors closed on the wheelchair passenger's escort, resulting in minor injuries. It is now the responsibility of the exit guard to make sure that doors are not closed on the passengers.

The other incident occurred on July 28, 1976. Lightning had struck the Lion Country Safari, putting one 700 ft length of track out of service with two trains on it. The operator of the first train behind the disabled section, frustrated that the train would not operate in the automatic mode, switched to manual and moved the vehicle to the disabled section. At the moment the train connected the disabled and normal sections, the entire system was brought down, with all vehicles stranded. Some passengers were trapped in the lions' area for more than two hours. They were delayed for so long because there was no existing evacuation plan for the system. Trains used to transport guests around the parking lots were brought into emergency service after the trains were pushed outside the lions' cage. A manually operated tow/push vehicle is used to move a failed train. The operators are no longer allowed to operate trains on manual unless they are given permission to do so.

Because of the amusement park atmosphere and the presence of numerous park attendants in addition to uniformed police officers, crime or passenger security is not a problem at King's Dominion.

5 SYSTEM ECONOMICS

In this section capital costs adjusted to 1976 dollars and annual operations and maintenance (O&M) costs for 1976 are presented. Total equivalent annual costs--capital plus O&M--are computed for appropriate service lives and discount rate. Average unit costs of service are computed for train miles, passenger trips, passenger miles, and capacity miles, or "place-miles," for seated and standing passengers. Methods of analysis are discussed in Appendix B. Historical cost data, analyses conducted to fill data gaps, and results are discussed.

5.1 Capital Costs

Capital costs for the UMI King's Dominion AGT system have not been previously published in the literature. Capital cost information for the system was obtained from internal accounting records maintained by King's Dominion. The site team obtained a project budget summary dated October 2, 1975 together with supplementary information from the controller to capture several minor cost items not in the AGT project budget but properly chargeable to the system. During the installation and assembly of the hardware, King's Dominion maintenance personnel assisted the AGT contractor as a part of the training program to familiarize King's Dominion personnel with system maintenance. These costs are not identified specifically in the capital cost estimate; it is believed they are included in capitalized general and administration (G&A) costs. The G&A costs shown for the AGT system are costs allocated by King's Dominion to the AGT system as capitalization costs. The site survey team is confident that essentially all contracted costs for the AGT have been extracted from accounting records. The total capital cost breakdown is given in Table 5-1.

The UMI contract was entered into in September 1973 and delivery was made in 1974. The system became operational in 1975. For inflation purposes, the base year is taken as 1974.

Table 5-1

SUMMARY OF CAPITAL COSTS: UMI, KING'S DOMINION
(1974 Dollars)

Construction		
Right of way	$ --	
Engineering and architecture	41,000*	
Project administration	827,000†	
Guideway‡	379,000*	
Tracks, switch, and transfer table	554,110*	
Station	151,000*	
Maintenance shop	111,000*	
Total engineering and construction		$2,063,110
Hardware		
Engineering and project coordination	364,710*	
Power supply and power rail	270,200*	
Maintenance yard equipment	32,700*	
Vehicles (6) (including night lights)	1,842,940*	
Control and communications	28,340*	
Total hardware		$2,538,890
Total system capital cost		$4,602,000

*King's Dominion accounting record.

†King's Dominion estimate.

‡Does not include tracks and switch, which were supplied under the hardware contract.

The total capital cost of the AGT system at King's Dominion includes two major expenditures: (1) costs for design, construction of facilities, equipment installation, and project administration; and (2) the cost of engineering and supply of the system hardware, which also included tracks and power rails. Detailed breakdown of costs was supplied by King's Dominion from their accounting records. Actual expenditures totaled $3,775,000. In addition to this, park management estimates that, based on their total park project workload, administration costs of $827,000 should be charged to the AGT system. Land value was estimated at $5,000 per acre in 1974 dollars. However, the guideway was installed to allow visitors to view the animals in the park. Use of land for the transit system promoted the basic purpose of the park. There was no alternative use for the land and no opportunity was sacrificed. Therefore, it would be inappropriate to include a right-of-way cost as an element of capital cost for the existing system. The total capital cost of the system, including administration, becomes $4,602,000.

Construction engineering and architecture costs are the actual costs incurred for site planning and station design.

The project administration cost is an estimate provided by park management. The basis for the estimate is not known.

The guideway cost includes $135,000 for roadbed preparation and $244,000 for equipment installation. The guideway runs along the edge of an existing access road where most of the earth work and drainage was already done. Due to this factor, roadbed cost was minimal. The total cost for guideway track, switch and transfer table is $933,110 or about $85 per linear foot. Tracks, switch, and transfer table includes $497,850 for supply of track structural elements, $27,210 for track switch, and $29,050 for a transfer table.

The station cost is the actual expenditure for the station building. The station is rather large (11,400 sq ft) because it must accommodate persons waiting to ride, but it is an inexpensive type of construction.

The maintenance shop cost includes $79,000 for actual construction cost of the maintenance shed and $32,000 for an air conditioner in the shed.

Hardware engineering and project coordination costs include $197,000 for design engineering of hardware and $167,710 for project coordination and system implementation costs.

Power costs includes $78,000 for power transformers and $192,200 for power rail.

The maintenance yard equipment cost includes $5,700 for a roller bed, and $27,000 for initial spares.

The vehicle cost covers six trains with bogies and an additional $50,000 for vehicle-mounted high-intensity lamps for night service.

The control and communications cost includes $22,820 for moving block automatic controls and $5,520 for a public communication system.

5.2 Operations and Maintenance Cost

The O&M costs for the King's Dominion AGT system have not previously been published in the literature. The accounting system used by King's Dominion does not collect costs for specific attractions (e.g., the AGT system). Accounts are classified by function for the entire park (e.g., maintenance functions and operation of the amusement park). Consequently, maintenance data are not available in fine detail. Estimates presented here represent management's "best guess" of maintenance costs.

5.2.1 Maintenance Costs

All maintenance is performed by King's Dominion personnel. Of the park's maintenance staff of about 28 personnel, 3 are assigned full time to the AGT, 2 are mechanical specialists, and 1 is an electrical specialist. Supervision is provided by allocation of about 10% of a maintenance supervisor's time. The total maintenance staffing estimated for the AGT--3.1 man-years in 1976--cost about $60,800 (average wages for maintenance department were $7.34 per hour plus fringes of about 30%).

Daily maintenance functions include preparing trains for operation each day. The preparation of four trains for operation--the initial complement for each operating day--requires about 3.5 man-hours of labor. At least one maintenance man is on duty during the hours the AGT system is operational. When some trains are out of service, preventive maintenance is performed. During winter months when the park is completely closed or open only on weekends, ample time is provided for more intensive maintenance and inspection. A member of the maintenance staff estimated that two additional maintenance personnel would be required for year-round maintenance rather than the current 119 days of operations.

Maintenance material costs are not well documented. The initial spare parts inventory has been drawn down only slightly since the system became operational. Some common parts, however, are not UMI furnished. They are drawn from the common stock of parts maintained for all attractions at the park's central maintenance facility. Bus bar brushes, of which there are nine per train at a unit cost of $14 each, originally were replaced every three months. "Wear-in" of the power rails now, however, has reduced the frequency of replacement to an expected annual cycle. Tire replacement from wear-out has not yet been experienced. No funds have been budgeted for major repair or overhaul of equipment.* Spare parts and lubricants were estimated to cost only $4,000 in 1976.

5.2.2 Operations Costs

Operations costs for the AGT system include operating labor, janitorial labor, electricity consumption, and G&A. The latter costs cover the entire amusement facility, and an allocation for the AGT system was not furnished.

Operating labor consists of the staff to operate the ride. As with other amusement parks, high school and college students are employed at or near minimum wages. Labor cost including fringes--unemployment insurance, FICA, and worker's compensation--were $73,137 for about 34,000 labor hours.

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*On the site visit of 14 September 1977, the number 1 train has accumulated 2,198 operating hours. At an estimated average speed of 6 mph, only 13,188 miles had been traveled. This is representative travel for all trains as the operating policy is to roughly equalize operating times for the six trains. The reported maintenance costs may not be representative of future costs when wear-out items, such as tires and motor brushes, approach their service life.

Operating labor required at any one time varies as a function of the number of trains in service. Minimum and maximum operators are:

	1 Train	6 Trains
Ticket seller	1	1
Ticket taker	1	1
Crowd control		2
Train operator	1	6
Console operator		1
Passenger assistance	1	2
Exit guard	1	1
Total	5	14

Cleaning of the trains is performed by a two-person cleaning crew working two hours per day at an estimated cost of $12 per day, or $1,600 for the season. In addition, the maintenance crew washes the exterior of the trains on a weekly basis as a part of the scheduled maintenance routine. The operating staff also assists in cleaning of trains that are not in service during periods of slack time.

Electricity consumption is not separately metered for the AGT system. Total consumption for 1976 was estimated at 399,000 kWh by the King's Dominion staff. At an average cost of 4.25¢/kWh for peak demand and total energy consumption, the estimated power cost in 1976 was $17,000.

5.2.3 Summary of Operations and Maintenance Costs

Estimated O&M costs for the King's Dominion AGT system for 119 days of operation in 1976 are given in Table 5-2.

5.2.4 Unit Cost of Operations and Maintenance

To evaluate the operations and maintenance of the Lion Country Safari ride, four O&M performance measures were used: O&M cost per train miles of travel (TMT), O&M cost per passenger miles of travel (PMT), O&M cost per passenger, and O&M cost per place miles of travel (CMT). The calculations are based on 1976 O&M costs and the 1976 annual VMT,

Table 5-2

OPERATIONS AND MAINTENANCE COSTS:
UMI, KING'S DOMINION

Operations		
Labor	$ 73,100	
Cleaning	1,600	
Electricity (399,000 kWh)	17,000	
Total		$ 91,700
Maintenance		
Labor	60,800	
Material	4,000	
Total		$ 64,800
Total O&M		$156,500

Note: Figures are estimates provided by King's Dominion administration.

PMT, patronage, and CMT. The first three measures indicate the O&M unit cost in 1976; the last measure indicates the potential performance of the system.*

Unit cost per TMT	= $6.18
Unit cost per PMT	= 0.09
Unit cost per passenger	= 0.18
Unit cost per CMT	= 0.06

5.3 Escalation

The capital cost estimates are escalated to 1976 dollars using cost indices discussed in Appendix B. The total capital cost is $5,490,000 in 1976 dollars, of which $2,423,000 is for construction and $3,067,000 for hardware.

*In 1976, estimated train miles were 25,330, total passenger miles were 1,801,000, total passengers served were 872,700 and total capacity miles were 2,431,680 (see section 4.2).

5.4 Equivalent Annual Cost

The equivalent annual cost of capital was calculated by the capital recovery factor approach (see Appendix B). An annual discount rate of 10% was assumed. The service life of AGT components depends on many factors and must be estimated by planners for each new site. To achieve comparability among systems we have employed the same basic service lives for all sites: 15 years for hardware and 35 years for construction. We have also made calculations for optimistic service lives--20 years for hardware and 50 years for construction--to illustrate sensitivity of equivalent annual costs to service life estimates.

The lives of the two AGT systems used for recreation purposes are more subject to obsolescence than to wear. For accounting purposes, King's Dominion uses a 15-year service life for both hardware and construction. This estimate probably reflects the expectation that the entire attraction will become obsolete in 15 years rather than the potential physical service life of the system components per se.

Equivalent annual costs of capital for three service life assumptions are given in Table 5-3.

Table 5-3

EQUIVALENT ANNUAL COSTS OF CAPITAL: UMI, KING'S DOMINION
(1976 Dollars)

	Service Life (years)		Equivalent Annual Cost of Capital
	Hardware	Construction	
Basic estimate	15	35	$654,400
Optimistic estimate	20	50	604,500
Commercial estimate	15	15	721,700

5.4.1 Total Equivalent Annual Cost

The total equivalent annual cost of capital and operations and maintenance, for the basic service life assumption and in 1976 dollars, is given as the sum of the equivalent annual cost of capital and the cost of operations and maintenance. Thus total annual equivalent cost is $810,900 in 1976 dollars.

5.5 Unit Cost of Service

The unit cost of service prorates the total equivalent annual cost of capital and operations and maintenance over four measures of service--train miles traveled (TMT); passenger miles traveled (PMT); passenger trips (patrons); and capacity miles (CMT) for seated and standing passengers. The following figures were derived:

Unit cost per TMT	=	$32.01
Unit cost per PMT	=	0.45
Unit cost per patron	=	0.93
Unit cost per CMT	=	0.33

5.6 Recapitulation

The inputs and results of the economic analysis are given in Tables 5-4 and 5-5. Table 5-4 shows major cost data in 1976 dollars and the equivalent annual cost of capital. Table 5-5 shows the unit costs of service.

Table 5-4

CAPITAL AND OPERATIONS AND MAINTENANCE COSTS: KING'S DOMINION
(1976 Dollars)

	Capital Cost (actual year)*	Escalated Capital Cost	Equivalent Annual Cost	Annual Operations and Maintenance Cost	Total Annual Cost
Construction cost	$2,063,110	$2,423,000	$251,200	N.A.	
Hardware cost	2,538,890	3,067,000	403,200	N.A.	$810,900
Operations and maintenance cost	N.A.	N.A.	N.A.	$156,500	

N.A. = not applicable

*In 1974 dollars.

Table 5-5

UNIT COST OF SERVICE: KING'S DOMINION
(1976 Dollars)

	Per TMT*	Per PMT†	Per Passenger	Per CMT‡
Operations and maintenance cost	$ 6.18	$0.09	$0.18	$0.06
Equivalent annual hardware cost	15.92	0.22	0.46	0.17
Equivalent annual construction cost	9.92	0.14	0.29	0.10
Total equivalent annual cost**	32.01	0.45	0.93	0.33

*TMT = Train miles of travel.

†PMT = Passenger miles of travel.

‡CMT = Place miles of travel or unit capacity miles of travel.

**Total equivalent annual cost does not necessarily equal the sum of the three items above because of rounding off.

6 SYSTEM DEVELOPMENT PROCESS

6.1 Role of AGT

An AGT loop system at King's Dominion is used to transport visitors in an amusement park and through wild animal enclosures called Lion Country Safari. Initially, private automobiles were used within the enclosures, but that practice created numerous problems for visitors, animals, and park employees. Walking and use of open vehicles are not acceptable alternatives. An AGT system with enclosed vehicles was installed as part of an expansion and conversion program to replace private automobiles on park roads within the enclosure.

6.2 History and Initiation

King's Dominion was constructed in two stages. Lion Country Safari was the first installation at this site. Planning for the addition of an amusement park adjacent to the animal enclosure began in late 1972. The two facilities were integrated and the AGT system was included in the design. Two companies were associated in this venture: Family Entertainment Inc., a subsidiary of Taft Enterprises, and Lion Country Safari, Inc.

6.3 Planning and Design

The details of the decision to add a full-scale amusement park at the site are not available. Once that decision was made, the decision to use AGT rather than automobiles was logical since use of AGT allows pedestrians inside the park to tour the wild animal area without the need to leave the park and return to their automobiles. There is an additional advantage in that increased capacity could also be achieved with AGT. Finally, an automated system with a narrator on board was chosen to save labor cost. A manually controlled system would have required both a narrator and an operator.

Design of the technical equipment and facilities was the responsibility of the supplier. The civil installation was designed and built with the aid of the owners' engineers and with some assistance from outside consultants. Design drawings were begun on April 24, 1973--one week after UMI had been selected as the supplier. The guideway alignment was completed in two weeks and was approved on May 8, 1973. This rapid progress was possible because much of the guideway alignment was at grade and parallel to the existing roadway. Final grading plans were approved on September 18, 1974. Design of other elements of the park proceeded in parallel.

6.4 Acquisition

Potential suppliers were selected and interviewed in early 1973. The participating companies were:

- Westinghouse Electric
- Rohr Industries
- Arrow Development
- Universal Mobility.

Unlike typical procurements by public agencies, there was no formal specification or bid process. Westinghouse was eliminated early in the discussions because its vehicles were too large and its system too costly. The final selection of UMI resulted from a series of three-way discussions among Lion Country Safari, Family Enterprises Incorporated, and UMI. A contract and price were agreed upon during these discussions. Representatives of the buyer said that UMI won because they were more responsive to the users' needs than other firms although their price was not the lowest. A letter of intent was issued April 17, 1973. A contract was negotiated with UMI during the summer and was signed on September 18. Under the contract, UMI designed and furnished vehicles, special wayside hardware, guideway, and power distribution systems. The owner designed and constructed facilities and installed the hardware.

Ground was broken on October 9, 1973. A work force of 300 park employees constructed the entire park, including the AGT guideway and station, and installed the AGT system with the assistance of one UMI employee on site. UMI delivered the first train in late summer 1974. On-site assembly of the train began on September 3, 1974 and was completed on January 28, 1975. On March 4, 1975 operation of two trains and debugging work began on a section of completed guideway. Completion of the remainder of the approximately 10,900 ft of guideway was delayed briefly by late delivery of fabricated steel. However, on April 8, 1975 four trains were in operation over the entire track. The park opened April 29, 1975 with five nine-car (96 passenger) trains (of the six ordered) available for service. The chronology of system development is provided in Appendix C.

The following firms were major participants:

Owner/Operator

Family Entertainment, Inc.

Lion Country Safari, Inc.

System Supplier

Universal Mobility Incorporated

Competing Firms

Westinghouse Electric

Rohr Industries

Arrow Development Corporation

6.5 Finance

The AGT system was financed as part of the entire project. Funds were from private sources. Details are not available.

7 CONCLUDING REMARKS

The UMI Type II Tourister AGT system at King's Dominion is evidently in a mature state of development. It is reliable, economical, and serves the needs of the operator. The system is less completely automated than some of the other AGT systems assessed by SRI. Important functions performed manually are vehicle door operation and train dispatch at the station.

The control system used at King's Dominion is appealing because it uses a simple, unified concept to accomplish train control, train protection, and station stopping. While there is no apparent reason why this system could not function effectively at higher speeds, some of the system simplicity may be compromised in a more complex guideway network. The control system has been reliable and satisfactory.

One of the most troublesome system components is the doors, which tend to become misaligned so that they do not open and close properly. The representative of UMI indicated that improved door mechanism has been incorporated in their newer vehicles.

Appendix A

AGT ASSESSMENT MEASURES: KING'S DOMINION

This appendix provides a detailed check-list of assessment measures associated with the description and performance of the King's Dominion AGT System. The descriptive measures essentially provide the basic facts about the design of the system. The performance measures provide data associated with system operations. The statements under the column heading "user" are qualitative descriptions about the system from user's point of view. The statements or numbers under the heading "operator" reflect the operational features of the system generally in quantitative terms. These were either provided by the system operators or were calculated by SRI team using some basic data provided by the operators. Much of the information presented in this appendix has been extracted from the main body of the report. Some of the information presented in this appendix may not be found in the main body of the report. Such information was either gathered independently or was inferred from the data in the main body of the report.

Appendix A

AGT ASSESSMENT MEASURES: KING'S DOMINION

Descriptive	User	Operator
1. System sizing		
Fleet size		
Total		6 trains
Peak-hour operating		6 trains
Off-peak operating		1 train
Number of vehicles per train		
Maximum		8 passenger cars and 1 lead control car per train
Peak hour		6 trains are operated during peak periods
Off peak		Fewer trains during off peak, depending on demand
Number of stations	1 station	1 station
Guideway configuration		
Closed loop or other		Closed loop; off-line maintenance area
Length		10900 ft of which 550 ft is elevated, rest at grade
Bidirectional service		Automatic-unidirectional; bidirectional in manual*
Station occupancy		1 train/station
Employees		Equivalent to 14
2. System costs		
Capital costs (construction and hardware)		
Engineering, architecture and project coordination		$1,232,710
Guideway, tracks, switch and transfer table		$933,110
Stations		$151,000 total cost
CC&CS		$28,340
Power supply and power rail		$270,200
Vehicle		$1,842,940
Maintenance facility and equipment		$143,700
		(1974, Based on data in Table 5-1) Total = 4,602,000
3. Technical description		
System description		
Gradeability		6-8%
Line capacity		
Seat		1800 passengers/hr (maximum)
Standee		No standees allowed
Crush		Not applicable
Degree of automation		
Employee-to-Vehicle Ratio		5 persons/train
System man-hour to VMT ratio		5.4 man-hours/train-hour
Fare collection		$1.50 collected manually
Existing automated operation		The train starts and runs automatically after push button closing of doors
Strategies		
Peak hour		
Off-peak hour		
Elderly and handicapped accommodations		Wheelchairs cannot be accommodated*
Operational speed	Slow enough to view animals well‡	5.0 ~ 6.2 mph average speed including stops†
All-weather capability		Rain;* light snow (no snow removal); wind gusting to 120 mph*
Subsystem description		
Vehicle		
Weight (empty and maximum design)		≠ 1900 lb empty, 5400 lb maximum
Dimensions (length, width, height, wheelbase, etc.)		≠ 12.17 x 6 x 7.4 ft
Design life (with average mileage per year)		Not available
Capacity		
Seated		12 seats/vehicle
Standee		None
Crush		None

*Data supplied by the management or operator.

†Estimate by the operator.

‡Data collected by SRI by observation of installation or passengers.

§Calculated result based on given information.

Descriptive	User	Operator
Speed		
Maximum		6.5 mph*
Onboard heating		Electric, hot water*
Onboard cooling		26,000 Btu Chrysler Air-Temp unit aboard front vehicle*
Onboard illumination		None, external fluorescent lighting and mercury night lights are used to view animals at night
Command, control and communications		
Hardware		Onboard Autopilot; directional signal rail≠
Software		None*
Vehicle control and management		
Operational control strategy		Continuous circulating trains
Headway protection		Fixed blocks with vehicle mounted autopilot
Merge strategy		Not applicable
Service policy		Continuous service
Routing policy		Not applicable
Empty vehicle management strategy		Not applicable
Dispatching policy		Number of trains on the loop are adjusted in response to demand
Failure management		Failed train is pushed by another train if feasible, otherwise passengers are evacuated
Steering		4 solid guidewheels per bogie bearing on guideway web*
Switching (captive/noncaptive)		Captive segment substitution*
Propulsion		280 V dc, 7.5 hp motors, 8 motors/train*
Power		480 V 3 phase ac*
Suspension		No secondary suspension system
Guideway		Two steel I-beams*
Stations		1 station, open-sided cement slab with roof*
Passenger information		Typical amusement ride, primarily audio
Braking (normal, backup, emergency)		Regenerative normal mode; spring-applied friction for emergency and station holding; no other backup.*
4. Service characteristics		
Levels of service		
Comfort		
Temperature		
Humidity		
Lighting		
Heating and cooling		26,000 Btu/hr ac unit on each train
Air Circulation		
Periods of operation		
Hours per day	10-12 hr/day*	10-12 hr/day*
Days per year	133 days/year*	133 days/year*
Accessibility or area coverage		Serves the Amusement Park Visitors
Patronage		6,562 passengers/day§ (1976)

Performance	User	Operator
1. Sociological		
Levels of service		
Comfort		
Seating room area	Ample‡	4 ft^2 per space seating*
Standing room area	None†	None
Seat availability (peak, off-peak)	Passengers not permitted to board unless seats available‡	
Lighting	Satisfactory‡	
Heating and cooling	Satisfactory‡	
Air circulation	Satisfactory‡	
Satisfaction	Very high‡	Less than 1 consumer complaint/month†
Ride quality	Good‡	
Convenience		
Transfers	N/A	
Service quality		
Frequency of service (peak, offpeak, policy, demand actuated)	3-18 departures/hour†	Mean headway = 225-1350 sec†
Mean wait time		Mean wait time = 1.5-10 min§
Average trip speed		6.0 mph†
Maximum trip speed		6.5 mph†
Cruise trip speed		6.5 mph†

Performance	User	Operator
2. Economics		
Capital costs		$4.6 million (1974); $5.49 million (1976 dollars)
Operating and maintenance costs		$156,500 (1976)
Per passenger		$0.18 (1976)
Per passenger mile traveled		$0.09 (1976)
Per train mile traveled		$6.18 (1976)
Per seat mile		$0.06 (1976)
Maintenance		
Labor		$60,000 (1976)
Materials		$ 4,000 (1976)
Operations		
Conducting transportation		$73,100 (1976)
Energy		$17,000 (1976)
General and administrative		Not available (1976)
Life cycle costs		$810,900/year; 35 years construction life; 15 year hardware life
Travel cost (fare)	$0.73 trip cost mi§	
3. Environment/land use/energy/safety and security		
Environment		
Impact	Frequent conflicts with animals‡	
Noise	Quiet‡	75 dBA (vehicle interior); 84-92 dBA with announcements and background music
Air pollution		Not applicable
Aesthetics	Attractive‡	
Urban disruption		Not applicable
Land use		
Guideway space requirements		0.38 acres/guideway mi§
Stations		0.126 acres/guideway mi§
Maintenance and other facilities		Not calculated
Energy		17.5 kWh/train mi§
Safety and security (on system versus off system)		
Accidents	2 incidences in 3 years	See section 4.6
Fatalities	None	None*
Injuries		See section 4.6
Assaults	None	None*
Vandalism	None†	None*
4. Operational and technical performance		
System		
Elderly and handicapped		
Accommodations	Cannot accommodate wheelchairs*	
Ease of use	Attendants available to help‡	
Routing efficiency		Not applicable
Vehicle load factor		0.74 (Annual Average, 1976)
Vehicle productivity		23 passengers/vehicle hour
Labor productivity		120 place miles/man hour
Operating cost productivity		Data not available
Availability		
Subsystem availability		Data not available
Traditional availability		Data not available
Proportion of delay (vehicle based)		Data not available
Successful trip ratio (vehicle based)		Data not available
Total system availability (traditional)		0.993
Subsystem		
Vehicle		
Acceleration		2 mph/sec
Deceleration (service and emergency)		2 mph/sec (service); 4.4 mph/sec (emergency)
Speed		
Line (peak and off peak)	Good for viewing animals‡	6 mph
Vibration (stationary vehicle)	Negligible‡	Not measured
Noise	Noise in front car only	75dBA (vehicle interior)

Performance	User	Operator
Jerk		
Acceleration		2 mph/sec^2
Deceleration		2 mph/sec^2
Tire life (where applicable)		Low guidewheel tire life*
Command and control		
Acceleration		2 mph/sec
Deceleration		2 mph/sec
Speed		6 mph
Stopping Accuracy		Mean deviation = $\pm$ 6 in
Headway		Upper bound free; lower bound to 300 ft
Steering		
Lateral ride quality	Sliding is perceptible‡	Not measured
Steering member wear		Negligible
Switching		
Response time		20 sec = response time*
Noise	Quiet‡	Sound pressure level = 76 dBA‡
Vehicle vibration	Negligible‡	Not measured
Propulsion and braking		
Tractive effort		Empty: 0.148 lb force/units of weight§
Power distribution system		
Power pickup wear		6.7×10^{-9} in./1,000 mi of vehicle travel§
Electromagnetic interference		Not measured
Voltage regulation		Not measured
Guideway		
Condition	Satisfactory‡	No derailments*
Roughness characteristics	Satisfactory‡	No wheel wear*
Maximum dynamic load		Not measured
Stations		
Dwell time		Mean time controlled by station attendant*
Throughput		2270 passengers/hr (based on average annual load fac
Comfort	Satisfactory	
Capacity (16 departures/hr)	High‡	3072 passengers/hr§ (boarding and deboarding)
Information and graphics	One sign, unobtrusively positioned‡	
Access and egress	60 sec†	
Train screens	None‡	
Fare collection		
Ease of use	Simple‡	
Service capacity		
System and subsystems		
Maintenance requirements		
Equipment		No special equipment needed
Labor		0.163 man hrs/veh-hr
Operating requirements		
Labor		0.44 man hrs/veh-hr
Reliability		MTBF = 96.5 hrs
Maintainability		MTTR - 48 min
Service life		Assumed 15 years for hardware; 35 years for construction

Appendix B

METHODS OF COST ESTIMATING AND ANALYSIS

Objective

One objective of the assessment of six existing AGT systems was to collect and present cost information on these systems in a manner that would be useful to planners of new AGT systems in the Downtown People Mover program and in other urban settings.

Various Problems and Aspects Associated with Cost Analysis

To approach the objective, a number of problems and aspects--both practical and theoretical--had to be taken into account, as discussed below.

Historical cost data obtained from published reports and by inquiries addressed to owners and participants in AGT system development projects are often incomplete or otherwise unsuitable, as guidance or indicators, for planners of future systems. Costs of some items are incorrectly reported or omitted. Separate costs of some items are not obtainable because the AGT facility was built as an integral part of a multipurpose facility. Where necessary, cost estimates have been derived by SRI staff members and consultants.

Urban settings for AGT systems are the main focus of interest in this research but none of the six AGT systems studied is in a typical urban setting--three are in airports, two are in recreation parks, and one is in a multipurpose commercial development owned and operated by private interests. The research staff has taken various measures to recognize possible differences between the actual settings observed and typical urban settings. Planners of new AGT systems are urged to pay particular attention to the stated conditions associated with cost estimates prepared for each site, and to make needed changes in cost estimates to fit the actual conditions of local sites.

Price changes must be taken into account to make cost data from different years useful to planners. AGT systems and their components were purchased or constructed in different years and at different price levels. Escalation adjustments have been made to state all capital cost estimates at 1976 price levels. Capital costs for each system are stated in 1976 dollars.

Total equivalent annual costs is the most convenient format for presentation of cost data on the six systems. However, initial capital costs are incurred in lump sums, and long intervals pass between replacements of capital assets while operating and maintenance costs are incurred year-by-year. To make these estimates commensurate, capital costs have been restated as equivalent annual series amounts for assumed service lives and interest rates. The result is equivalent to the uniform annual payment that would be needed to repay a loan with interest by the end of the series life. Equivalent annual costs of capital and annual operating and maintenance costs can then be added to produce total equivalent annual costs.

Unit costs of service per vehicle mile, per passenger mile, etc. are quite useful in making comparisons. These are computed by dividing total equivalent annual costs by measures of service performed.

Growth or decline in costs of operation and in amounts of service rendered are likely to occur from year to year during the life of each AGT system. For example, patronage and costs may increase for many years, then level off, and finally decline as the AGT system or the entire facility approaches obsolescence. Growth and decline are site-dependent characteristics--the experience of an existing site will seldomly, if ever, apply at another. Therefore, growth and decline have not been treated in this research.

Discussion of Terms and Parameters Used in Cost Analysis

A discussion of several terms and parameters used in the cost analysis is presented below. Values of various parameters used in the study are also mentioned where applicable.

Joint-use and multipurpose refer to facilities and services shared by an AGT system and one or more additional functions. An example is an AGT station located within an air terminal building.

Free-standing and independent refer to facilities and services provided solely for an AGT system such as an AGT maintenance facility.

Conceptual design or duplicate facility refers to a hypothetical free-standing or independent AGT system designed solely for transit service. It is functionally equivalent to the transit portion of a system having joint-use or multipurpose characteristics. This concept allows estimation of costs of an AGT system without the need for division of costs among an AGT system and other functions.

Actual cost is the dollar amount paid for a specified asset or service.

Allocated cost is a division of the cost of a joint-use facility or multipurpose service among numerous functions and is usually based on some estimate of the percentage of use. For example, if an AGT station occupies 1% of the space in a shopping mall, one might say that the allocated cost of the station is 1% of the cost of the entire building complex. Allocation of costs is common in accounting practice, but cost allocations made for one site will seldom be well suited for decision making at another site. Therefore, allocated costs must be used with caution.

Marginal cost is an estimate of the additional cost or cost increment made necessary by the addition of an optional function, such as an AGT station, to an existing or planned facility, such as a hotel or office building.

Duplicate cost is an estimate of the cost of a hypothetical duplicate facility discussed above. In this study it is the estimated cost of duplicating the essential AGT functions observed in an existing joint facility at a hypothetical new site where the AGT system could be independent or "free standing."

Price indices are factors used to adjust estimates of costs of assets acquired in given years to the price levels of a common year--1976 in this research. Indexes and escalation procedures must be used with care to avoid introduction of serious errors. This is especially true when systems having dissimilar characteristics--such as buses and AGT systems--are to be compared. In this work separate indices are used for three cost categories:

- Hardware
- Construction
- Professional and administration services.

The selection of various indices was made in consultation with UMTA and its subcontractors. A brief description of various indices is given below.

Hardware--The Wholesale Price Index for Machinery and Motive Products is used to escalate all hardware costs including vehicles; command, control, and communications; power distribution system; station equipment; and power rails.* Commodities included in this index are:

1. 42%--Electrical machinery and equipment: wiring, integrating instruments, motors, transformers, switchgear, electronic components, and accessories.
2. 14%--General-purpose equipment: elevators, escalators, mechanical power transmission equipment, conveyor belts, monorail conveyors, valves, and bearings.
3. 14%--Tools: metal working tools and machine-shop products.
4. 8%--Heavy equipment: tractors, construction equipment.
5. 22%--Miscellaneous equipment: mining, textile, food, woodworking, printing industries.

Construction--The Engineering News Record (ENR) Construction Cost Index for 20 cities is used to escalate all construction costs including guideways, stations, utilities, maintenance, and support facilities. The components included and their relative weight in the index are (1) base price of structural steel shapes (38%); (2) consumer's net price of cement exclusive of bag (7%); (3) lumber (17%); and (4) common labor rate (38%).

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*The selection of this index is based on MITRE letter to UMTA, # W24-3789, Subject: "Inflation Rates for AGT Socio-Economic Research Program," 27 July 1977.

Table B-1

COST INDICES FOR ESCALATING AGT CAPITAL COSTS

Year	Hardware (Wholesale Price Index for Machinery and Motive Products) Index	Hardware Conversion Factor to 1976 Prices	Construction (Engineering News Record Construction Cost Index for 20 cities) Index	Construction Conversion Factor to 1976 Prices	Professional Services (Consumer Price Index for Urban Wage and Clerical Workers, U.S. City Average) Index	Professional Services Conversion Factor to 1976 Prices
1965	--	--	91	2.45	--	--
1966	--	--	95	2.35	97.2	1.75
1967	100.0	1.66	100	2.23	100.0	1.70
1968	103.0	1.61	108	2.07	104.2	1.63
1969	106.0	1.56	119	1.87	109.8	1.55
1970	110.6	1.50	130	1.72	116.3	1.46
1971	115.3	1.44	148	1.51	121.3	1.40
1972	118.2	1.40	164	1.36	125.3	1.36
1973	121.2	1.37	177	1.26	133.1	1.28
1974	136.3	1.22	188	1.19	147.1	1.16
1975	156.2	1.06	206	1.08	161.2	1.06
1976	165.8	1.00	223	1.00	170.3	1.00

Source: N. D. Lea and Associates, Inc.

Professional and Administration Services--The Consumer Price Index for Urban Wage Earners and Clerical Workers, U.S. City Average, All Items is used to escalate all costs for professional services such as A&E, design, project management, systems integration, and acceptance testing.

Service life is the period of service expected of an asset. Service life may be determined by wear or exhaustion of the asset or by obsolescence of the entire facility. Equivalence calculations start with the service life of the AGT subsystem having the longest expected life--usually the structures. Subsystems with shorter service life are assumed to be replaced at the same initial cost, stated in 1976 dollars. The selection of service life is based on experience and judgement.

Two sets of service life assumptions have been made for all systems. One, characterized as "basic," uses 15 years for hardware and 35 years for construction. A second, characterized as "optimistic," uses 20 years for hardware and 50 years for construction. In addition, a third set, characterized as "commercial", uses lives of 15 years for both hardware and construction and was applied to the two recreation parks--King's Dominion and Disney World. These short lives refelct the possibility that obsolescence, rather than use and deterioration, will determine the end of service.

Salvage value is the expected value of an asset at the end of the service life. Salvage values are neglected in this analysis.

Discount rate is the time value of money to the owner of an AGT system or the rate of interest that would be attractive for a given investment in an AGT system. A discount rate of 10% was used in the study, this being a typical discount rate currently prevailing. However, planners should use the rate predicted to be available for the specific case.

Equivalent annual cost of capital, R, is found by the following equation:

$$R = P\left[\frac{i(1 + i)^n}{(1 + i)^n - 1}\right]$$

where

P = capital cost

n = service life

i = discount rate.

Operating and maintenance costs are annual outlays for goods and services required by AGT systems.

Total equivalent annual cost is the equivalent annual cost of capital, R, plus the cost of operations and maintenance.

Cash flow analysis is not employed in this report but would be an appropriate tool for certain purposes. For example, cash flow analysis is required to determine fare structure adequate to repay capital and interest and to recover operating and maintenance costs. If a cash flow analysis is desired, all cash receipts and outlays must be estimated for each time period over the life of the system. For example, actual cash expenditures for interest must be used, rather than the discount rate used in equivalent annual cost calculations.

Some Specific Comments on Capital Cost Estimates

AGT systems include numerous items or groups of capital assets, and there is no uniformity among systems in the breakdown of systems into subsystems, components, and so forth. However, it has been possible, with fair accuracy, to classify assets under three headings--professional and administrative services, hardware, and construction.

Professional and Administrative Services--Detailed historical records of the cost of consultants and administration were usually not found. In such cases these costs were calculated as a fraction of the cost of major assets in consultation with the system designers.

Hardware--Estimates of hardware costs obtained from the AGT sites appear to be reasonably complete and dependable. AGT hardware was usually purchased for cash under one or a few contracts. It is noteworthy that published reports of hardware costs usually cite the price bid by the system supplier, rather than the final contract amount. Consequently, the published figure often omits such elements as the costs of change orders and items furnished by other suppliers. Data obtained from accounting records were usually considered dependable and were used.

Right-of-way was not purchased for any of the systems studied. In each case, the AGT system occupies a small part of a large parcel of land acquired to serve a broad variety of purposes. Right-of-way costs will differ greatly among urban sites, and may be quite substantial in certain cases. Where owners have used the allocation technique to estimate a right-of-way cost to meet accounting needs, that estimate is reported.

Site preparation costs are included in the analysis in those cases where historical data were found. However, where the data were lacking, estimates were not derived by the research staff.

Utility relocation was not encountered as a cost factor in any of the systems studied. Again, urban sites will differ greatly in this respect and gain little from the experience of the six AGT systems treated in this research.

Construction costs for civil works--mainly tunnels, elevated structures, and stations--have presented the most difficult cost-estimating problems. Available historical data of dependable quality were always used. In several cases the cost of major elements of the civil works had never been estimated by the owner (or anyone else) until the restudy stage of this research. This lack of data is understandable. In many instances an AGT facility element was incorporated into the design and construction of another, much larger facility. In such cases there is no theoretically correct way to identify the cost of the AGT facility and, in some cases, no need to make a cost allocation. Only a few owners treat AGT systems as profit centers and have a need to account for the cost of the AGT system.

To overcome the lack of historical data, special studies have been made to derive construction cost estimates. These estimates fill data gaps and present a complete--but qualified--cost picture for use by planners of future AGT systems. Three main approaches are available to estimate construction costs:

- Duplicate Cost Approach. Costs are estimated by assuming free-standing duplicate facility with appropriate dimensions.
- Allocation Cost Approach. Costs are estimated by allocating a suitable fraction of the total cost to AGT system.
- Marginal Cost Approach. Costs are estimated as the additional cost that must have been incurred because of the inclusion of the AGT system.

In the present study, one or the other approach was used where appropriate.

Appendix C

CHRONOLOGY OF EVENTS: KING'S DOMINION

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1972 Planning began for the addition of an amusement park (to be called King's Dominion) next to Lion Country Safari. Planning included an AGT system through the Safari portion of the park.

1973 Potential AGT system suppliers were interviewed in January.

Discussions between the potential vendors and Universal Mobility Inc. (UMI) were conducted in January and February.

UMI won the competition, and a letter of intent was issued on April 17.

Design of the AGT site and route alignments began on April 24.

Guideway alignment was approved May 8.

Final grading plans were approved June 26.

Contract with UMI signed September 18.

1974 Construction of the amusement park began.

UMI delivered the first unassembled train in late summer. Assembly began on September 3.

1975 First train assembly completed on January 24.

Construction completed on January 25.

On-site testing and debugging of two trains began on March 4.

Four trains operating over the entire track by April 8.

The park opened April 29, with five of the six trains ordered available for service.

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☆ U. S. GOVERNMENT PRINTING OFFICE : 1978—724-272/1165