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Radio Frequency Deicing of Collector Rails for AGT Systems

RICHARD KWOR AND PRATUL AJMERA

Radio frequency (RF) induction heating has been proposed as an alternative deicing technique for automatic guideway transit (AGT) collector rails under adverse weather conditions. The concepts of a practical RF deicing system are discussed. A working frequency of 450 kHz is used for the RF generator, and 430 magnetic stainless steel is selected as the rail-capping material for efficient coupling. Experimental setup for a model RF deicing system is described. With 2.5-kW RF generator power, successful deicing was accomplished up to a rail speed of 3.2 km/h for rail temperatures as low as -30°C. The performance of this test system is assessed, and possible future improvements are suggested.

In recent years, many automatic guideway transit (AGT) systems have been developed. These systems are designed to transport people and cargo over short distances safely and automatically. In general, they all employ sophisticated computers and other electronic equipment to provide operational efficiency and flexibility. Under normal weather conditions they are very reliable. However, frequent shutdown does occur during periods of severe cold weather. One of the main reasons for system failure is the interruption of power and signal communications due to frost and ice formation on the collector and conductor rails. Icing of power and/or signal rails occurs frequently and often before the loss of traction due to winter weather.

Various snow- and ice-control methods have been adopted or suggested (1). Most of the feasible approaches fall into one of the following categories:

1. Rail heating,
2. Covered rails,
3. Mechanical scraping,
4. Spraying with chemicals,
5. Modified collector brush and modified rail, and
6. Inductive control (contactless pickup).

The last method--inductive control--has been used in several systems (1) and has proved to be quite successful in minimizing the effect of ice on signal communication. For systems that use direct physical contact for signal pickup, other methods in the above list are more appropriate. One method that has had limited success is direct rail heating. Rail heating, which uses electrical resistance elements, was tried in several AGT systems (1-4). Other deicing techniques that use advanced technologies such as lasers, microwaves, or ultrasonics have been suggested, and some research is under way (5) to investigate their effectiveness.

In this paper, a novel deicing concept that uses an old, well-known phenomenon in electrical engineering is described. The basic idea is to heat the top surface of the collector rail with radio frequency (RF) energy, which creates a thin layer of water at the interface between the ice and the rail. The loosened ice can then be easily scraped away with a mechanical scraper. RF induction heating is efficient in several respects. First, the heat is generated within the top few micrometers from the rail surface right where it is needed and, hence, little is wasted by being transferred to the ambient. Second, modern RF generators have respectable conversion efficiencies. Third, this deicing system is very responsive in that rail surface temperature changes occur rather rapidly. There are other advantages that will be discussed later in the paper. With proper choice of frequency, rail material, and work coil design, effective rail deicing at moderate vehicle speeds and subzero ambient temperature is possible with input power as low as a few kilowatts.

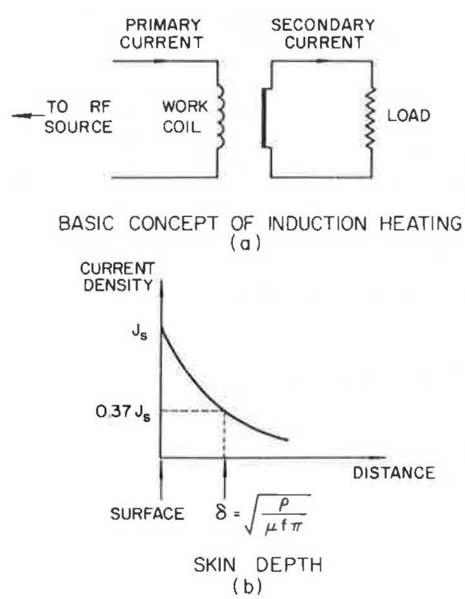
This paper reviews the basic theory of RF heating and presents the RF collector rail deicing system concepts. Important designing criteria are provided and discussed. Deicing experiment results that use a prototype RF system are reported. Finally, areas for future system improvements are suggested.

BASIC THEORY OF RF INDUCTION HEATING

Induction heating is based on three main principles: electromagnetic induction, "skin effect", and heat transfer. The basic concept of induction can be shown to be similar to the well-known transformer theory. An alternating current is passed through the primary coil (called the work coil) in the neighborhood of the work load, which can be considered to be a single-turn, short-circuited secondary winding (Figure 1a). The current in the work coil develops a magnetic field that induces an electric current in the secondary circuit. Because of the high turn ratio, the current (I) induced in the secondary circuit will be high and considerable loss in the form of I^2R heating will develop in the load, thus raising its temperature.

In magnetic materials, there is another form of loss called the hysteresis loss, which may also contribute to the heating. The induced current falls off from the surface to the center of the work load, and the rate of decrease is higher at higher frequencies. The rate is also dependent on two proper-

Figure 1. Basic concept of induction heating and skin depth.



ties of the material, namely, the resistivity (ρ) and the relative permeability (μ). The term skin depth is the depth where the current density has fallen to 0.368 (1/e) of its surface value (Figure 1b). The skin depth (δ) is related to frequency and material properties by the following equation:

$$\delta = \sqrt{\rho/\mu f \pi} \quad (1)$$

At high frequencies, the skin depth will be small and the induced current will concentrate near the surface, which results in rapid surface heating. Of course, part of the heat generated will be conducted into the rail away from the surface, thereby reducing surface heating. For optimal performance, therefore, some form of insulation may be helpful. This will be discussed in more detail later.

The skin depth for primary current (current in the work coil) is also small at high frequencies and some heating results in the work coil, which must thus be water cooled. Because the main objective is to maximize the heat in the load, coil losses must be kept to a minimum, i.e., the coil must be designed for maximum efficiency. The coil efficiency (η) is defined as

$$\eta = P_{work}/(P_{work} + P_{coil}) \quad (2)$$

where P_{work} is the power loss in the work load and P_{coil} is the power loss in the coil.

An approximate expression for the idealized coil efficiency relation can be written as follows:

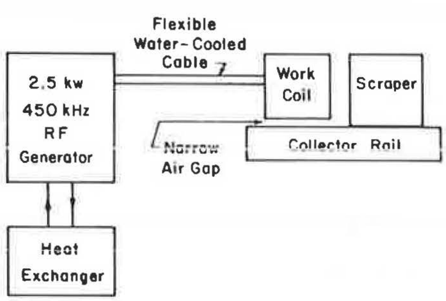
$$\eta \cong 1/(1 + \sqrt{\rho_c \mu_c/\rho_w \mu_w}) \quad (3)$$

where ρ_c and ρ_w are the resistivities for the work coil and the load, respectively, and μ_c and μ_w are the relative permeabilities for the work coil and the load, respectively (6). Thus, for best efficiency, the work coil should be made of silver-plated copper, which has a low ρ_c and a unity μ_c. In addition, the work load should be made of a high resistivity and permeability material such as steel. A more detailed account of the choice of coil and rail materials is given in the next section.

RF DEICING-SYSTEM CONCEPTS

The basic RF deicing system is shown in Figure 2. It consists of an RF generator, a flexible RF power cable, a work coil, a mechanical scraping attachment, and a heat exchanger. For the generator, the major decision criteria are frequency and power level. A reliable deicing system should work in severe weather conditions with ambient temperatures as low as -30°C. Under these conditions, ice may form from atmospheric precipitation, wet splashes, or even moisture in the air. To completely melt the ice layer becomes increasingly expensive as the thickness of ice is increased and the temperature is decreased. Even at moderate speed, an enormous amount of energy is needed to raise the temperature of the ice from a subzero temperature to freezing point to supply the necessary latent heat of fusion for melting and to compensate the heat lost through conduction and convection. At 56.4 km/h, for example, just for the melting process alone, approximately 200 kW of power must be supplied to a 0.32-cm-thick layer of ice atop a typical signal rail. It is beyond any doubt that completely melting the ice on the rail is not a cost-effective approach.

Figure 2. Basic components of RF deicing system.



An ideal solution will be to melt a thin layer of ice at the rail and ice interface, thus breaking the ice-rail bond. The rest of the ice is then removed by a subsequent scraping operation. Because of the nature of RF heating, this ideal situation can largely be achieved. By choosing a relatively high frequency, i.e., a frequency between 10 kHz and 1 MHz, the skin depth can be made very small. As a result, most of the energy is dissipated in the top thin layer of the rail next to the ice, which results in rapid heating and melting of the interface ice layer. Because the heat is very much localized and is generated where it is most needed, the RF deicing system is inherently efficient.

Initial estimates show that an RF generator with output power less than 10 kW should be adequate for typical AGT rail deicing. Moreover, the conversion efficiency for the RF generator itself is very high; thus, the overall system efficiency [from the alternating current (AC) power line to heat in the rail] should be quite respectable. As mentioned earlier, this efficiency is very much dependent on coil design and rail material. The coil-load coupling efficiency is of critical importance in the overall system performance. This point will be addressed further later.

Modern RF generators use solid-state silicon-controlled rectifiers (SCRs) as the rectifying elements. Hence, these generators are compact, rugged, and reliable and are suitable to be vehicle mounted. However, the oscillator tube of the generator and the work coil itself must be water cooled. The deicing system thus requires a closed-circuit water circulation system--namely, a heat exchanger. The RF power from the generator is delivered to the work coil via a flexible water-cooled coaxial cable specially designed for the best power transfer.

EXPERIMENTAL SETUP

Experiments were designed to test the feasibility of the RF deicing technique and to establish guidelines for future prototype designs of an AGT RF deicing system. Figure 3 is a sketch of the experimental setup. The RF power from the Lepel 2.5-kW, 450-kHz generator is fed via a water-cooled coaxial cable (made by L.C. Miller Company) to the work coil, which is enclosed in an environmental chamber. The coil is of a multiple-turn pancake shape, which is designed to deliver energy efficiently into the rail and at the same time to ride freely over the rail surface.

A square-shaped copper tube is employed in the construction of the coil (Figure 4). Because the distance between the coil and the rail must be small for high energy transfer efficiency, the coil is coated with epoxy to prevent spark-over caused by the water on the rail. In order to simulate the relative motion of the coil with respect to the rail, the latter is pulled by a motor through a pulley system. The maximum speed attainable for this setup is about 3.2 km/h. As was discussed earlier, the best coil efficiency is obtained with a work piece made of high-resistivity and high-permeability material.

Our test rail is a modified version of the new rails designed to be used in Vought Corporation's Airtrans system installed at the Dallas/Fort Worth Airport. It is made of stainless-steel-clad aluminum (Figure 5). Such a rail has many advantages over the old copper-clad steel-rail system used earlier, especially in the RF deicing application.

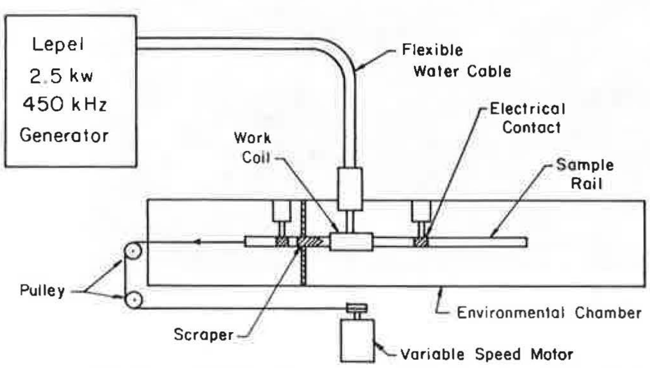
For the Airtrans system, 304 nonmagnetic stainless steel has recently been used to replace the old copper-clad rail. For our experiment, 430 magnetic stainless steel is used. Except for the magnetic properties, this steel is roughly similar to the 304 steel in corrosion resistance, strength, and other mechanical properties (7). Like the 304 stainless steel, the 430 steel is also a general-purpose type and is easily available.

Sample rails (with cross section shown in Figure 5) were made. Deicing experiments were performed by using the 430 steel-clad rails. A rail with a 304 stainless-steel cap was also used for the purpose of comparison. Because steel is a relatively good thermal conductor, some of the heat generated near the surface of the rail is conducted to the bulk of the rail, which decreases the overall deicing efficiency.

It is estimated that some form of insulation beneath the stainless-steel cap may slow the conduction process and help to increase efficiency (8). Hence, two modified sample rails were made, one with a hollow cavity beneath the cap and the other with asbestos insulation (Figure 6). These rails were used in our experiments to determine the effectiveness of insulation.

For some experiments, the ambient temperature around the rail must be maintained at a constant subzero point. This is accomplished inside the environmental chamber, which is a long wooden box insulated with thick styrofoam and cooled by a stream of cold air.

Figure 3. Experimental setup for RF deicing system.



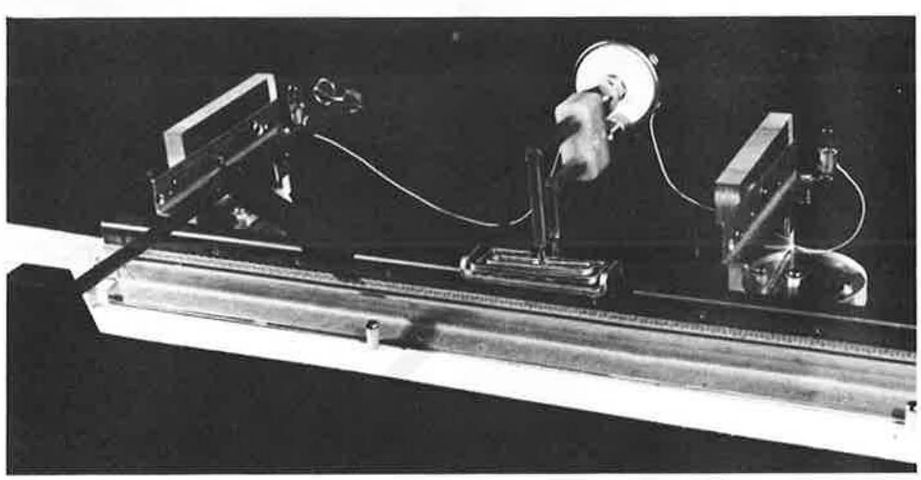
In the Vought Corporation's AGT system, the signal is picked up with a graphite collector shoe that is physically in touch with the rail. Signal transfer fails when the intimacy of contact is broken by a layer of ice. Two small pick-up contacts made of the same variety of graphite are used in our experiment to measure the contact resistance before and after RF deicing. A small light bulb is connected in series with each pick-up contact and the rail. A good electrical contact will be indicated by a lighted bulb. Finally, a mechanical scraper is installed about 5.1 cm away from the work coil. At very low rail speeds, when using our work coil, 2.5 kW of RF power is sufficient to completely melt approximately 0.32 cm of ice. The scraper becomes useful when the rail is moving at higher speeds. A more detailed account of the function of the scraper is given in the next section.

RESULTS AND DISCUSSIONS

The 430 stainless-steel-clad sample rails used in the experiments were each 1 m long. The surface of the rail under test was first carefully cleaned and degreased to ensure good ice adhesion. It was initially cooled down to -10°C in a dry-ice box. Water was then sprayed onto its surface and a thin layer of ice gradually built up until its thickness reached about 0.32 cm. This ice layer was strong and without cracks. The ice-covered rail was further cooled down to dry-ice temperature (~ -56°C) before it was quickly transferred to the environmental chamber for testing. For the duration of the experiment, the chamber was kept at -10°C and the rail temperature was approximately -35°C.

The distance between the work coil and the rail surface was set at 0.63 cm. The RF power output from the generator was tuned to its maximum, and the ice-covered rail was pulled through below the work coil at various speeds, ranging from less than 0.81 to 3.2 km/h. At lower speeds, the power coupled to the rail was enough to completely melt the ice layer. Under this condition, the portion of the rail, after passing through the work coil, made good electrical connections to the aft-contact as evidenced by the lit-up test bulb. Generally, because of the cold environment, the water film on the rail surface refroze within a few seconds. A solution to this is to remove the water by using a jet of warm compressed air, which will be discussed later.

Figure 4. Relative positions of work coil, scraper, and contacts inside environmental chamber.



At speeds around 3.2 km/h, complete melting of the ice layer no longer occurred. Instead, a water film was formed at the ice-rail interface. The ice layer now loosened from the rail surface was immediately removed by the scraper (Figure 7). Even though a speed of 3.2 km/h is rather slow, this result is considered to be encouraging because our prototype work coil is still not of the optimal design. Moreover, the experiments were performed for a rail temperature of -35°C, a situation rarely encountered. For higher temperature ranges and with further improvements in coil design, satisfactory deicing should be possible at higher vehicle speeds. Because of the limitation of our linear-motion testing setup, deicing experiments with higher rail speeds have not been carried out. However, a 5.5-m-diameter rotating drum test facility at the Vought Corporation is now being modified for future high-speed testing (9).

The power coupled to the rail was estimated by measuring the generator plate voltage (V_p), the plate current (I_{po}) under no load (no rail under coil), and the plate current (I_p) under load (with rail under coil). V_pI_{po} gives the power dissipated in the work coil and $V_pI_p - V_pI_{po}$ is the power coupled to the load. The results are given in Table 1. It is seen that, for our prototype coil, only about 0.58 kW is coupled to the rail, which results in a coupling efficiency of only 19 percent for the 430 stainless-steel rails. As expected, the efficiency for 304 stainless-steel rails is much lower. The data also show that the coupling efficiency can be increased if the air gap between the coil and the rail can be reduced. Because a reduction of gap to less than 0.63 cm is not practical, the development of a more efficient coil becomes the only choice for improving system performance.

The evaluation of the performance for insulated rails was carried out in the following manner. Some 40-60 tin-lead solder with a melting point of 183°C was cut into small pieces of equal sizes. One piece

Figure 5. Cross section of stainless-steel-clad aluminum collector rail.

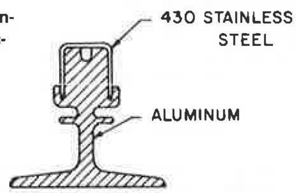


Figure 6. Sample rails for insulation effectiveness experiment: (a) control rail, (b) hollow rail, and (c) asbestos-insulated rail.

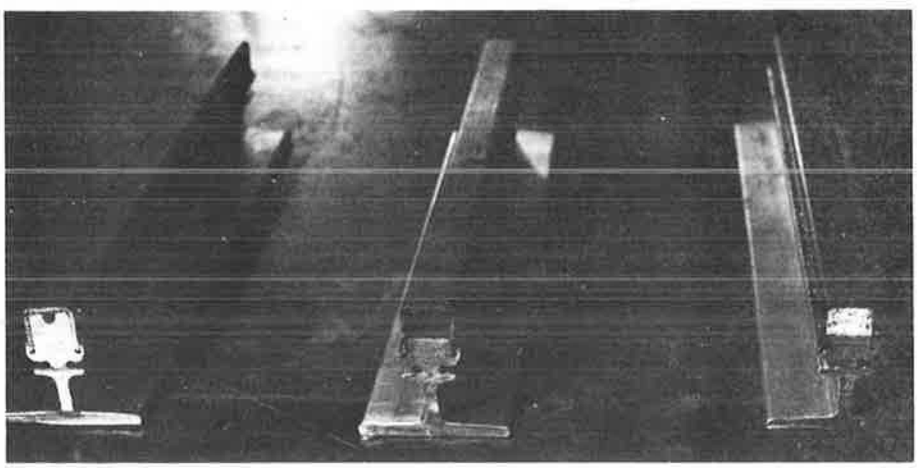


Figure 7. Actual deicing in progress with rail moving at 3.2 km/h.

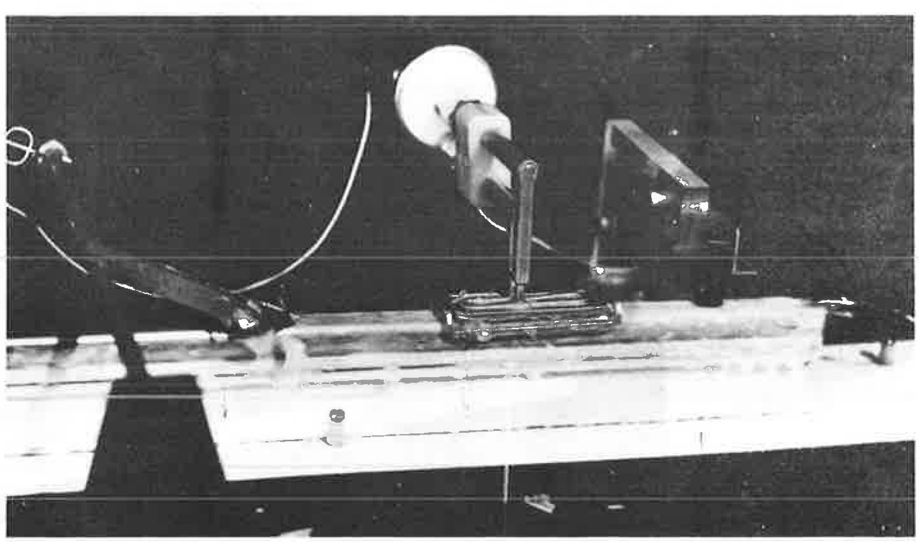


Table 1. Data for calculating coil coupling efficiency.

Load Condition	Plate Voltage (V_p) (A)	Plate Current (I_p) (A)	$P_{coil} + P_{work}$ (V_pI_p) (kW)	P_{work} (kW)	η (%)
No load	4350	0.55	2.4	0	
Air gap between work coil and rail = 0.63 cm					
430 rail	4250	0.70	2.98	0.58	19
304 rail	4325	0.58	2.51	0.11	4.4
430 rail plus ice	4250	0.70	2.98	0.58	19
Air gap between work coil and rail = 0.32 cm					
430 rail	4250	0.75	3.19	0.79	25
304 rail	4250	0.61	2.59	0.19	7.3

Table 2. Time taken for small flat piece of 40-60 solder to melt on RF-heated rails.

Sample Rail	Plate Current (A)	Time to Melt (s)
304 SS standard	0.63	12.2
304 SS hollow	0.63	8.2
304 SS asbestos	0.63	7.9
430 SS standard	0.75	2.4
430 SS hollow	0.75	2.1

Note: Distance between work coil and rail surface = 0.25 cm.

was flattened on each of the following rail samples: 304 stainless-steel (SS) standard rail, 304 SS rail with a hollow section beneath, 304 SS rail with asbestos insulation (as shown in Figure 6) along with 430 SS standard rail, and 430 SS rail with a hollow section.

Each of these sample rails with solder on it was in turn placed under the RF coil with a coil-rail clearance of 0.25 cm. The exact time required for the solder to melt was recorded. The results are given in Table 2. The following three pertinent observations are made from the data given in this table:

1. As we already know, the 304 SS rail heats up at a much slower rate than the 430 SS rail;
2. Because of the long time required for 304 SS rails to heat up, thermal insulation becomes an important factor; and
3. Little improvement on the heating efficiency is obtained by thermally insulating the 430 SS rails.

Because thermal conduction is a rather slow process, the advantages gained from insulating the rail depend on the power density coupled to the rail. In the case of the 430 SS rails, the coupled power density is higher, and hence only a smaller fraction of thermal energy is conducted away before the solder melts as compared with the 304 SS rails. This can be further seen by comparing data from Tables 1 and 2. From Table 1, for an air gap of 0.32 cm, the ratio of coupled power efficiency between the 430 SS and the 304 SS rails is about 3.4. From Table 2, for a 0.25-cm air gap, the ratio of time necessary to heat the surface to 183°C for 304 SS rail to that necessary for 430 SS rail is 5 for the standard rail configuration and 3.9 for the hollow configuration. Clearly, the lower coupled power efficiency in 304 SS implies a larger amount of thermal losses for attaining the same surface rail temperature and, in such cases, the insulation does play an important role. However, when the coupled power density is high, the insulation does not substantially affect the heating of the surface rail, as evident from Table 2 data on 403 SS rail samples. Hence, in such cases, for the initial deicing cycle, insulation is not necessary. However, good insulation will certainly slow down the refreezing of water on the rail surface. Whether or not rail insulation plays an important role in overall system performance will depend on the actual engineering design of the deicing head (coil, scraper, electrical contacts), the coupled power density, and the speed of motion. In our opinion, the effectiveness of thermal insulation needs to be studied further.

In passing, it must be noted that the use of insulated rails poses no current-carrying capability problem for the signal rail, which carries a small amount of current. However, since large currents (up to 350 A) flow in the power rails, the insulation cavity, if used, must be appropriately designed and care taken to maintain a sufficiently large contact area between the stainless-steel cap and the aluminum base to allow a low resistance path for current flow.

ENERGY CONSUMPTION FOR RF DEICING

Many of the existing AGT systems, such as in Morgantown, West Virginia, employ electric rail heating to combat snow and ice problems (3). It is of interest to estimate the energy consumption of RF heating and compare it with that of resistive heating. Energy consumption depends on many factors such as climate, guideway length, operating hours, rail design, etc. For analysis purpose, a baseline AGT system is assumed. Its characteristics are given in the table below:

Item	Value
No. of cars during operating hours	
7:00-9:00 a.m.	18
9:00 a.m.-5:00 p.m.	4
5:00-7:00 p.m.	18
7:00-11:00 p.m.	2
Guideway length (km)	10
No. of rails	4
No. of vehicles	20
No. of heating hours per year	250

From the table, it is seen that the average number of cars operating each hour is 7. We estimate that 5-kW RF power will be sufficient to deice one rail under most winter conditions. Thus, 20 kW is needed for each vehcle. The total annual energy consumption by using RF heating is as follows

$$7 \text{ cars} \times 20 \text{ (kW/car)} \times 250 \text{ h} = 3.5 \times 10^4 \text{ kW-h} \quad (4)$$

On the other hand, for resistive heating, the power input to the rail depends on many factors, such as temperature, wind speed, shape of rail, etc. A power requirement as high as 98 W/m per rail is sometimes necessary (9). However, for moderately cold weather, the average power requirement is about 49 W/m per rail (4). For a 10-km guideway with a four-rail collector system, the annual energy consumption is as follows:

$$4 \times 49 \text{ (W/m)} \times 10 \text{ km} \times 250 \text{ h} = 4.9 \times 10^5 \text{ kW-h} \quad (5)$$

On a per-rail basis, resistive heating energy consumption is about 1.2x10^5 kW-h/rail/year. RF heating consumes about 0.88x10^4 kW-h/rail/year, which is about 7 percent of that for resistive heating for the baseline AGT system under consideration here.

It is important to note here that the energy requirement for the direct electrical rail heating system is independent of the frequency of operating cars, while that of the RF inductive heating system is not. In the latter system, the energy requirement is proportional to the frequency of operating vehicles. This implies considerably less energy consumption during the nonrush hours when fewer cars are operating. As a result, such a system shows promise for an energy-efficient solution to the problems.

CONCLUSIONS

RF induction deicing appears to be a promising alternative to the direct electric rail heating method. RF deicing systems can be attached to future AGT vehicles for adverse weather rail deicing operation. The prototype system built in our laboratory has successfully demonstrated the concept of RF rail deicing. Based on this work, we recommend further research and development work in the following areas:

1. Work coil coupling efficiency needs to be increased. This can be accomplished by improving the design of the coil. Using silver-plated copper tubings and including a ferrite concentrator for the work coil will also improve performance.
2. A provision for automatic matching of the load impedance to the RF generator is needed.
3. The possibility of using frequencies other than the 450 kHz used in this work should also be investigated with improvements in overall system efficiency in mind along with other considerations such as cost, compactness, and ruggedness.
4. A more effective mechanical scraper design is also needed. A nozzle for warm compressed air installed right next to the scraper will be useful in blowing and drying the thin layer of water on the rail surface, thereby avoiding the refreezing problem. The heat exchanger necessary for the RF generator can supply part or all of the energy necessary to warm the compressed air jet.
5. In the absence of ice and at a slow vehicle speed, efficient RF coupling results in rapid rail surface heating and oxidation. Some feedback control mechanism is thus needed for rail overheat protection.

With all the above improvements incorporated, the RF deicing system may prove to be a good alternative solution to AGT adverse weather problems.

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Impact of People Movers on Travel: Morgantown–A Case Study

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Impact studies of the Morgantown People Mover (MPM) were conducted for two separate phases of construction. Estimates of MPM corridor travel by mode were made before and after opening of phase 1 in October 1975. Estimates of travel by mode, user group, and trip purpose were also made before and after the opening of the expanded system in August 1979. Highly similar impacts resulted both times. Several thousand person trips were diverted from the automobile to the MPM. Users, who are primarily but not exclusively students and faculty, expressed levels of satisfaction with the system nearly as high as users of private automobiles. Despite initial concern about safety before operation began, users now perceive MPM to be extremely safe.

In October 1975, the first phase of the Morgantown People Mover (MPM) system (referred to in the past as the Personal Rapid Transit System) was opened for passenger service. MPM is a revolutionary new mode of public transportation, built as a research development and demonstration project by the Urban Mass Transportation Administration (UMTA). Because this system was the first of its kind ever operated in a city, it provided a unique opportunity to study the interaction between a new mode and its service area.

Although the system installation at that time represented only the first phase of a much larger system, it was believed that some measurable impacts could still be derived from its first few years of operation that, it was hoped, could later be verified when compared with the impacts of the expanded system. That has definitely been achieved. As will be reported later in this paper, some of the most impressive impacts of the system, such as the measurable shift from automobile use to MPM use, appeared in both studies.

The MPM impact study was designed to record the effects of system operation on traffic and associated activity in the area adjacent to the MPM. The intent of the study was to provide information that should be useful to other cities contemplating public transit, particularly those planning for automated guideway transit (AGT) type installations.

Specifically, the major objectives of the study were to

1. Measure the service and accessibility of the system,
2. Determine the nature of system patronage, and
3. Measure the impact of MPM on the travel and traffic adjacent to the MPM corridor.

OVERVIEW OF TRANSPORTATION IN MORGANTOWN

Morgantown is a university city of about 30 000 population. West Virginia University (WVU) is the largest employer in the area, and some 19 000-20 000 students attend WVU in Morgantown. All of the WVU buildings were once located in a compact area contiguous with Morgantown's central business district (CBD). However, as WVU expanded, new buildings, which included classrooms, dormitory facilities, athletic facilities, and a medical center, were located several miles from the older buildings and became known as the Evansdale Campus. The original buildings near the CBD became known as the Main (or Downtown) Campus. In Figure 1, the Walnut Street station is located in the CBD and the Beechurst Avenue station serves the Main Campus. The Engineering, Towers, and Medical Center stations serve the Evansdale Campus.

The city has very few roads running in the north-south direction. The most heavily used of the north-south arteries is Beechurst Avenue, which is essentially a two-lane road, although its northern extension, Monongahela Boulevard, is four lanes wide. Most other north-south traffic is carried by the heavily used University Avenue, a two-lane road east of the Beechurst-Monongahela route at a slightly higher elevation. These routes are essentially the only routes between the Main Campus and the Evansdale Campus, and they must be used for all travel across Morgantown in a north-south direction.

The private automobile is the primary mode of transportation in Morgantown. Automobiles are used by students, faculty, and staff of WVU, as well as by the non-WVU-related residents of the area. However, parking is in short supply in the CBD and at most locations on the WVU campus; it is particularly limited at the Main Campus.

Prior to the advent of the MPM, most student trips within the WVU campuses were made by university bus. WVU operated a fleet of approximately 16 regularly scheduled buses, each bus having a seating capacity of 45-55. The university buses served all major activity centers on the Evansdale Campus and stopped at Campus Drive near the Main Campus. Passengers could get on or off university buses only at designated stops.

The City of Morgantown operates a very small transit system. In addition, bicycling is seldom used as a mode of transportation because of Morgantown's hilly terrain.

MPM SYSTEM CHARACTERISTICS

The MPM system is a computer-controlled (Figure 2), fully automated collection and distribution transportation system. Each vehicle (Figure 3) is air-conditioned and heated and is capable of carrying 8 seated and 12 standing passengers. The vehicles are electrically powered and receive power from a power rail (Figure 4) and operating instructions from an inductive loop embedded in the guideway.

The vehicles run on headways of 15 s at a maximum speed of 30 mph. The right-of-way for the vehicles is an exclusive guideway (Figure 5). The guideway is constructed at three grades: at grade, above grade, and a very short section in a cut-and-cover tunnel.

To summarize, the major innovations of the MPM and those that distinguish it from earlier operational transit systems include the following:

1. Central computer-control function,
2. Demand-activated service,
3. Small personalized vehicles,
4. On-board switching,
5. Short headways,
6. Off-line stations, and
7. Nonstop trips from origin to destination.

MORGANTOWN MPM SYSTEM

The MPM system was constructed in two phases. Phase

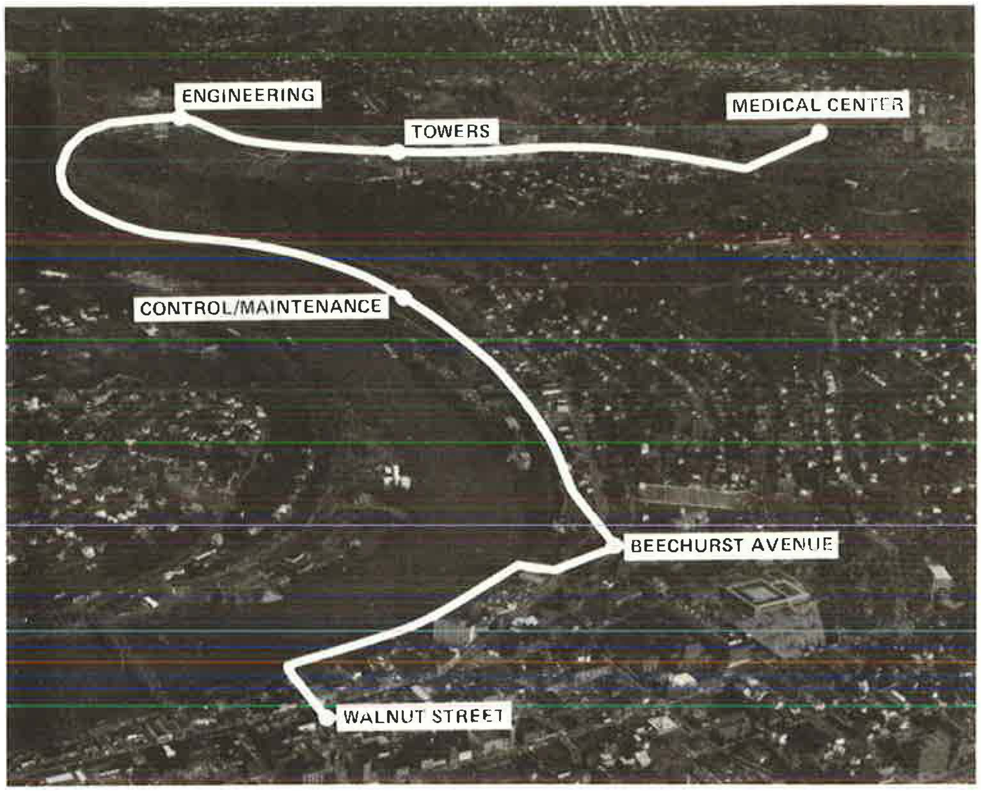


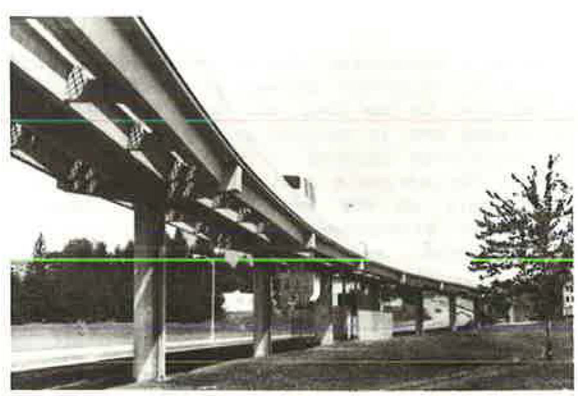
Figure 1. System configuration, Morgantown.

Figure 2. Control center.

Figure 3. Vehicle.

Figure 4. Power collector, pneumatic tire, and lateral wheels.

Figure 5. Guideway.



1 of the MPM system was completed in October 1975 and phase 2 in October 1979.

Phase 1 consisted of a three-station system connected by 5.4 miles of equivalent single-lane guideway and served by 45 vehicles. Phase 2 represented the completion of the system. In phase 2, two new stations (see Figure 6) were built, the guideway extended to 8.7 miles, and 26 new vehicles were added to the system. These vehicles operate at a maximum speed of 30 mph and a minimum headway of 15 s.

SYSTEM OPERATIONAL DESCRIPTION

The MPM system is operated in either a schedule or demand mode. During those periods when passenger demand is highly predictable, the system is operated in the schedule mode. Vehicles are dispatched between origin-destination pairs on a preset schedule. When passenger demand is less predictable, the system is operated in the demand mode. Vehicles are then dispatched only in response to a passenger request.

Passenger actions on entering the system are always the same, regardless of the mode in which the system is operating. Normally, a passenger would arrive on the concourse level of the origin station where static and dynamic displays provide direction (Figure 7) to the platform that services his or her destination, proceed to the platform level, insert a coded card (fare cards are included in student fees but can also be purchased locally) or exact change in a fare gate (Figure 8), and press a button that selects the destination. A gate display illuminates, which informs the passenger to proceed to the vehicle loading area. A vehicle destination display above the loading gate provides vehicle boarding instructions. If assistance is needed for any reason, a dedicated telephone link to the central operator is available near each entry gate area. The passenger is kept informed of changes in the system operating status via the station public address system.

Figure 6. Medical Center station.

Figure 7. Destination displays.

The passenger boards a vehicle when it arrives at the loading gate, and the display indicates that the vehicle is assigned to his or her destination. The door closes and the vehicle automatically proceeds to the destination. At the destination station the vehicle stops at an unloading gate, the door opens, and the passenger leaves the station through an exit gate.

Elevator service is provided from station concourse levels to each platform to permit use of the system by the handicapped and the elderly. The system operates between the hours of 6:30 a.m. and 12:00 midnight on Monday through Thursday, 6:30 and 1:00 a.m. on Friday, 9:30 and 1:00 a.m. on Saturday, and 9:30 a.m. and 12:00 midnight on Sunday.

MPM OPERATIONAL HISTORY

It seems appropriate at this time to take a few moments and summarize the operational history of the system over the past six years. Very briefly, the system, as expected, has matured and has showed a steady increase in dependability and ridership and a reduction in cost per passenger mile. The table below summarizes the operating statistics for 1980-1981:

Item	Quantity
Total labor, fuel, parts, and unclassified (benefits, insurance, etc.) ($)	2 160 537
No. of operating days per year	338
Avg system cost per day ($)	6392
No. of miles driven per year	1 168 723
Avg system cost per vehicle mile ($)	1.848
Total passengers per year	3 087 314
Avg cost per passenger trip ($)	0.699
Avg cost per passenger mile ($)	0.384

Overall system dependability has continued to improve. Table 1 summarizes its performance since the first month of operation. Note that during the last 12 months, the system's dependability averaged 97.7 percent. Dependability is the product of system availability (downtime divided by operating time), trip reliability (probability of completing the trip successfully once one is on the vehicle),

Figure 8. Automated fare gate.

Table 1. System dependability.

Phase	Year	Month	System Dependability (%)	Phase	Year	Month	System Dependability (%)
Phase 1	1975	October	84.33	Expanded system	1979	July	79.6
		November	81.59			August	85.7
		December	74.37			September	90.6
	1976	January	64.36			October	90.9
		February	69.14			November	93.9
		March	86.44			December	93.7
		April	92.90		1980	January	92.2
		May	94.48			February	95.0
		June	92.80			March	91.8
		July	93.19			April	91.2
		August	91.27			May	96.4
		September	92.67			June	97.6
		October	91.16			July	97.5
		November	92.45			August	94.9
		December	90.53			September	96.5
	1977	January	82.93			October	96.6
		February	95.19			November	96.1
		March	93.88			December	96.8
		April	96.53		1981	January	98.3
		May	98.56			February	96.1
		June	98.98			March	98.4
		July	99.01			April	97.9
		August	97.85			May	99.0
		September	96.88			June	99.0
		October	96.30			July	98.1
		November	97.47			August	99.5
		December	97.11				
	1978	January	93.37				
		February	91.04				
		March	94.20				
		April	96.85				
		May	97.74				
		June	98.63				

Notes: System dependability = system reliability times system availability times vehicle availability.
System average between August 1980 and August 1981 was 97.1 percent.

and vehicle availability (number of vehicles available divided by number of vehicles required).

DATA-COLLECTION PROCEDURES

Impact studies were conducted for the phase 1 system, which began operation in 1975, and also for the expanded system, which began operation in 1979. However, the data-collection procedures were different in each study. For the 1976 study, impact data were collected primarily by means of a telephone household survey among randomly selected households in Morgantown. The survey asked detailed information about the previous day's tripmaking throughout Morgantown. The data were expanded on a zonal basis to provide information on modal use. MPM users were also given a very short questionnaire on entering the system. On departing the system the questionnaire was collected. A small sample of the people who completed the form were then contacted by telephone for additional information. Unfortunately, problems were encountered in the telephone survey due to difficulty obtaining the head of the household and the length of the survey form. For these reasons, a different approach was taken in 1979 and 1980.

In the expanded system survey, which was conducted in early April 1979 and late March 1980, emphasis was placed on surveying individual corridor trips rather than households. A questionnaire was developed that sought information on trip origin and destination, purpose, satisfaction with various aspects of the trip, and the tripmaker's household characteristics. (Questionnaires are available from the researchers on request.) The questionnaire was handed out to a sample of automobile drivers at all intersections from which trips entered the MPM corridor, and it was also handed out to a sample of university bus system users (1979) and MPM users (1980) at system entry points. The questionnaires were completed at home and mailed back.

Traffic ground counts and observed vehicle occupancy were used to estimate total corridor person trips. The returned automobile-intercept survey forms were then expanded to equal total estimated corridor person trips. Great care was taken to expand the survey data separately for each intersection approach where survey forms were distributed. A similar procedure was followed for expanding survey forms distributed on the bus and MPM. On-off counts were obtained and used as estimated control totals for expansion. Altogether, 4126 usable questionnaires were returned in 1979 and 5195 in 1980, which represented roughly 7 and 8 percent of total corridor person trips, respectively. This represented a return rate of about 30 percent almost uniformly across modes.

The City of Morgantown and surrounding areas in Monongalia County were disaggregated into 54 zones along boundaries consistent with 1970 census enumeration districts. Origins and destinations of trips were coded to these zones. Those zones within easy walking distance (about 10 min) from MPM stations were designated as the primary market area (PMA). These 24 zones included all of the WVU campus and dormitory zones, the CBD of Morgantown, and adjacent residential areas, which housed a high proportion of WVU students and employees. The PMA contained the MPM corridor except for one section near the middle, which was located more than a 10-min walk from any station.

MAJOR FINDINGS

One of the most striking findings was the change in perception of system safety following the opening of

Table 2. Modal split of person trips in MPM corridor.

Item	Preoperational Survey, 1979				Operational Survey, 1980			
	Total Trips[a]	Percentage of Trips: Via Automobile	Percentage of Trips: Via University Bus	Maximum Error of Estimates[b]	Total Trips	Percentage of Trips: Via Automobile	Percentage of Trips: Via University Bus	Maximum Error of Estimates[b]
Trips with ends both in PMA	23 086	57.6	41.6	2.0	23 670	49.9	49.1	1.9
Trips with one end in PMA	24 885	96.2	3.0	0.7	29 735	93.2	5.6	0.8
Trips with either end in PMA	9 354	99.9	0.1	0.2	10 949	99.4	0.2	0.3
Total corridor trips	57 325	81.3	18.0	1.0	64 354	78.3	20.7	0.9

[a]Includes city bus. [b]Estimates are for 90 percent confidence interval.

Table 3. Comparison of system impacts: 1976 phase 1 versus 1980 expanded system.

Mode	1976	1980	Mode	1976	1980
Automobile			Total trips[a]		
Preoperational	10 369	13 308	Preoperational	17 893	23 086
Operational	8584	11 809	Operational	17 316	23 670
Change (%)	−17.2	−11.3	Change (%)	−3	+2.3
Transit[a]			Transit share (%)		
Preoperational[b]	7524	9594	Preoperational	42	42
Operational[c]	8732	11 627	Operational	50	50
Change (%)	+16.1	+21.2	Change	+19	+19

Note: Statistics are for person trips with both ends in the PMA.
[a]Excludes city bus. [b]Includes university bus. [c]Includes MPM.

phase 1. Prior to opening, people thought that the MPM would be less safe than the automobile and bus. But following a year of operation, MPM was perceived to be more safe than the automobile or bus. These perceptions still exist and have been reinforced by the safety record of MPM. To date (August 1981), after serving almost 11 million passengers and operating 4.3 million vehicle miles, there has not been a single system-induced injury or death.

The most important traffic impact was a marked shift in ridership from automobile to MPM among trips within easy walking distance of MPM stations. This occurred simultaneously with a large increase in overall automobile travel in the corridor. The total number of person trips in the corridor increased by nearly 7000/day between 1979 and 1980. Of this increase, the majority (nearly 6500) represented automobile trips that had at least one end outside the PMA and thus were not potential MPM trips. The net increase among trips that had both ends in the PMA was very small (only about 500) but was accompanied by a large shift from automobile to MPM. In fact, MPM carried about 2000 more PMA person trips per day than had the university bus system, whereas the highway system in the corridor carried approximately 1500 fewer PMA automobile person trips following the opening of the expanded system. Thus, there was a clear shift from automobile to MPM among trips with both ends in the PMA, as seen against the background of a large overall increase of 12.3 percent in total corridor person trips (Table 2).

A second major finding was that the impact of the MPM was nearly the same following both the opening of the phase 1 system and the opening of the expanded system, especially among tripmaking within the PMA. Both times, the share of PMA trips made by transit (university bus versus MPM) increased from 42 to 50 percent following the opening of the system. This reflected a decrease in automobile person trips of 17.2 percent in 1976 versus 11.3 percent in 1980, and an increase in transit person trips of 16.1 percent in 1976 versus 21.2 percent in 1980. Neither time did total trips within the PMA change by more than 600 (Table 3). Thus, based on the data, the system appeared to be influencing similar changes in travel behavior at two points in time separated by four years.

It was expected that WVU students and employees would be the groups experiencing most of the impacts due to the configuration of the guideway and the fact that the only parking readily available at four of the five stations was restricted to individuals with WVU parking stickers. The impact studies verified this and indicated that impacts occurred primarily among school and non-home-based trips. Among home-based school trips that had both ends in the PMA, transit use rose from 64.8 to 73.2 percent following the opening of the expanded system, and non-home-based school trip transit use rose from 62.5 to 79.8 percent. Transit use for non-home-based work trips rose from 11.1 to 18.3 percent, and for non-home-based other trips it rose from 13.2 to 22.1 percent. Among other trip purposes there was no noticeable shift in modal use (Table 4).

The impact study also verified that the strongest impact had occurred among students who did not live in dormitories but in private housing. These were the students most likely to own automobiles and use them for school-related trips. Transit use in this group increased from 38.8 to 52.7 percent for trips made within the PMA, and automobile use dropped by a corresponding percentage (Table 4). Dormitory students, who were less likely to own automobiles, registered a smaller change from 78.9 to 87.7 percent transit use. Transit use by WVU employees changed from only 7.7 to 18.1 percent for trips entirely within the PMA. Similarly, other Morgantown residents not affiliated with WVU made only 7.1 percent of their within-PMA trips on MPM (the university bus system had not been available to them). The data suggest that WVU employees and townspeople are reluctant to abandon the convenience of their automobiles in return for a combined walking and MPM trip.

An examination of user satisfactions indicated that more automobile users were satisfied with their mode of travel than were transit users, both before and after opening the MPM. However, an interesting finding was that satisfaction with each mode increased after the expanded MPM was opened (Table 5). The MPM scored high levels of satisfaction (better than 75 percent of users expressing satisfaction) with respect to overall trip duration, overall ease of making the trip, cost of trip, and overall satisfaction. It scored nearly as well as the automobile mode in these areas. But in terms of satisfaction with waiting time, walking time, and vehicle occupancy it scored lower. In fact, 9 percent fewer MPM users were satisfied with waiting time than university bus system users. This may be related to the fact that bus system users could always sit inside the buses while waiting for their

Table 4. Impact by trip purpose and user status: trips with both ends in PMA.

	Preoperational Survey, 1979				Operational Survey, 1980			
		Percentage of Trips				Percentage of Trips		
Item	Total Trips	Via Automobile	Via University Bus	Maximum Error of Estimates[a]	Total Trips	Via Automobile	Via University Bus	Maximum Error of Estimates[a]
Home-based work trips	2098	85.9	11.4	4.7	2665	84.0	13.5	4.1
Home-based school trips	8596	34.8	64.8	3.2	9015	26.4	73.2	2.7
Home-based other trips	3818	83.2	16.0	3.7	2812	81.8	16.9	4.2
Non-home-based work trips	1961	88.2	11.1	4.5	2055	78.9	18.3	5.2
Non-home-based school trips	4220	37.2	62.5	4.6	3878	20.2	79.8	3.7
Non-home-based other trips	2325	85.2	13.2	4.3	2851	76.6	22.1	4.6
WVU faculty and staff	3843	89.9	7.7	3.0	3989	80.2	18.1	3.6
WVU dormitory students	7204	21.1	78.9	3.0	6388	12.3	87.7	2.4
WVU nondormitory students	8377	60.7	38.8	3.3	9051	46.8	52.7	3.0
Other Morgantown residents	2734	98.6	-	-	3293	89.5	7.1	3.0
Nonresidents, non-WVU	929	59.8	39.8	9.8	949	67.2	31.8	8.8

[a]Estimates are for 90 percent confidence interval.

Table 5. Traveler satisfaction with trips made in corridor.

	Automobile				Transit			
	1979		1980		1979[a]		1980[b]	
Item	Percent	Maximum Error of Estimates	Percent	Maximum Error of Estimates	Percent	Maximum Error of Estimates	Percent	Maximum Error of Estimates
Trips under 10-min perceived travel time within PMA	42	2	49	2	25	2	17	1
Travelers satisfied with overall trip duration	73	2	80	1	66	2	75	1
Travelers satisfied with ease of making trips	73	2	82	1	68	2	78	1
Travelers satisfied with waiting time	83	1	88	1	67	2	58	2
Travelers satisfied with walking distance	83	1	90	1	62	2	65	2
Travelers satisfied with vehicle occupancy	82	1	80	1	58	2	67	2
Travelers satisfied with cost of trip	NA		53	2	NA		83	1
Travelers expressing overall satisfaction with trip	NA		84	1	NA		76	1

Notes: NA = not applicable.
Estimates are for 90 percent confidence interval.
[a]Data for university bus.
[b]Data for MPM.

trips to begin, whereas MPM users have to stand outside on the station platforms while waiting. In all other areas the MPM scored better than the university bus, with generally about 9 percent more MPM users expressing satisfaction. The MPM scored better than the automobile in only one area--satisfaction with trip cost. More than 30 percent more MPM users were satisfied with trip cost than automobile users.

Questions were asked regarding perceived trip duration. The automobile was regarded as superior to MPM, as evidenced by nearly 50 percent of the automobile users expressing the belief that total trip duration was less than 10 min. Only 17 percent of the MPM users perceived that trip duration was less than 10 min, an even smaller percentage than university bus system users. This was probably related to decreased satisfaction with waiting time for MPM. Despite this, more MPM users were satisfied with overall trip duration than university bus system users. This apparently contradictory result may indicate a bias on the part of MPM users to react more favorably to the overall characteristics of the trip because of a favorable overall satisfaction with the mode. Clearly, overall satisfaction with the MPM was high (76 percent of the users) and within 8 percentage points of the automobile. Thus, despite MPM shortcomings in regard to waiting time, walking distance, and vehicle occupancy, the percentage of users who expressed overall satisfaction was high.

CONCLUSIONS

The MPM appears to have achieved a shift in modal split from automobile to MPM for those trips that both begin and end near the system's stations. Impact was strongest for WVU students who do not live in dormitories. Although waiting time for vehicles appears to be a source of dissatisfaction for users, the general reaction is more favorable than it was for the bus system and almost as high as for the automobile mode. System dependability has improved with operational experience and is currently about 97 percent. Despite high initial capital costs, the system has relatively low labor requirements, which should help to keep operating costs from escalating as rapidly as those for conventional driver-operated systems. This fact alone should help to sustain a continuing interest in such systems for urban transportation.

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Assessing Consumer Market Potential for Electric Vehicles: Focus-Group Approach

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A demonstration of focus-group techniques in analyzing transportation energy-conservation program activities is described. The Electric Vehicle Commercialization Project of the Electric and Hybrid Vehicle Program of the U.S. Department of Energy (DOE) was the test case for the demonstration. This application builds on previous focus-group studies in transportation as well as previous electric vehicle (EV) market studies. During the winter of 1981, six focus-group meetings were held, two each in Tampa, Spokane, and Sacramento. The cities were selected to complement the cities used in previous DOE focus-group research. Respondents were recruited based on criteria to identify the most likely purchasers of new EVs. The focus-group meetings were structured around a discussion guide that covered topics such as adjustments to down-sizing, perceptions of future energy shortages, and, most importantly, reactions to EVs likely to be available in the short to medium range. The results of the focus groups are consistent with previous quantitative studies of EV market potential, in that the market for vehicles likely to be available in the near term appears to be very limited. The major impediments to market penetration are limited range, long battery recharge period, and high costs.

Various approaches have been used to analyze the market potential of new products, services, or technologies. This paper describes a study that applied the focus-group technique, a qualitative market research tool, to assess the potential market for electric vehicles (EVs).

The study was built on two recent lines of transportation research. First, focus groups have been used to study problems such as ridesharing (1), intercity passenger rail service attributes (2), transit marketing (3), and fuel-efficient new cars (4). Second, quantitative modeling approaches have been used to estimate potential market shares for EVs (5,6). Inasmuch as new products such as EVs may involve attributes that are difficult to quantify, the qualitative approach in focus-group research is complementary to the quantitative studies.

The remainder of the paper is organized as follows. First, background information, which includes the objectives of the study and the particular EV issues of interest, is presented. The second section briefly describes focus-group methods and is followed by a discussion of the specific research design used in the EV study. Specific findings of this study are then described in detail. The final section highlights the conclusions drawn from the study.

BACKGROUND

The U.S. Department of Energy (DOE) has implemented a wide variety of programs that relate to the use of energy in transportation. One program is the Electric and Hybrid Vehicle (EHV) Program created by the Electric and Hybrid Vehicle Research Development and Demonstration Act of 1976. The legislative intent of the Act was to accelerate the commercialization of electric and hybrid vehicles to reduce petroleum consumption and the related dependence of foreign oil sources. As part of a larger consumer representation project for DOE, the EHV Program's Electric Vehicle Commercialization Project was selected as a demonstration case to test the usefulness of focus-group techniques in planning transportation energy-conservation-program activities. The focus-group task was planned and supervised by Charles River Associates and conducted by the marketing research firm of Elrick and Lavidge, Inc.

The purpose of this research was twofold: First, to demonstrate the use of focus-group techniques in planning transportation energy-conservation programs and to determine if these techniques will be useful in subsequent research, and second, to gain a preliminary understanding of consumers' perceptions of EVs as they exist now and as they might fit into daily driving in the future. The research objectives of the focus groups include

1. Improved understanding of potential consumer markets for EV technology,
2. Identification of fruitful consumer markets for EVs, and
3. The updating of existing data bases on consumer preferences relative to EVs.

The objective of the EV commercialization program is to aid private-sector decisionmakers in developing market strategies for commercial EVs. The focus-group program will enhance the understanding of several issues for the EV market. These include

1. Consumers' perceptions of the threat of a gasoline shortage;
2. Consumers' perceptions of EV technology and its availability, practicability, advantages, and disadvantages;
3. Consumers' evaluations of the important design trade-offs in EV production, which include range versus payload, range versus cost, and recharge period duration; and
4. Consumers' general utility for a limited-purpose vehicle such as EVs, and market segments likely to purchase an expensive limited-purpose vehicle.

The results of this study provide background information and input for possible further quantitative studies on EV commercialization.

NATURE OF FOCUS-GROUP RESEARCH

This section provides a brief description of focus-group techniques. For the interested reader, additional detail is provided in several other sources (7-15).

Focus-group interviewing is a common marketing research technique. Small panels of consumers discuss their attitudes toward a product or service. The panels usually consist of 6 to 12 participants led by a moderator. The format is open-ended but loosely structured around a discussion guide, which the moderator uses as a plan for prompting discussion. The guide outlines major themes or questions designed to elicit consumers' attitudes and feelings toward the service or product. The sessions usually last 1-2 h, are generally tape-recorded, and are often transcribed for analysis. A variety of qualitative and quantitative techniques have been used to interpret the results.

Because the focus-group technique does not require a large number of respondents, it can be relatively inexpensive. However, because the sample is often small, the primary data are qualitative, and focus-group respondents may self-select in a biasing fashion; care should be taken in generalizing the group results to the population at large. Decisionmakers and analysts should be careful not to place as much confidence in focus-group data as they would in the results of a major quantitative field survey. Focus groups should be used as exploratory tools in conjunction with other field research techniques. For instance, they may be used to develop a survey instrument or to design a pilot program for later evaluation.

The social or peer context of focus-group sessions encourages candid, informal expression of concerns and sheds light on the methods by which consumers communicate their impressions of the service, product, or proposed policy to each other. These communications data may provide insights not available through individual or household interviewing.

There are a number of applications in which focus-group techniques can be used effectively by transportation planners or policy analysts to improve their understanding of complex attitude and behavior interrelations. These include the following:

1. Exploratory research: Focus groups can be used to develop and test the analyst's conceptual model of the ways in which consumers think about and use the program, product, or service in question.
2. Questionnaire design: Focus-group data can be used to suggest hypotheses for qualitative analysis and to refine the language used to gather survey data.
3. Program development and evaluation: Focus groups of prospective users can help improve the usefulness and market acceptability of a new program or service. Focus groups of users and nonusers of a current service may suggest changes to enhance the general acceptance and utility of the service.
4. Marketing refinement: Focus groups can provide feedback on a program's public image and suggest marketability strategies to increase the program's acceptability to target users.

RESEARCH PROCEDURE

Six focus-group sessions (with a total of 51 people) were conducted in January and March 1981. Two sessions each were completed in Sacramento, Spokane, and Tampa. In each city, one group was composed of women and one of men. Other requirements specified that participants be

1. The principal drivers of new, small fuel-efficient cars that were purchased during the past 12 months;
2. Responsible for and/or have participated in the decision to buy that car;
3. Members of households that own two or more automobiles that were purchased new by members of the household; and
4. Between the ages of 18 and 65.

If EVs were to become widely available, it was envisioned that market penetration in this consumer segment would be significant. The study team anticipated that households that owned two or more automobiles purchased new would be wealthy enough and have sufficient investment in automobiles to afford an expensive limited-performance vehicle such as an electric car. Because a commercial EV would compete most directly with compact and subcompact automobiles, the study team chose to interview drivers from these households who recently purchased new small cars. We hoped to find to what extent an EV could serve as a substitute for the participants' new small vehicle.

The particular sites were selected for a variety of reasons. First, they represented generally smaller communities than had been sampled in earlier DOE consumer focus-group research on EVs (6). Second, these sites extended the climatic range represented in the earlier data (Spokane is cooler and Sacramento and Tampa provide hotter climates). Third, these sites were chosen because of their low reliance on fossil fuels for electric power. Consequently, significant EV penetration in these communities could have a noticeable effect on oil consumption. Finally, since some of the research issues dealt with consumers' responses to gasoline shortages, each of the selected sites had some fuel supply interruptions or rationing in 1973-1974 or 1979.

The moderator's discussion guide consisted of several distinct sections. First, at the start of each group the moderator briefly introduced herself and the focus-group concept. She then went around the table asking respondents to introduce themselves and asked questions about their new cars, about what they had replaced, and about the other vehicles in the households. Second, respondents were briefly questioned about their awareness of gasoline shortages and how shortages and price increases have affected their driving habits. Respondents were also polled on their expectations concerning future fuel shortages and price hikes. Third, the moderator queried the group concerning their awareness and opinions of alternative transportation fuels and innovative technologies to replace the internal-combustion engine vehicle (ICEV). Fourth, after considerable discussion of the alternatives, a standardized EV concept sheet was passed to each respondent and read aloud. [For a complete text of the discussion guide and concept statement, see report by Charles River Associates (15).] This concept was used as a basis for a specific discussion of the unique features of electric cars. Finally, open discussion of the EV was closed and some quantitative consumer preference data on various attributes of EV and ICEV technologies were gathered for later analysis. This paper only reports on the qualitative results.

The basic EV concept described to the respondents in the concept sheet was contrasted to the conventional ICEV on 11 dimensions: range, recharge time, hook-up availability, noise and pollution, fuel cost, cargo capacity, speed and acceleration, purchase price, battery replacement cost, total operating cost, and fuel availability. The concept scenarios for each of the considerations are briefly described below. Respondents were told that EVs available in the next 5-10 years will be different from today's ICEVs in several important ways:

1. EVs would not have the range between refuelings that we have come to expect from gasoline cars. In normal city driving, the batteries would run down after about 75 miles.
2. Recharging would take up to 8 h, depending on how far they had traveled and how long it had been since the last recharge. After a relatively short trip, it would only take 1-2 h to fully recharge.
3. Recharging would require a special electric hook-up that power companies would install free in owner's homes. In the first years of the electric car, owners would not expect to be able to recharge anywhere but at home. Quick charges and spare batteries would not exist.
4. Unlike gasoline cars, the new EVs would be virtually noiseless and pollution free. They would be at least as comfortable as today's small cars. All the usual options would be available.
5. Fuel in the form of electricity would only

cost half as much as gasoline would for the same miles traveled.

6. The batteries and motor would take up a lot of room. There would be one-quarter less cargo capacity in the back of electric cars because of the space required for the battery.

7. Partly because of the weight of the batteries, electric cars would not be quite as fast as gasoline cars, but they would have a top speed of at least 60 mph. They may accelerate more slowly than a gasoline car.

8. The purchase price of the electric vehicles, not including the batteries, would be comparable to today's small four-passenger automobiles such as the Honda, Chevette, or Toyota; they would cost between $5500 and $6500.

9. Batteries would cost between $2000 and $2500 to purchase. Battery leasing arrangements would also be available at a cost of approximately $80/month. Every two or three years the electric car's battery would need to be replaced.

10. The high cost of batteries would be partly offset by the lower cost of electric fuel. The average monthly cost of ownership and operation (including purchase, financing, maintenance, fuel, and battery replacement or battery lease) would be between $220 and $250 (in today's dollars). A small four-passenger gasoline-powered automobile currently costs about $200/month. The operating costs of gasoline vehicles would increase more rapidly than EV operating costs as oil prices rise.

11. Unlike gasoline-powered cars, electric cars would not be affected by gasoline lines, gasoline price hikes, or oil embargos. Because most recharging would take place overnight, when demand for electric power is at its lowest point in the day, electric cars would not be affected by "brownouts" or electric power shortages.

FOCUS-GROUP RESULTS

This section presents the qualitative analyses of the focus-group results. These analyses are based on the participation of the first two authors in each session (Nelson as an observer and Payne as the moderator) and analyses of the tapes and transcripts from the sessions. Because the qualitative analysis is based on the impressions formed from the available evidence, there is necessarily a larger component of judgment than is the case in quantitative analyses. Although this fact indicates that generalizations should be made somewhat cautiously, a richer variety of findings emerges than is likely from standard quantitative methods.

The quantitative data for trade-off analyses gathered at the end of each session were designed to update the data available from an earlier analysis (6). Quantitative analysis of these data would result in utility or demand models similar to those developed by Morton and others (6) and Beggs and others (16). This analysis is a topic for further research.

Focus groups are useful for conducting research on alternative vehicles, but locating and recruiting qualified participants can be extremely difficult.

This research, as is often the case with focus-group studies, was a pilot project. One of the project's goals was to determine the feasibility of using group discussions for EV research.

It can be said without qualification that the method, per se, is both appropriate and productive as a means of investigating attitudes toward alternative vehicles. When homogeneous groups are involved (as was the case here), people can share ideas and attitudes based on their experiences, comment critically in response to new ideas in the form of concept statements, and handle the trade-off assignment with only minor difficulty.

Recruiting the respondents was much more difficult than conducting the focus groups. It will be recalled that to qualify for inclusion in these groups, men and women must have purchased a new fuel-efficient vehicle within the previous year and also have another automobile in the household that had been purchased new (although not within the past year). This combination was exceedingly difficult to find. Because contacts were not made in a strictly random manner, accurate incidence figures were not available. The experience of the field services suggest, however, the incidence was little more than one or two percent.

The respondent recruiting method varied by city. In Tampa, the field service was able to locate and invite enough qualified men and women via their own card files and informal referrals. The study team experienced the fewest problems finding people in Tampa. Interviewers in Spokane, after having little luck with cold calling and referrals, were able to obtain names of new car buyers from area car dealers. The worst frustrations took place in Sacramento, where a total of 815 contacts were made via card files, referrals, and cold calling but yielded only 8 qualified individuals who agreed to participate in the groups; there were 22 qualified refusals. Strict privacy laws prevented recruiters from obtaining names from car dealers. Finally, for a fee of $1500, names of 5000 new car buyers were secured from a company in San Francisco to which the California Department of Motor Vehicles sells it listings. There was a two-week lag between the request and the receipt of the lists.

This experience suggests that in any future studies of this sort, where incidence is likely to be low, provisions should be made in terms of both time and money to obtain recent motor vehicle registrations before attempting any recruiting.

Many felt they had been pressured--by financial considerations--to downsize in their most recent automobile purchase. But other considerations, such as size, handling, and image, also affected their choice.

Many respondents said that soaring gasoline prices had caused them to look for a car with better gasoline mileage. There were many characterizations of comments concerning full- or mid-sized cars as gasoline "hogs". But simply buying a smaller car that got better gasoline mileage than previous cars was not a satisfactory answer for some respondents. They had other considerations, such as roominess and front-wheel drive, which are considered useful and valuable resale features. Others, however, had more emotional reasons for choosing their small car, e.g., the image of the car.

Consumers' newer, more economical automobiles seem to balance out their household's fleet. Many save their beloved Cadillac for long trips and zip around town in their small cars. Also, most participants were making other efforts to cut gasoline expenses.

Participants often owned as many as four vehicles for use by members of their households. Their fleets usually included at least one older, larger car (truck or van), which seems to be considered a relic from the days of inexpensive gasoline and long Sunday drives in the country. The smaller cars were generally driven by the family member who does more driving around town (i.e., commuting to work, chauffering children to school and meetings, grocery shopping), thereby leaving the larger vehicles for longer trips when comfort becomes more important than good gasoline mileage. The larger vehicles were also used for carpooling or trailering boats and other recreational vehicles.

However, it should be noted that there were exceptions to the trend mentioned in these groups. In some instances the smaller car was used for longer trips where gasoline economy takes a precedence over comfort. One Tampa resident packed his family into the Toyota Tercel for the family vacation and left the Chrysler Newport in the garage; the family protested, but it was either "we go in the economical car or we can't afford the vacation".

As prices have risen, focus-group respondents have become more aware of the gasoline they are buying. Filling up the tank is now considered a significant expenditure. Cutbacks in driving seem most apparent in personal travel. Many people said that if shopping trips can be consolidated, they may wait several days and run their errands all at one time. Leisurely drives are being eliminated. A few respondents noted that they attempt to trim commuting costs by occasionally trying a bus or some other transportation alternative to the personal automobile. It also should be noted that for some, the idea of cutting back on driving is still just that--an idea. Others noted that they have made very minor but relatively painless changes in their driving habits, such as reducing freeway speed.

Some participants said that because they now own cars that get higher gasoline mileage, they have not seen the need to cut back on their driving. Others are simply willing to absorb the high cost of gasoline to be able to continue to drive whatever, whenever, and wherever they want to.

Although some respondents felt that Americans must alter their travel habits, most will not readily accept the available alternatives such as transit and alternative fuels.

There was discussion of gasoline rationing during World War II and during the gasoline shortage of 1973 when consumers had to stand in line--sometimes for hours--to fill up their tanks. But there was an air of disbelief concerning a severe shortage occurring in the foreseeable future. Several participants felt that oil supplies were dependent on the whims of American oil companies. There were a few people who believed, however, that the American perception of the automobile was going to have to shift, i.e., it must be used more efficiently and economically.

Although public transit was noted as an alternative travel mode, focus-group respondents were quick to point out that few public transit services are oriented to serving many of the trips they make. Bus service, in all cases, was described as inconvenient, slow, and undependable.

Alternative fuels, such as methanol and propane (or even solar or hydro power), were mentioned as a means of reducing the American public dependence on gasoline. However, these fuel technologies were seen as still in the early stages of research and far away from widespread use. Diesel-powered vehicles were also discussed. It appears there are many barriers to widespread consumer acceptance of diesel technology for family cars. Individuals who had owned (or known someone who had owned) a diesel car reported a variety of problems, including a noisy, sluggish engine; frequent mechanical problems; unavailability of diesel fuel; and too little savings (about 10¢/gal) at the pumps for the extra trouble.

In theory, the EV concept seems to be an acceptable transportation mode; however, consumers seem disturbed by limited range, long recharge periods, and high battery replacement cost.

When the moderator mentioned EVs as an alternative mode of transportation, the immediate reaction was that the dependence on batteries would pose a problem. Others speculated that even if consumers could cope with the time span needed to recharge the car's batteries, power companies would not be able to handle the increased demand for electricity that would result from the appearance of EVs.

A few participants recalled hearing about or seeing EVs being used by a local company (e.g., utilities) that was experimenting with the concept. Many of the group members felt that such in-town use for deliveries or short-distance commuting was the ideal use for the cars. Otherwise, they said that some rethinking of life-styles would be necessary before the vehicles could be mass-marketed for personal travel.

After hearing the concept statement, respondents generally agreed that EVs represent a workable transportation idea. Many of the participants felt that electric cars might be practical for them at some point in the future.

There appear, however, to be several wrinkles to be ironed out of the existing product. Very few participants indicated a willingness to bother with frequent battery recharging, particularly when they were on business trips that exceeded the range of the vehicle. There was also some concern about the price of regular maintenance. Some respondents expected to find a "technological fix" over the horizon. They felt that technological problems regarding the frequency of recharging and the cost of replacing batteries will soon be resolved. In addition to showing concern for how the EV would run, some group members were interested in the automobile's body styling for aesthetic as well as safety reasons.

Respondents in Tampa, especially the men, spent much time in the group ruminating about the hazards inherent with the batteries in EVs. They worried about inhaling the acid after an accident, explosions, the effect of the weather on performance, and atmospheric pollution.

Respondents seemed unwilling to accept the realities of EV technology.

For decades Americans have been led to believe that with the scientific expertise we have at our disposal, there is no problem we cannot solve. The significant breakthroughs that have been accomplished seem not to be viewed as marvels but rather as commonplace and routine. Solutions to complex problems are expected, and when they do not occur, consumers express intolerance. The standard complaint is, "If they can put a man on the moon, I don't see why they can't...." This attitude was certainly evident in these groups. There was resistance to accept the descriptions in the concept that EVs will have only a limited range, will take up to 8 h to recharge, that batteries will be large and heavy, and quick charges and spare batteries will not exist.

Many respondents had their own easy solutions. Some said the answer was to turn to the sun and the wind, which were certainly viewed as lower in cost than both gasoline and electricity and perhaps glamorous as well. The example of the battery-powered watch was heard more than once. Of all the drawbacks posed by EVs, limited range is the one that upsets people the most. Thus, the idea of self-recharging batteries was offered as a logical solution by several participants. Some people wanted to turn the EVs into miniature trolleys.

Participants appeared resistant to any major change in their driving habits, but grudgingly noted that they could see a limited use for an electric car within the American life-style.

In the final analysis, none of the respondents seemed to really want to have to make dramatic changes in their travel habits. Most admitted that they would probably have to be pushed into buying an EV by changes in exogenous factors such as gasoline availability.

Even as they said that they may not have a future choice in the matter, some participants still qualified their acceptance of the EV concept. In addition, many thought the electric car would be a limited-use vehicle.

Although the participants in these groups had more than one car at their disposal, they seldom thought in terms of fleets, except perhaps for long versus short trips. Even more remote from their thinking is the idea of special-purpose vehicles. People are now accustomed to thinking of their cars as essentially interchangeable, especially with regard to range, and it is their desire that EVs also fit into this mold. Carrying this logic further, if a vehicle is going to be less versatile than its counterparts, it certainly should not have as high a price tag. Individuals are unwilling to pay as much, or more, for an EV that has such limited usefulness compared with gasoline-powered cars.

Inherent in the EV concept is the idea of having to give up something. The higher costs of owning and operating conventional cars already seem to be perceived as sacrifices. The prospect of having to resort to limited-performance EVs cuts further into another corner of the American dream.

It was clear that self-interest, rather than concern for some greater common good, will be the driving force if EVs are ever to be accepted. No one in these groups saw EVs in a positive light because they will decrease our dependence on foreign oil. People do not think in such global terms (literally or figuratively). People are concerned about their own (often short-range) needs, which typically translate into, Will gasoline be available to me and how much is it going to cost? To promise vehicle owners that they will not have to worry about gasoline shortages because they will use electricity instead did not interest them. This was not viewed as an opportunity for freedom but simply changing the name of the captor.

Respondents speculate that electric power may be an appealing alternative now because it is generally in plentiful supply. But what will happen, they ask, if EVs really catch on and the demand for power increases dramatically? They envision power shortages in the same way we have experienced gasoline shortages in the past. Such concerns came to the fore especially in Tampa, which has apparently experienced brownouts in recent years.

In addition to availability, consumers worry about cost. Again, this issue was discussed more vehemently in Tampa, in part because electricity there is considerably more expensive than in the other cities surveyed. The rate in Tampa is 5.346¢/kW-h, more than twice the rate in Sacramento and almost three times the rate in Spokane. Spokane residents realize that they now enjoy some of the cheapest electric power available anywhere in the country. But at a time when energy sources seem to be a here today, gone tomorrow phenomenon, they do not take that reasonable cost structure for granted.

There was definite reluctance to believe that, as the EV concept presented to the respondents states, "fuel in the form of electricity will only cost half as much as gasoline would for the same miles traveled." Thus, given the choice between the known (high gasoline prices for vehicles with high flexibility and long range) and the unknown (EVs, which are perceived to be costly and have severe drawbacks), consumers appear to be more likely to opt for the known. Without the motivation of a crisis in gasoline supplies, encouraging many consumers to consider EV alternatives is going to be a very tough sale.

CONCLUSIONS

The focus-group results suggest some tentative conclusions on the potential market for EVs and on the factors that are important for the consideration and choice of such vehicles. The qualitative findings are consistent with many of the previous quantitative analyses that estimate a very small market share for the type of EV likely to be available in the near to medium range (5).

The analysis of the focus-group data suggests that there is at best a very limited market for EVs in the near term. Barring major transportation fuel supply interruptions, EVs will remain largely a novelty. The principal barriers to consumer acceptance are limited range, long recharge periods, and the high costs of batteries. Among women, especially housewives, limited passenger room and cargo space may also be an acceptance barrier.

Some of the conclusions from the focus-group studies are as follows:

1. Responding households tend to use their smaller cars for the bulk of their around-town driving, but often bring the older, larger vehicles out of the garage for longer trips.
2. As gasoline prices soar, many people have been attempting to trim their bills by cutting back on short shopping trips, riding in company vans to work, or easing up on the gasoline pedal. Because their new cars do not guzzle gasoline, a few participants noted that they feel that they can now drive more than before without feeling guilty.
3. Many believe that Americans may have to lessen their dependence on the automobile, but alternative forms of transportation to the gasoline-powered car do not seem to be very attractive. Public transportation is generally perceived as inadequate, and new fuels such as diesel, methane, or propane (or even those generated from the sun or water) are considered too experimental to be useful to the public in the near future.
4. In theory, the EV concept seems to appeal to consumers as an acceptable means of transportation. However, they do view the EV's battery limitations as posing major barriers to acceptance. These limitations include limited range, long recharge period, and high battery replacement cost.
5. Car owners admit they will not easily accept radical changes in their driving habits, but some seem to see a potential limited use for EVs.
6. The market segment studied in this project contains some subsegments that might be more amenable to EV use than other subsegments. The more likely EV subsegments are better educated, younger, and of higher-income households of related individuals. However, households of individuals with these demographic traits, but not related as a family, probably do too much independent traveling and too little ridesharing to accommodate an electric car.

There were noticeable differences in responses of participants to the EV concept between cities. Tampa respondents tended to be most negative and Sacramento participants were most positive toward (but certainly not wholeheartedly embracing) the EV concept. However, it is premature, based on this limited evidence, to flatly assert that Sacramento presents the most favorable market for EVs. Many alternative explanations for the perceived differences in response between sites are possible. These explanations include differences in recruiting techniques, changes in the discussion guide, and moderator skill improvement. Differences in the socioeconomic composition of the driving population, driving patterns, and cost of electricity (which is high in Tampa compared with Spokane and Sacramento) may have also influenced responses across sites. The group results suggest a hypothesis that attitudes, life-styles, travel patterns, and economics may favor EV acceptance in Sacramento and Spokane relative to Tampa, but this hypothesis remains to be rigorously tested by using quantitative data. On some dimensions (e.g., fuel cost and air-conditioning availability), it may be that the EV is more attractive in Spokane than in Sacramento, but this also remains to be tested. Such hypotheses could be quantitatively explored by using the consumer preference card ranking data collected from respondents at the end of each session.

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The Mobility Enterprise: Improving Automobile Productivity

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The mobility enterprise is a particular version of a shared-vehicle fleet, which attempts to solve the problem of low automobile productivity. The automobile operates much of the time with unused capacity, i.e., vacant seats and empty cargo space. Because programs to fill those vacant seats (e.g., promotion of ridesharing and high-occupancy vehicle use) have fallen far short of their objectives, a new approach is warranted. The enterprise's central concept is matching vehicle attributes to travel needs. Generally, a household purchases vehicles for those few trips that require a large capacity rather than for the majority of trips (usually to work) that have minimal vehicular needs. If a household could tailor its "immediate access" fleet to these frequent trips and still retain reasonable access to larger-capacity special-purpose vehicles (SPVs), considerable economies could be achieved. The household is relieved of owning seldom-used excess capacity, and automobile productivity and efficiency are greatly improved. Having easy access to a shared fleet of SPVs also affords a household an increase in the quality and economy of its travel experiences. This paper discusses questions of institutional barriers, consumer response, and organization and management that are keys to the fate of the enterprise in the transportation climate of the foreseeable future.

The mobility enterprise proposes a sharing among its participants of special-purpose vehicles (large sedans, trucks, recreational vehicles, and so forth) in order to relax the multipurpose requirements of the family car or cars. Research recently begun at Purdue University is aimed at determining how this concept might become a practical reality.

After years of promoting public transit and carpooling to conserve energy, planners and analysts have begun to recognize that many consumers prefer the convenience of the personal automobile. At the same time, automobile efficiency (fuel economy) has undergone significant improvement while automobile productivity has remained disturbingly low (1,2). Currently, the automobile industry is engaged in a series of redesigns aimed at improving fuel economy. These measures involve a conversion to front-wheel drive, use of lighter-weight materials, and a continuation of vehicle downsizing. But these improvements will be achieved at an ever-increasing cost (1,3,4).

There are undoubtedly a variety of measures for improving automobile productivity. The enterprise concept explores the potential for appealing to that large market segment that has been unresponsive to ridesharing programs. It is based on matching more closely a person's trip requirements to vehicle characteristics. Three features of a mobility enterprise--retained automobile autonomy, easy access to an expanded fleet, and reduced expenditures--are the keys to its success. They are interrelated. An enterprise member's minimum attribute vehicle (MAV) provides him or her, by definition, with the most economical means of accomplishing the most frequent trips. When a trip can be made by using their own MAV, members know they can travel without delay. When a member's MAV is inappropriate for a desired trip, he or she must seek access to the appropriate special-purpose vehicle (SPV). This process may involve delays if the vehicle is garaged elsewhere. It may also involve some advance planning, paperwork, and out-of-pocket costs, depending on the procedures of the enterprise. There is even the possibility that the desired vehicle may not be immediately available because of a prior reservation. Such departures from guaranteed access and instant gratification are aspects of the mobility enterprise that must be offset by clear benefits. Such benefits appear to be possible, since the enterprise can offer several improvements:

1. Wider range of vehicles available for temporary use by an individual,
2. Less-complex set of criteria in buying a car,
3. Trip and ownership economies that can be translated into more disposable income or increased mobility, and
4. More efficient use of society's scarce or expensive resources.

SOME OBSERVATIONS

Capabilities of Personally Owned Automobiles Significantly Underused

Although approximately 80 percent of the trips in this country are taken in vehicles with more than four seats, only about 20 percent require a vehicle that large (5). A car buyer typically considers the maximum number of people, pounds of cargo, or degree of performance that he or she will have to use a certain (often very small) fraction of the time. The result is lengthy off-peak periods with underused capacity. The range requirements for a large percentage of tripmaking are also remarkably low. For example, a golf cart with a 30-mile range and higher speed capability has attributes sufficient for about 70 percent of all trips made.

People Prefer to Drive Themselves

Ridesharing and public transit promotions have failed to generate a widespread willingness to give up the flexibility, accessibility, and personal autonomy associated with individually owned vehicles. Taken together, these higher-occupancy modes still account for only a small amount of the peak-hour travel (2). The prospects for seat filling, therefore, appear less bright than promoting the better use of individually owned vehicles.

Transportation Expenditures Remain Nearly Constant

The increases in the real costs of travel during the past eight years have meant a slightly greater proportion of a household's disposable income being spent on transportation and a reduction in the amount of travel by a household (6). Both trends represent a deterioration in mobility.

The proportion of personal consumption expenditures (PCE) devoted to transportation, which was fairly constant at 12 percent since 1950, rose steadily in the 1970s from 11.9 to 13.6 percent (7). Sudden gasoline price increases had the added effect of curtailing vehicle miles traveled (according to news items from the Federal Highway Administration in May 1980 and August 1981).

Enterprise Idea a Familiar One

The idea of sharing a high-dollar-value item by rotating its use is not new to this country, as the recent increases in shared-vacation real estate indicate. In the area of transportation, the renting of recreational vehicles has proliferated in response to rapidly rising purchase and operating costs. In these and similar cases, individuals have pooled their resources to acquire capabilities they could not reasonably have as individuals. They have made commitments and sacrificed some autonomy to enlarge their options.

Although a majority of the European experiments have been of the "drive it and leave it" variety (starting, predictably, with bicycles), others more clearly resemble the plan envisioned here. Notable among 11 European projects are (a) the "White Bicycle" program begun in the Netherlands in 1965, which lasted two years, and (b) the more recent "Paydrive" shared-car rental scheme in the United Kingdom, which has been in operation since 1979. The bulk of these experiments were carried out with little or no government support, and the overall status of such enterprises in Europe is considered to be "fairly healthy" (8).

Different Demographic Groups Have Different Tripmaking Needs and Vehicle Ownership Patterns

Travel needs differ for a variety of factors such as age, occupation, household size, and income level. Enterprises based in retirement communities, commercial centers, and high-rise residential zones will encounter different travel patterns. In fact, in some cases demographic homogeneity of membership may render the enterprise impractical. A mix of members may be necessary. The seasonal variations of travel patterns and special vehicle needs must also be anticipated, either in terms of membership mix or fleet makeup. Persons of different income levels will have different perceptions of their MAV (described later) and may require significantly different services from the enterprise.

ENTERPRISE DESIGN CONCEPTS

In a successful mobility enterprise, membership should enhance rather than limit the quality of individual mobility. Certain basic structures suggest themselves:

1. Diversified rental fleets: Rental agencies add SPVs (mini-cars, recreational vehicles, and so forth) to their existing car and truck fleet to provide a full range of vehicles. They can offer streamlined discount reservation service to enterprise card holders.
2. Broker-based enterprise: Existing rental companies or new organizations can offer an enterprise management package. It can be assembled by a broker on a subscription or sign-up basis, or "natural enterprises" (neighborhood or employee groups) can work out their own deals.
3. Enterprise-controlled broker scheme: The broker carries out administrative, storage, and maintenance functions under guidelines set by the enterprise. The enterprise may meet monthly to review rules and operations, and the broker may have the right to advise on rules, renegotiate agreements, or insist that financial liability be restricted to enterprise members.
4. Pure enterprise: Enterprise members (probably neighbors) carry out all functions internally through periodic meetings, rotating committees, and so forth.
5. Automobile company enterprise: Automobile manufacturers, working through their dealers, may consider the possibility of selling transportation rather than just automobiles. Each automobile agency could sell or lease the personal MAV to enterprise members. Then it could provide and manage the special-purpose fleet.

These five basic structures are a starting point. They begin the process of formulating and testing the operation of a mobility enterprise. Within a given structure, a variety of schemes can be devised to address questions of enterprise size, membership qualifications, fleet composition, scheduling, reservation system, fees, financing, maintenance, pickup or delivery, insurance, and legal problems.

RESEARCH ISSUES

Research issues related to the mobility enterprise cover a broad range of disciplines: economics, management, law, sociology, operations research, engineering, design, and so forth. The issues described in the following sections require considerable interaction among researchers in the various disciplines. The research needs and data requirements presented are only suggestive at this point, in that in-depth research tasks are still being formulated. For this presentation, we consider four broad categories for research.

Enterprise Membership: Attractions and Obstacles

The demand for mobility enterprises with various alternate designs must be estimated. To do this, an understanding of consumer choice mechanisms is required. Two complementary strands of research activity--disaggregate demand modeling and investigations of social behavior--have produced results that can be of use.

The heart of the enterprise project is to evaluate travel choice by matching trip requirements (a set of attributes) to vehicle characteristics (a set of attributes). Thus, the cost, roominess, performance, range, and comfort of the various automobiles, when matched with necessary trip attributes, determine vehicle choice.

Research will focus on three related decisions: the form of car ownership, vehicle type choice, and vehicle use. The car-ownership decision (e.g., to rent or to buy) is postulated to be determined by the accessibility and cost characteristics of the vehicle and by the socioeconomic characteristics of the individual. Choice of vehicle type is conditioned by the attributes already mentioned (roominess, efficiency, and so forth), while vehicle use is determined by the operating cost of the vehicle and current travel needs of the families.

In addition to economic considerations, a number of social and psychological variables may be significant in the recognition of potential barriers to a successful venture. What kinds of people are typically attracted to such enterprises? Is self-organization more of a middle-class phenomenon? Do the less affluent have a greater need for sharing SPVs? What kind of enterprise structure is most functional, and does function vary by type (food, agricultural, and so forth)? What is the best method for getting people to join the enterprise: word of mouth, media advertisement, or an appropriate combination of both? In fact, how much can be generalized from nontransportation enterprises to mobility enterprises? Answers to these and other pertinent questions could be crucial to the outcome of the project.

Another concern is the cargo-carrying capacity of the MAV that might be covered by an ancillary organization such as a commercial goods delivery system. A major obstacle to asking consumers to give up their large automobiles is their persistent need for consumer goods transportation (e.g., groceries, small appliances, and small furnishings). In a sense, people now take their "cargo vans" with them everywhere they go. In the past, when mass transit was more widely used, merchant delivery systems were commonplace. Demand for such services decreased, however, as personal mobility in large cars increased. An enterprise based on a merchant delivery scheme can be marketed not as an exercise in self-restraint but as a liberating convenience. The participant becomes liberated from the expense and bother of maintaining a personal fleet and the burden of inefficient transportation of goods.

Vehicle Characteristics and Fleet Operations

MAV Design

The MAV may be defined as that vehicle that would meet the highest percentage of the transportation requirements of the household. It may be already apparent that the selection of the MAV is traveler specific, and the attributes of the MAV help determine how much access to the shared fleet would be necessary. There would not necessarily be a universal MAV, at least not in every detail. The configurations of the MAV will be of interest to the project's researchers and, ultimately, to the automobile industry. The central question here becomes, What are the characteristics of the MAV and how do they vary with the socioeconomic characteristics of the families?

Shared Vehicle Fleet

Given a fixed number of members, how many shared vehicles should be purchased? Bounds can easily be set: no more than enough to guarantee availability "on call" and no fewer than the number based on 100 percent utilization, i.e., perfect scheduling. The optimum number should be based on a comparison of the marginal cost of an additional vehicle with the value of the declining marginal increase in accessibility associated with that vehicle. The number of members is also important. It will be shown below that, given a fixed probability of use by each member in an interval of time and a fixed number of vehicles per member, the larger the number of members, the more accurately shared use can be predicted. This increased predictability allows a decrease in the shared-car safety margin necessary to ensure that a car is available, thus decreasing the cost of the enterprise to its members.

Types of Services

All of the possible types of services that can be offered by the proposed enterprise system should be explicitly identified. Hours of operation, methods of pickup and drop-off services, and so forth must be considered.

It will be necessary to develop a set of service functions and determine the demand for the level of each service. For example, the expected delay in getting a desired vehicle will depend on the number of customers predicted for this type of vehicle during a given time period. An appropriate relation can be developed to represent delay as a function of volume (9).

Reservation System

How shall a reservation system work? Recent advances in minicomputers will probably allow the development of an interactive scheduling network that will permit reservations to be processed at fairly low costs. Nevertheless, the concept of a shared, prescheduled fleet, with each member having a terminal where he or she can check the current status of the idle fleet and make reservations, requires careful planning and experimentation.

Pricing System

Another major issue, of course, will be how the system should be priced. Will guaranteed access be allowed at a price? Will there be a "parking sticker" system with a different fee for differing likelihoods of access? Will people reserve and then not use a car? (A penalty system based on the airlines' experience is a possibility.) Should the reservation system be based on a first-come first-served basis, on rewarding planning, or on a continuous auction of time slots with the possibility that someone would be "bumped" at the last minute by someone willing to pay more? Should peak-period users be charged a premium? If so, should the proceeds be used to subsidize off-peak users or be used to purchase more cars, thereby increasing peak-period capacity? Efficiency and equity trade-offs will be involved in the final selection.

Organization and Administration

Any organizational structure suggested for a mobility enterprise can be evaluated in terms of how well it is suited to operational requirements and members' attitudes. Certain universal considerations apply.

Membership Mix

A basic issue is the diversity of enterprise member characteristics. The optimum amount of diversity is clearly an open question. It would be impractical to have the population so homogeneous that there would be peak load problems for particular vehicles. That is, if the enterprise consisted primarily of college professors, many members might want a recreational vehicle in order to go on vacation at the end of a semester. Some amount of diversity in the membership of the enterprise would be necessary to balance the loads over time. Conversely, too much diversity may result in missing some scale economies that would be present if there were fairly large use of a particular type of vehicle.

Legal and Institutional Matters

With respect to societal reaction to the enterprise concept, in general or with respect to transportation, what have been the main legal, institutional, or other factors that have aided or impeded their development and use? What laws (e.g., automobile licensing, insurance regulations, reserved parking spaces, tax legislation) will make it easier or harder for the enterprise to survive? If MAVs are a key to success, will it be necessary to get special legislation to allow them on the streets? In a more heterogeneous transportation modal environment, how would traffic safety be ensured?

Demonstration Project

A large-scale demonstration will likely be necessary at some point to prove the concept. Before that, there is need for some small-scale experiments in scheduling, vehicle design, and consumer behavior. A simulation model (9) will help choose the best combination of strategies to employ in the actual demonstration project.

Table 1. Comparison of automobile-ownership alternatives.

Alternative	Vehicle Type	Vehicle Price ($)	Ownership Cost ($)	Operating Cost ($/mile)	Miles Driven	Total Annual Cost ($)
1	GAV	8100	1851	0.18	10 000	3656
2	MAV	3800	626	0.13	7 000	1512
	GAV[a]	8100	757	0.18	3 000	1280
Total[b]			-	-	10 000	2792

[a]Alternative 2 GAV averages 0.4 vehicle/member. [b]Totals are on a per-member basis for alternative 2.

Table 2. Total vehicle expenses: major components.

Expense	GAV	MAV
Purchase price ($)	8100	3800
Value after four years (10) ($)	4133.69	3249.58
Avg miles per year	10 000	7000
Avg miles per gallon	25	45
Annual payments[a] ($)	2607.62	1223.33
Annualized present worth of resale ($)	756.70	596.81
Annual gasoline cost at $1.40/gal ($)	560	217
Maintenance[b] ($)	688.70	370.72
Insurance[b] ($)	555.96	297.96
Total annual cost[c] ($)	3655.58	1512.20
Total four-year cost[c] ($)	14 622.32	6048.80

[a]Interest rate = 0.13.
[b]Maintenance and insurance costs for $3000 vehicle are $0.05/mile and $250/year, respectively; these values increase linearly with purchase price.
[c]Includes depreciation.

How big should a demonstration program be? It is fairly clear that many of the major benefits of the enterprise to the traveling public will be evident only when a large enough fraction of the traveling public has joined the enterprise. For instance, congestion benefits that arise from a fleet of smaller vehicles will be felt only when those vehicles make up a significant percentage of the traffic stream. In addition, the safe operation of smaller vehicles will be enhanced when they comprise more than a small fraction of the traffic stream. The demonstration should be sufficiently large to examine scale effects on fleet operations. At that same time, questions concerning start-up and transition that are difficult to model must be at least partly answered.

PRELIMINARY ECONOMIC ANALYSIS

Economic Incentives

To complement the simulation model (9), an analytical economic approach is being developed. This approach begins by quantifying the possible economic incentives to join a mobility enterprise and then seeks an effective user fee structure.

Consider an individual who has the option of either buying a standard all-purpose family vehicle or joining the enterprise, where he or she will obtain a MAV plus access to a fleet of shared vehicles. Let us consider a modest case, wherein the standard family vehicle will be a compact car that costs $8100, has 25 miles/gal fuel economy, and would be driven 10 000 miles/year. The individual's MAV would cost, say, $3800 and get 45 miles/gal. Either car, if chosen, would be kept four years. If he or she joined the enterprise, assume the MAV would be useful for only 7000 miles of the household's travel each year, thereby leaving 3000 miles of travel to be made by higher-attribute vehicles. To simplify this first analysis, we will assume that the individual borrows the all-purpose car from a shared fleet to travel those 3000 miles that have special requirements.

Table 1 compares two alternatives. Alternative 1 is the common practice of buying a general attribute vehicle (GAV). Alternative 2 estimates the costs associated with owning or leasing a MAV while having access to a shared fleet of GAVs. GAVs are used only for trips in which MAVs do not suffice, so their per-driver mileage is only 3000 annually. But since they are shared among several users, their utilization rate (miles per vehicle per year) should increase, thereby decreasing per-mile costs. Table 1 is based on a ratio of 0.4 shared vehicles per enterprise member. The accuracy and impact of this ratio on the analysis and design is discussed later. Table 2 gives the assumptions used in the cost analysis. These, of course, are subject to modification and refinement as the research proceeds.

The difference between the $3656 yearly GAV cost and the $2792 enterprise cost is a measure of economic incentive to join the mobility enterprise. The notion of economic incentive assumes that an individual makes such a rational economic assessment. Modal choice in urban travel has traditionally defied pure economic rationality, but increased travel costs have caused some recent modal shifts to ridesharing, if not to transit. Furthermore, the level-of-service differences are so small in this MAV versus standard car comparison, especially when compared with the magnitude of the total cost disparity, that this analysis merits proceeding further.

A GAV-only household pays $3656/year for its automobile travel. Switching to a MAV for 7000 miles results in total costs of $1512. The remaining amount, $2144, can be spent on the shared vehicle for the 3000 miles for which the MAV is unsuited. If the household does not choose to use a shared GAV that much, its membership in the enterprise can enable it to decrease its total travel budget even further.

Managing the Shared Fleet

The proper ratio of shared cars per member depends on member demand. Let the probability that a given member will want to use a shared vehicle during a time interval t be P_t and assume that all members have the same probability. The value of P_t will be influenced by the socioeconomic characteristics of the member, the attributes of the MAVs, and the shared fleet's pricing policy.

Preliminary consideration of the dependence of the probability that no shared car will be available--the failure probability--on P_t, the number of shared vehicles, and the number of members has produced some interesting results. Let P_t be the same for each household during time interval t, m represent the size of the shared-vehicle fleet, and n represent the number of households in the enterprise. If α represents the number of vehicles actually demanded in time interval t, the probabil-

Figure 1. Shared-vehicle availability.

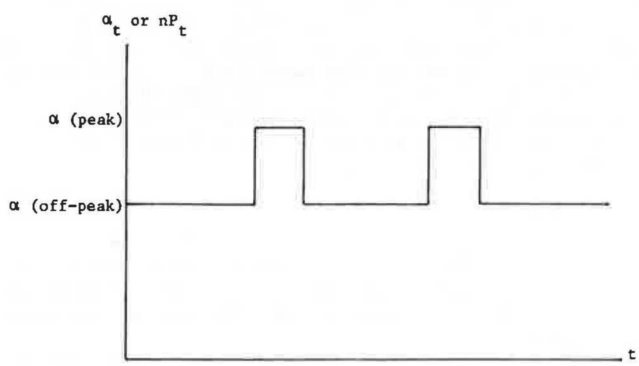
Assume Enterprise has 40 members (n=40) and ...

Number of cars in shared fleet (m)		P_t = .40	P_t = .50	P_t = .60
	m = 16	.56 (.5)	.92 (1.0)	.99 (1.0)
	m = 20	.13 (0)	.56 (.5)	.87 (1.0)
	m = 24	.008 (0)	.13 (0)	.44 (.5)

Cell Entries = Pr (cars demanded exceeds supply) = Pr (α > m)

P_t = Pr (each member wants car)

Figure 2. Time-demand diagram.



ity that more than m cars will be demanded in t is as follows:

$$\Pr(\alpha > m) = \sum_{\alpha=m+1}^{n} \binom{n}{\alpha} P_t^{\alpha} (1 - P_t)^{n-\alpha} \quad (1)$$

A simple example (n = 2, m = 1, P_t = 0.5) produces Pr(α > m) = 0.25. Figure 1 shows how the failure probability for a fixed number of members is influenced by changes in P_t and m. Further, it can be shown that Pr(α > m) approaches the following limiting values as n increases, holding m/n and P_t constant:

$$\Pr(\alpha > m) = \begin{cases} 0 \text{ if } m/n > P_t \\ 0.5 \text{ if } m/n = P_t \\ 1.0 \text{ if } m/n < P_t \end{cases} \quad (2)$$

These limit values for Pr(α > m) are the parenthetical cell entries in Figure 1. Large enterprise membership will bring with it greater certainty that sufficient cars are available; this increased certainty must be traded off against possible diseconomies of scale, which leaves the optimal membership size to be determined.

Another trade-off involves the use of a peak and off-peak price differential to decrease peak P_t and the purchase of more cars; both reduce failure probability at the expense of the consumer. Early modeling efforts reveal the peak/off-peak pricing structure to be a potentially complex and delicate area. Certainly, P_t and therefore Pr(α > m) will vary between time intervals t. A time-demand diagram for a representative family or for the membership as a whole (Figure 2) illustrates this variation. In designing a mobility enterprise's shared fleet, we can directly vary fleet size (m) by simply purchasing more cars, but we can only influence P_t by a peak/off-peak differential use charge. Influencing P_t, especially with respect to variations with time, requires as much a clear concept of management objectives, as it requires an accurate understanding of consumer response to management actions. The classic confrontation between efficiency and equity seems to arise here, as does a need to develop accurate information regarding peak-period direct price elasticities and peak-period price and off-peak use cross elasticities.

We could set fleet size m so high as to cause Pr(α > m) to approach zero, but at such a considerable cost that user fees would be prohibitive. Efficiency argues that we manage the peak demand to maintain shared-vehicle availability at minimum cost. If we are determined to minimize the cost of ensuring that Pr(α > m) = 0, we can institute some congestion pricing scheme to drive off some peak demand. The extra revenue so generated can be applied either to (a) increase the fleet size or (b) provide a subsidy to off-peak users. Option a seeks an equilibrium that provides better peak service to peak users as a direct result of the peak surcharges. Option b transfers this extra revenue within the enterprise and rewards those who avoid the peak periods. Both options carry elements of efficiency and equity, and it may be that a combination of the two may be most effective.

The use of congestion revenues may induce some members to switch to off-peak times, others not to use the shared fleet at all, and some even to drop out of the group. Quantifying the first action requires a knowledge of cross-elasticities between time periods with respect to fares, a brand of information in very short supply [as American Telephone and Telegraph (AT&T) found out in its now classic long distance dialing peak/off-peak price experiments]. Analyzing the decision not to use the shared fleet at all involves a knowledge of direct elasticities. The need for both sorts of information will require a specific data-gathering and survey effort. Analysis of option b (the extent to which peak demand is curtailed and off-peak use is subsidized by a transfer of revenues) involves the same possible membership responses and data need.

A moment's reflection on the possible extreme shapes of the time-demand diagram (Figure 2) gives us some clues as to the type of information we should gather. If the diagram had no peaks (P_t or

α essentially constant with t), no peak surcharge would be necessary and $m = \alpha = nP_t$ would be the ideal fleet size. If the diagram had very pronounced peaks, might we expect very inelastic demand for those periods? Not necessarily. The peaks may simply reflect multitudinous, but mild, preferences expressed in the absence of surcharges. Data on the substitutability or changeability of expressed time-of-travel choices must be collected.

A survey instrument is currently being refined that will attempt to gather preliminary data regarding trip substitutability and advance planning. The survey has two objectives:

1. To determine what techniques the enterprise could use to effectively and equitably reduce temporal variations in shared-vehicle demand, and
2. To determine the optimal mix of attributes to look for in the enterprise's shared GAV, once the MAVs attributes have been established.

Demographic information will be cross-tabulated with various data obtained from retrospective trip diaries. In addition, it will be necessary to bracket a dollar saving per household, which must be present in order to elicit any trip planning or postponement on the part of prospective members. Initial work has begun in the area of focus-interview formulation as a necessary precursor to the actual survey instrument. Preliminary data should include not only the current trip demands of a wide cross section of family units but also the degree of education with regard to the concept of vehicle sharing and MAVs that will be needed in order to obtain valid survey results. The concepts of a mobility enterprise will be foreign to many interview (and survey) participants; therefore, education of the respondent is a necessary step in ensuring validity from these techniques. Once the survey instrument is refined, it is planned to be administered locally, regionally, and nationally.

A simplified but illustrative relation between MAV and shared-GAV attributes is given in the table below:

MAV Price ($)	Shared Vehicles per Member
6210	0.40
5720	0.425
5240	0.45
4750	0.475
4260	0.50
3770	0.525
3280	0.55
2790	0.575
2310	0.60

As MAV attributes decrease (represented by decreasing price), the need for access to a GAV must increase. Fortunately, so does the amount of money available to each household after the MAV purchase. Translating the resulting demand rate for shared GAVs into the expected required shared-fleet size produces the column on shared vehicles per member. This relation indicates a potentially delicate trade-off. The more economical a MAV, the less versatile it is likely to be. How much versatility can an enterprise member retain before the efficiency of the MAV is lost and/or the advantages of access to a GAV fleet are nullified?

SUMMARY

The goal of the mobility enterprise is to improve automobile productivity by matching individual trip requirements to vehicle characteristics. Within this framework, some specific objectives are to

1. Predict the membership of such an enterprise according to the probable public reaction vis-à-vis automobile autonomy, access to an expanded fleet, and reduced expenditures;
2. Consider basic enterprise service structures (e.g., diversified rental fleets, broker-based enterprises, and so forth);
3. Research issues in the various disciplines (e.g., law, economics, sociology, operations research, and so forth) as they relate to the enterprise concept;
4. Determine the user fee structures that achieve the best combination of efficiency and equity;
5. Describe appropriate vehicle characteristics and designs; and
6. Develop a large-scale demonstration model that involves scheduling, vehicle description, and consumer behavior.

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Business and Travel Impacts of Boston's Downtown Crossing Automobile-Restricted Zone

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The findings from the downtown Boston automobile-restricted zone project are presented. In contrast to other pedestrian and transit malls, Boston's Downtown Crossing project involved the elimination of all automobile traffic within a zone of 12 blocks, which included 6 different streets, plus improvements to bus service in the area. Travel and business patterns were observed before, during, and after construction of the new pedestrian zone. There were continuing increases in pedestrian volumes following initiation of the automobile restrictions. At the same time, there were major shifts from automobile to transit and walking as the means of traveling to the area, and much of the anticipated increases in traffic volumes on diversion routes did not occur. The historical trend of decreasing retail activity in the downtown area was halted since implementation of the project, although the relation between automobile restriction and long-term economic revitalization is complicated by a variety of other factors that occurred simultaneously.

The Downtown Crossing project was developed with the specific objective of improving the urban environment of Boston's downtown retail district through the implementation of an automobile-restricted zone (ARZ). The project involved much more than simply restructuring traffic patterns to reduce the impacts of the automobile, however; it also included elements to provide better pedestrian facilities and urban design features and to encourage transit use.

During the past two decades, more than 100 U.S. cities of varying sizes have instituted some form of ARZ. The technique most frequently implemented has been the closure of the main downtown shopping street and its conversion to either a pedestrian or a transit mall. The Downtown Crossing project, in the true sense of an automobile-restricted "zone", was an effort to move a step beyond current programs in the United States that have tended to be somewhat piecemeal in nature and address the issues of environmental improvements and traffic restriction in a coordinated and comprehensive way over a major segment of the city center. This paper summarizes the characteristics of the Downtown Crossing project and discusses the changes in travel patterns and business activity that were associated with it.

OBJECTIVES

The primary goals of the ARZ project were to address three classes of problems:

1. Travel: Travel within the central business district (CBD) was characterized by vehicular congestion on the streets, pedestrian congestion on the sidewalks, and a high level of pedestrian and vehicle conflicts. The Downtown Crossing project separated vehicular traffic from the main shopping streets that had high pedestrian volumes and widened sidewalks on other streets to help create a more safe and pleasant walking environment. Transit use was encouraged through the addition of bus service to the ARZ. The automobile traffic pattern, long plagued by a confusing maze of noncontinuous one-way streets, was streamlined into a more direct pattern of primary streets, and traffic flow was further improved through elimination of on-street parking in the area.
2. Physical environment: The image of the retail area was unattractive. Much of the area was made unpleasant by crowding, conflict with automobiles, noise, pollution, and a neglected physical environment. The project sought to attract more people to the area and to encourage those already there to stay longer. To achieve this, there were physical improvements, including the development of mini-parks and bench areas, and programs for improved police enforcement, maintenance of the physical setting, and management of activities in the area.
3. Economic revitalization: Together, the transportation system changes and the physical environment improvements were intended to support and expand the market for downtown retail activities and to add impetus to the preservation, enhancement, and revitalization of the downtown area.

PROJECT OVERVIEW AND HISTORY

The ARZ includes an area of 12 blocks, which affects 6 different streets in the core retail area. Automobile traffic was banned on three blocks of the main retail street, Washington Street. This street section was originally a transit mall, but much of it is now a fully pedestrianized zone. Another major retailing street that intersects Washington Street is Winter Street/Summer Street, which was also closed to automobile traffic and converted to a pedestrian zone. Automobile restrictions were also implemented on sections of four other streets.

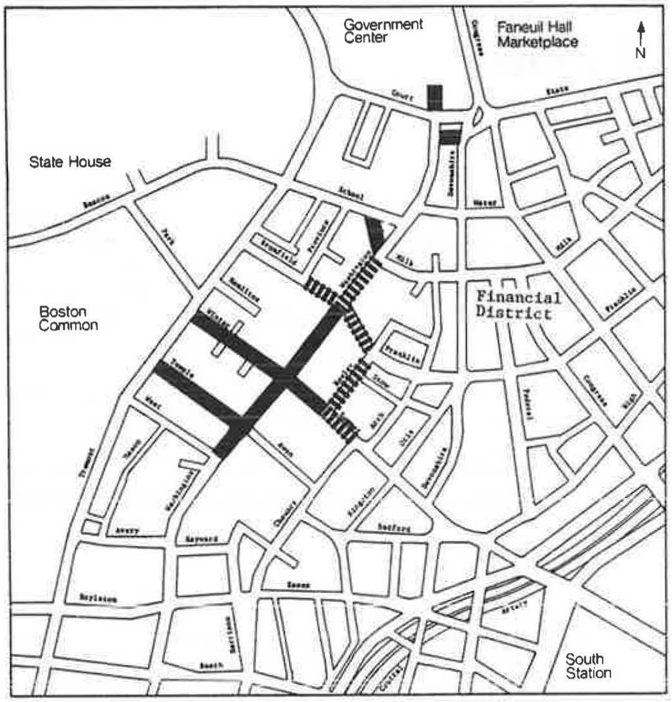
The project was planned and implemented in a relatively short time period. The initial consultant feasibility study and alternatives analysis were conducted as part of the Service and Methods Demonstration (SMD) program of the Urban Mass Transportation Administration (UMTA) and were completed in September 1977. Within a year, the final design plan was developed, an implementation strategy was agreed on, funding was secured, and construction for the special bus lanes was completed. The ARZ and transportation circulation policies were officially implemented in September 1978. Physical improvements, such as bricking of the street surfaces and the placement of benches, new lights, and other pedestrian amenities were essentially completed by September 1979. Total capital costs were \$3 million, of which slightly more than half was funded by the Federal Highway Administration (FHWA) and UMTA and the rest by the City of Boston. An additional \$2 million of UMTA SMD funds paid for noncapital elements including promotion, parking and traffic enforcement, maintenance, and new bus operations.

KEY PROJECT FEATURES

Automobile Circulation

As shown in Figure 1, automobile traffic was eliminated from a zone of 10 continuous blocks in the core retail area and segments of 2 other nearby streets. Some of the automobile-restricted blocks (shown by dashed lines on the map), however, remained open for taxis. Two additional blocks were originally closed to automobile traffic but were reopened six months later. The traffic circulation plan also involved the reversal of one-way traffic on several streets and the elimination of all on-street parking in a large area around the ARZ.

Figure 1. Automobile-restricted streets.



Closed to traffic

Closed to general traffic but open to taxis

Originally closed to general traffic; later re-opened

Pedestrian Space

The plan provides increased space for pedestrians on the more congested shopping streets. The pedestrian zones on Winter, Summer, and Washington Streets received new brick paving, lighting, plantings, information kiosks, and bollards. Benches were placed on Summer Street. There were major sidewalk widenings on several other streets, and segments of two streets were converted into park space.

Transit Circulation System

For the first two years, six local bus routes and four express bus routes were extended into the Downtown Crossing area, lengthening each of the routes from 0.5 to 1 mile in length. A transit priority route was developed, which used a combination of exclusive transitways and contraflow bus lanes to permit the buses to operate primarily on traffic-free routes and, hence, to serve the heart of the retail core with minimal interference from other traffic.

Originally, Washington Street was a transit mall with limited delivery access. After eight months of operation, the bus loop was modified to eliminate the buses from Washington Street during its reconstruction and bricking. After construction, the bus lane on Washington Street was not reopened due to the earlier experience of pedestrian and bus conflicts there.

Service Access

Service vehicles have been allowed on all the pedestrian and bus streets before 11:00 a.m. with the exception of one block of Summer Street where there are no delivery requirements. After 2:00 p.m. the streets are open only for time-sensitive deliveries such as the U.S. mail, newspapers, etc.

Taxi Access

Taxis are allowed access to Temple, Hawley, Bromfield, and Franklin Streets for pickups and drop-offs, and a number of new taxi stands were provided within the area. In the evening, taxis are allowed to proceed up Washington and on Winter.

Signing System

A signing system to orient and inform motorists of the new rules was implemented as part of the traffic circulation system. A system of pedestrian signs and information kiosks provides publicity and information and helps orient pedestrians to the whereabouts of retail shops, bus stops, and taxi stands.

Ongoing Support Elements

The project plan included special funding for (a) enforcement of parking restrictions and assignment of additional officers at key intersections, (b) upgraded maintenance of the area, (c) programs to promote the area, and (d) a subsidy to cover the operating expenses of 10 bus route extensions into the area.

IMPACT EVALUATION EFFORT

Whereas previous evaluations of impacts of ARZs have been limited by a lack of comparable preproject and postproject data, the Downtown Crossing evaluation effort included the collection of information on conditions in the study area before implementation (June 1978), during construction (June 1979), and after project completion (June 1980). The data collection included more than 11 000 surveys in each of the three years, with separate surveys of pedestrians, area employees, bus riders, parking lot users, and merchants. In addition, traffic counts, pedestrian counts, shopper counts, and transit passenger counts were made at 120 locations around the project area. The data-collection effort included measurement of air quality and noise levels; inventories of business establishments, floor space area, and land values; crime and accident reports; and photographic records. Findings from these data are presented elsewhere (1).

Comparison of before and after changes in travel and business patterns are, of course, just one component of a project impact measurement. It is also necessary to make judgments as to what changes in those patterns would have occurred over the same time period without the project. Realistically, that assessment depends on observation of past trends and consideration of other simultaneous local factors that affect travel and business patterns. Inherent in the analysis design is the contention that much can be learned from observing the shifts over time in traffic volumes, modal split, and retail sales associated with implementation of the Downtown Crossing project, even if some of those changes can be attributable, in part, to factors outside the project.

EFFECTS ON PEDESTRIAN ACTIVITY

The primary objective of the Downtown Crossing project was to encourage pedestrian activity and ultimately strengthen the retail economy of the area. Following an historical trend of decreasing patronage of the core retail district, the project clearly succeeded in increasing pedestrian activity levels.

Figure 2. Daily volume of visitors in Downtown Crossing area.

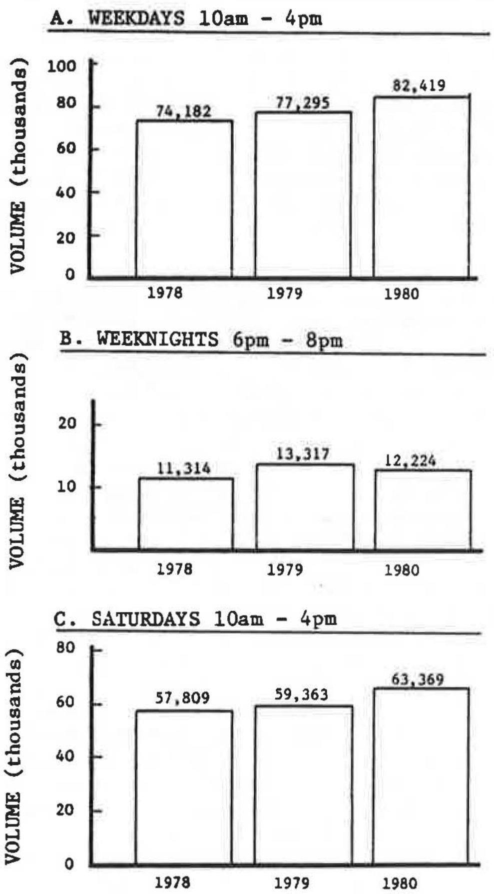
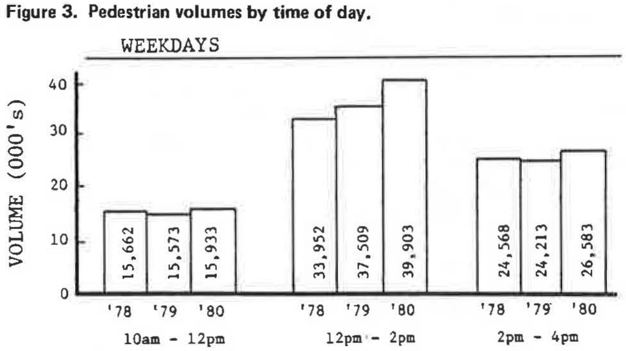


Figure 3. Pedestrian volumes by time of day.



As shown in Figure 2 (data from 1978-1980 pedestrian counts), the number of pedestrians entering the Downtown Crossing area increased following the restriction of automobile traffic (which occurred after the 1978 survey) and continued to increase even more for the daytime periods following the bricking of the street and placement of pedestrian amenities (which occurred after the 1979 survey). Only for the evening shopping period was there no continued increase in pedestrians between 1979 and 1980. Overall, the number of visitors increased 11 percent for weekdays and 10 percent for Saturdays.

The increases in pedestrian volumes were not evenly distributed. The northern blocks, which are located closest to the government and financial office districts, had increases in sidewalk volumes that exceeded 15 percent, while the southernmost blocks actually experienced decreases in pedestrian volumes. In fact, the largest increase in pedestrian volumes occurred on a block that had sidewalk widening and restricted vehicular access, rather than on the blocks that were fully bricked and totally pedestrianized. This outcome shows that the location of the block relative to activity generators can be as or more important than the form of automobile restriction in determining changes in pedestrian volumes.

In general, the health of the Downtown Crossing area and the observed increases in pedestrian volumes are to a large extent attributable to the presence of a large office work force nearby. About 120 000 persons are employed in office buildings within 0.5 mile of the ARZ, and another 8000 are employed in retail stores. Nearly half of all the pedestrians in Downtown Crossing are downtown employees. The 5 percent growth in downtown office employment during the 1978-1980 period alone would account for a 2 percent increase in weekday pedestrian volumes (compared with the 11 percent increase actually observed).

By comparing shifts in the employment status of all pedestrians over the 1978-1980 period, it is found that while downtown employees accounted for less than half of all weekday visitors, they accounted for nearly two-thirds of the 1978-1980 increase in visitors. The shape of the time-of-day distribution of pedestrian volumes, shown in Figure 3, reflects the substantial contribution of downtown area workers (data from 1978-1980 pedestrian counts). The clear peak between noon and 2:00 p.m. on weekdays can be attributable to the large number of workers entering the area during their lunch period. Much of the total increase in weekday pedestrian volumes between 1978 and 1980 occurred at lunchtime; there was a 17 percent increase in the lunchtime pedestrian volumes between 1978 and 1980 compared with only a 6 percent increase in volume for the rest of the weekday. The lunchtime period overall accounted for nearly three-quarters of the total weekday increase in visitors between 1978 and 1980.

The continued increases in pedestrian volumes are especially significant because they have occurred in the face of new competition nearby. The Faneuil Hall Marketplace opened in stages in 1976-1978 (preceding the Downtown Crossing project) and features 200 restaurants and specialty shops located within a mile of Downtown Crossing and closer to many of the office buildings. Whether Faneuil Hall Marketplace has had a positive or negative impact on shopping activity in the Downtown Crossing area has been the subject of debate. A survey of employees at selected office buildings located near both retail areas showed an increased number of trips to both areas, but a relative decrease in the proportion of midday visits to Downtown Crossing and a relative increase in the proportion of visits to Faneuil Hall Marketplace. This suggests that the increases in employee visits to the ARZ have occurred despite the presence of a nearby competing area.

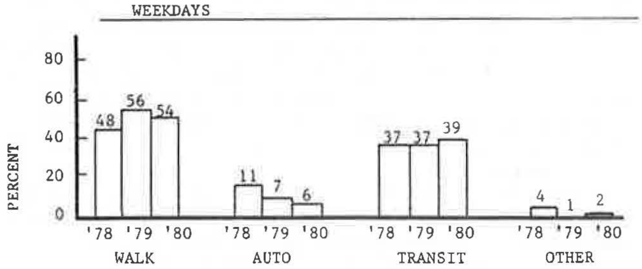
EFFECTS ON TRAVEL CONDITIONS

Changes in Mode of Travel

In the face of extreme traffic congestion and levels of transit ridership to the area that were declining between 1970 and 1977, the Downtown Crossing project was successful in contributing to a substantial shift away from use of the automobile on both weekdays and Saturdays.

There are several reasons why the ARZ and associated policies would be expected to have a substantial impact on mode of access to the area. The ARZ

Figure 4. Mode of access to Downtown Crossing area.



did make traffic access to the immediate area more circuitous. In addition, the elimination of on-street parking and the shift of parking capacity to locations a few blocks away translated into longer walks from parking facilities to the retail district. In addition, there were substantial extensions of local bus service into the area. All of these changes would tend to make automobile travel less attractive and encourage shifts to transit for shopping trips.

Figure 4 (data from 1978-1980 pedestrian interviews) shows a dramatic decrease over time in the proportion of trips coming into the Downtown Crossing area by automobile. Most of the shift occurred between 1978 and 1979 following the closing of the streets and related parking changes. There was, however, also a continued decrease in automobile use between 1979 and 1980. There were corresponding increases in the walk-trip proportion and a slight overall increase in transit use on weekdays. [The proportion of all trips coming directly by Massachusetts Bay Transportation Authority (MBTA) bus without additional use of subway or automobile increased from 2 percent in 1978 to 7 percent in 1980, while the subway share of all trips dropped slightly from 34 to 32 percent.]

The 1978 to 1980 change in the weekday walk and transit modal distributions actually reflects two offsetting trends. For those employed in Boston, there was a continued increase in walk trips relative to other modes of travel, while for those not employed (i.e., housewives, students, out-of-town visitors, etc.), there was a relative increase in transit use. Both groups had substantial decreases in reliance on the automobile.

The observed shift away from automobile travel is clearly attributable to far more than just the ARZ. In fact, there was also a clear shift from automobile to transit among downtown office workers, although that shift was proportionally smaller than the modal shift observed for Downtown Crossing visitors. [The automobile mode proportion decreased from 0.24 to 0.17 for trips to work (a 30 percent drop) while it decreased from 0.11 to 0.06 for Downtown Crossing visitors (a 45 percent drop).] The mode-to-work shift among the office workers occurred even though the exclusion of automobile traffic in the retail district in itself had a minor impact on vehicular access to office buildings elsewhere downtown, and overall capacity of facilities for long-term parking did not appreciably change between 1978 and 1980. There were substantial improvements in local bus circulation, but local buses only accounted for 11 percent of trips to work downtown. The mode-to-work change as well as some of the modal change for Downtown Crossing visitors is attributable to the dramatic increases in fuel prices in 1979 as well as rising parking prices, a freeze on new parking facilities, and the opening of a new rapid transit route extension.

Traffic Diversion

The downtown Boston street system dates back to the 18th century, and by 1810 the network resembled the pattern that exists today. The maze of narrow, noncontinuous one-way streets and the complex intersections downtown contributed to produce traffic congestion throughout much of the day. Much of the congestion problem was attributable to double parking, illegal parking, and illegal use of loading zones, combined with heavy pedestrian volumes and narrow streets.

With or without the ARZ, simplification of the mazelike pattern of traffic circulation, elimination of on-street parking, and improved enforcement within the area were identified as the keys to reducing the extent of automobile congestion in the area. A major concern of those involved in the planning of the ARZ was the impact that traffic limitation on major downtown streets might have on traffic conditions on other already heavily used streets. All on-street parking was eliminated from the expected diversion routes to facilitate greater capacity and smoother traffic flow on those streets.

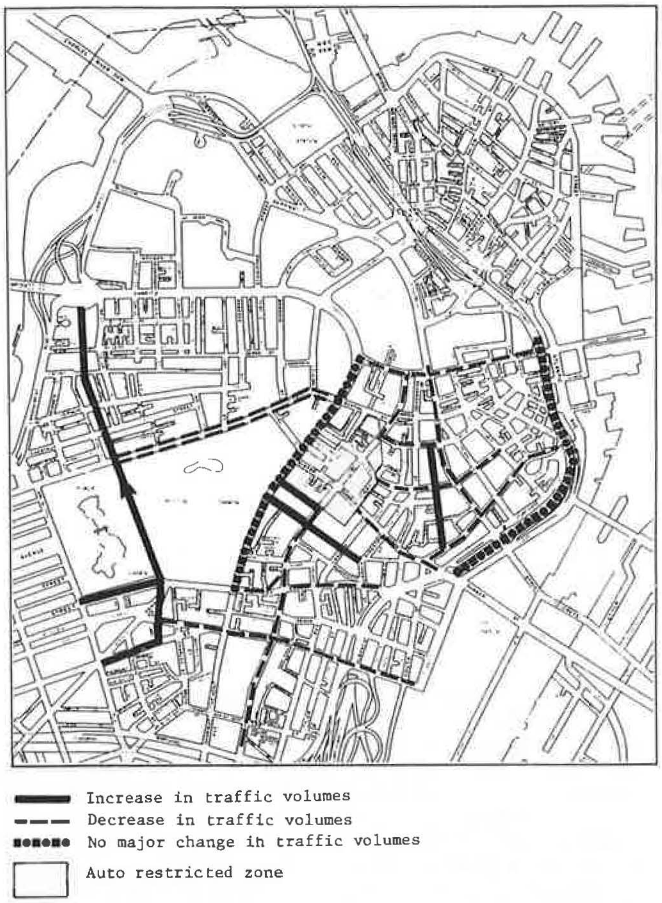
A comparison of the traffic counts taken during the summers of 1978, 1979, and 1980, which covered the periods before and after initiation of the project, indicates that most of the predicted increases on nearby parallel streets did not occur and that there were in fact decreases rather than increases in vehicular traffic on most of the local streets near the ARZ. In most cases, the diverted northbound and westbound traffic can be traced to alternative routes farther away. Figure 5 outlines the major traffic routes as of 1978 and distinguishes between those that experienced increases and those that experienced decreases in traffic volumes in the 1978-1980 period. It clearly shows that many automobile travelers avoided the entire area rather than merely shifting a block or two away from the automobile-restricted streets as was originally expected.

There was a 5 percent overall decrease in areawide volumes in the 1978-1980 period. In the area shown in Figure 5, total daily traffic on all north-south routes decreased from 62 000 to 59 000, while traffic on all east-west routes decreased from 51 000 to 47 000. There are two explanations for this decrease in areawide traffic volumes. Of this reduction in area traffic volumes of 7000 vehicles daily, up to 6000 can be attributed to observed increases in ridesharing and the modal shift away from automobile travel among Downtown Crossing visitors. At the same time, analysis of traffic counts on diversion routes indicates that several thousand vehicles are avoiding the entire area daily. An increase in traffic on Charles Street on the opposite (west) side of Boston Common accounts for much of the northbound traffic diverted from Washington Street, but there was a substantial diversion of east-west traffic not reflected by increases in volume on other streets in the study area. It is likely that some travelers are now approaching destinations in the government complexes to the north of the Downtown Crossing from the north rather than traveling through the study area.

Parking Demand

Supporting the finding of an overall decline in automobile trips to downtown in general and the Downtown Crossing area in particular, surveys and counts of parkers at selected on- and off-street facilities in 1978 and 1980 showed a 22 percent decrease in vehicles entering between 10:00 a.m. and 4:00 p.m. The decrease was particularly sharp for

Figure 5. Change in traffic volumes, 1978-1980.



those people who had destinations in Downtown Crossing, among whom the number of vehicles parked at the surveyed sites decreased 37 percent and the number of persons coming by automobile decreased 29 percent. At the same time, automobile occupancy for parkers visiting Downtown Crossing increased among both those traveling to work (from 1.29 to 1.76) and among shoppers (from 1.72 to 1.98).

The particularly sharp decrease in Downtown Crossing parkers can be related to the disproportionate reduction in on- and off-street capacity within two blocks of the ARZ and the significant shift toward transit use and ridesharing among Downtown Crossing visitors. In fact, while there was a decrease in reports of trouble parking for those traveling to work (from 28 to 20 percent), there was an increase for shoppers (from 23 to 38 percent). This latter finding reflects the fact that, while there was little change in total capacity at parking lots and garages, there were major reductions in on-street space and increases in enforcement of no-parking zones, both of which were formerly frequented by parkers for shopping or personal business trips.

Bus Service Changes and Impacts

Although Boston has one of the most extensive systems of public transportation, with subway, bus, and commuter rail services, MBTA relied almost extensively on the subway system to serve the CBD. Local bus routes to the downtown area all terminated at subway stations on the periphery of the central retail and office district. The extension of six local bus routes and four express bus routes within the ARZ was originally viewed by the merchants and the city as a crucial means of maintaining accessibility to and within the area.

Attitudes toward the bus extension routing changed over time. The high pedestrian volumes on Washington Street led to continuing pedestrian and bus conflicts. Even the merchants came around to feeling that the buses were more of a detriment than a help to their business and asked that they be removed. Eight months after the initiation of the transitway on Washington Street, the downtown bus loop was modified to eliminate all bus service on all but one block of that street. The initial discussion was prompted by the temporary need to remove all vehicles for street reconstruction and bricking, but buses never again traveled on those blocks of Washington Street.

Both counts and surveys indicated that the number of bus riders bound for destinations in Downtown Crossing had increased 26-30 percent following the extension of the bus routes. These increases were substantially greater than the 9 percent increase that had originally been forecasted, but more than half of the new riders represented trips shifted from other transit lines. Those who shifted from other transit lines enjoyed substantial time and cost savings, as most of them were saved a transfer to the subway. In addition, businesses directly beside the bus stops reported significant gains in shopper volumes. Nevertheless, passengers who shifted from other routes meant no additional revenue, and those who saved a transfer to the subway meant a loss of revenue to MBTA. As a result, the total increase in revenue to the MBTA system (net of interroute shifts and transfer losses) amounted to just 5 percent of the cost of the route extensions. On that basis, MBTA eliminated all of the bus route extensions at the end of 1980, 27 months after they were initiated and 15 months after UMTA's demonstration subsidy ended.

ECONOMIC IMPACTS

Retail Expenditures

The Downtown Crossing ARZ covers the major shopping streets that account for most of the sales in the downtown retail district. Although Boston's downtown retail district has fared better than many downtown shopping areas, it was showing signs of decline in the 1970s. Downtown retail sales had been declining in constant dollars (controlling for retail price inflation) since the end of World War II, and over the 1972-1977 period it declined 15 percent (2). While the downtown retail area declined, retail sales over the entire metropolitan area increased 8 percent between 1972 and 1977 (after controlling for price inflation).

Results from the pedestrian interview surveys showed that, in contrast to prior trends, the number of purchases in stores in the Downtown Crossing area increased substantially following initiation of the ARZ and other physical improvements. As a result of both increases in pedestrian volumes and an increase in per-capita purchase rates, the number of total weekday store purchases was up 26 percent in 1980 compared with the level in 1978. There was a slight decline in the total amount spent per pedestrian over 1978-1980, which reflects the disproportionate growth in lunchtime pedestrian activity. Overall, the pedestrian surveys indicated that the increase in retail expenditures over 1978-1980 was nearly the same as the Boston-area price inflation for apparel and upkeep goods over the two-year period (12 percent).

Table 1. Changes in sales by area businesses between 1977 and 1979.

Establishment	Change in Total Sales Volume (%)	No. of Businesses Reporting: Decreasing Sales	No Change in Sales	Increasing Sales
Type				
Clothing	7	1	0	12
General merchandise	13	1	0	2
Restaurant or bar	14	1	1	11
Shoes	20	0	0	7
Jewelry	39	0	0	18
Books, records, or cards	48	1	0	11
Hair and beauty	19	3	1	3
Services	46	0	1	6
Sporting goods or cameras	7	3	3	13
Wholesale and manufacturing	19	1	2	10
Miscellaneous	13	5	0	18
Size[a]				
Small	25	12	7	53
Medium	29	6	1	48
Large	13	1	1	9
Ownership				
Independent	28	10	8	84
Chain or subsidiary	26	9	1	31
Location				
On an improved street	33	4	3	37
Near an improved street	24	16	6	78
Total	27	20	9	115

Note: Changes in sales are not adjusted for inflation, which averaged 12 percent for apparel and upkeep goods and ranged up to 16 percent for personal care goods and 21 percent for restaurant meals.

[a]For size of establishment, small = 1-5 employees, medium = 6-25, and large = more than 25.

The observed changes in weekday store visits and retail sales between 1978, 1979, and 1980 indicate a substantial turnaround from the historical trend of accelerating losses. They also support the finding that there was no adverse impact on retail activity during mall construction and that downtown retail activity has in fact continued to strengthen since implementation of the ARZ. Factors such as Boston's tercentennial and the popularity of nearby Faneuil Hall Marketplace may have contributed to the observed retail patterns, but it is generally perceived that the upgrading of the area's physical image and the promotional activities funded under the Downtown Crossing project were major reasons for the strengthened retail activity. The lack of any observed adverse impact from the street reconstruction process can be attributed to both the existence of a substantial market of downtown employees and the completion of construction in a relatively short period of time.

Merchant Impacts

On the basis of merchant surveys, Table 1 (data from 1978-1980 business establishment surveys) gives the reported percentage change in area sales by type of store and the number of businesses with increasing and decreasing sales. The total (unadjusted) volume of sales for all stores responding to the survey questions increased by 27 percent from 1977 to 1979. This is significantly higher than the unadjusted sales volume increase computed from the pedestrian surveys, and is partly attributable to the lack of sales-volume data for the two largest department stores in the merchant survey responses. Most categories of stores reported increases in sales exceeding the rate of price inflation. The type of stores showing the greatest increase in total sales were books, records, and cards and services. (There was also a large increase in sales volume for jewelry, which largely reflects the substantial increases in market prices over the period rather than true shifts in the amount of business.) Stores selling more expensive goods such as clothing and sporting goods and cameras reported the smallest increase in sales. In general, sales volumes increased more for the small and medium-sized stores than for large stores. Stores located on the improved streets had a substantially greater increase in sales than those on other nearby streets. The proportion of businesses with decreasing sales was highest among the store categories of hair and beauty, wholesale and manufacturing, general merchandise, and sporting goods and cameras.

Because reported costs and sales figures are subject to inflation and fluctuations independent of the downtown improvements, managers of area businesses were asked to evaluate the impact of the Downtown Crossing project on the profitability of their establishment. Although most of the businesses (72 percent) had a favorable attitude toward the project's impacts on the downtown image, just 39 percent thought that it actually helped their business. Of the remainder, 46 percent concluded that the project had no effect on their establishment and only 15 percent felt that it had hurt their business.

The effect of Downtown Crossing on businesses varied by business size, ownership, and type. According to the perceptions of the merchants (Table 2), larger businesses and chain stores were hurt less and helped more by the project than were smaller and independently owned ones. The finding that smaller stores perceived less benefit from the project than did larger firms is consistent with survey findings from Philadelphia's Chestnut Street Mall. There, 29 percent of the small (less than 24 employees) stores reported increased business and 38 percent reported decreased business, while among larger stores 42 percent reported increased business and only 20 percent reported decreased business (3, p. 192).

Business Mix

Changes in the types of businesses operated in the area are another indication of project impacts. Examination of the number of stores entering and leaving the area shows a net increase in the number of restaurants and chain stores. The increase in eating and drinking places largely resulted from the conglomeration of fast food shops within The Corner, a shopping complex within the area, but is nonethe-

Table 2. Perceived effect of Downtown Crossing on individual businesses.

Establishment	Percentage Helped	Unaffected	Hurt
Type			
Clothing	49	32	19
General merchandise	60	10	30
Restaurant or bar	58	24	18
Bank	50	45	5
Shoes	72	12	17
Jewelry	29	57	14
Books, records, or cards	65	31	4
Hair and beauty	32	52	16
Services	28	60	12
Sporting goods or cameras	55	36	9
Wholesale and manufacturing	10	72	18
Miscellaneous	31	51	18
Size[a]			
Small	31	48	21
Medium	53	34	13
Large	50	41	9
Ownership			
Independent	29	55	16
Chain	58	29	13
Location			
On an improved street	41	45	14
Near an improved street	38	46	16
Total	39	46	15

[a]As defined in Table 1.

less consistent with increases in the proportion of such establishments associated with the Chestnut Street Mall in Philadelphia (3, p. 193) and the Mid-America Mall in Memphis (4, p. 28). In general, quick-stop types of businesses particularly benefitted from the increase in foot traffic.

Downtown Development Impacts

There has been no major store or building improvement in Downtown Crossing since implementation of the project in fall 1978. Even prior to implementation of the Downtown Crossing project, however, there was little vacant ground floor retail space on Washington Street and there was little need for storefront renovation. Significant vacant retail space did exist, however, on other nearby streets that have been subject to automobile restrictions but have not received physical improvements and that has not been filled since implementation of the Downtown Crossing project. In addition, vacant upper-floor space has remained plentiful in the Downtown Crossing area.

The fact that there were no major store, office, or hotel openings or new development projects initiated in the immediate vicinity of Downtown Crossing over the 1978-1980 study period has two consequences. On the one hand this indicates that short-term impacts of the Downtown Crossing project on private-sector investment were minimal. It also means that the observed changes in pedestrian and retail activity were not directly affected by the openings of any new public or private facilities in the area. Ultimately, however, it must be recognized that the Downtown Crossing project represents just one of a number of independent activities contributing to the growth of the economy of the downtown retail district starting in the late 1970s. Other public and private investments taking place during the two years immediately preceding the project included completion of a sidewalk canopy unifying the storefronts along Washington Street, reconstruction of the Jordan Marsh department store building, and conversion of the former Gilchrist department store building into a 30 store shopping complex (The Corner). Faneuil Hall Marketplace, located near the downtown retail district, also opened during that period. Construction has since started on two new development projects on Washington Street near the ARZ: a $30 million high-rise apartment and retail building (the Devonshire) and a $100 million hotel and retail development (Lafayette Place). The Downtown Crossing project was not, however, directly responsible for either of these private investments, as the decisions to proceed with those projects were made before the Downtown Crossing project was initiated.

CONCLUSIONS

In evaluating the impact of an ARZ or any other downtown improvement project on downtown business investment, it is critical that the distinction between revitalization projects and redevelopment projects be understood. Commercial revitalization projects such as pedestrian and transit malls rely on improvements in the physical amenity and aesthetic image of an area to increase the attraction of existing downtown shopping districts. Depending on the condition of the buildings in the area, a revitalization project may not necessarily call for any immediate corresponding private-sector investment in renovations or new construction. This is in contrast to commercial redevelopment projects, which are based on new construction or conversion of existing buildings to create commercial activity where it did not previously exist; such projects by their very nature require substantial private-sector involvement in developing and promoting the new center.

Downtown Crossing and the nearby Faneuil Hall Marketplace invite comparison in part because both projects involved substantial public funding for the creation of pedestrian streets and were designed to encourage or facilitate new commercial activity. However, the Faneuil Hall Marketplace project involved the redevelopment of warehouse buildings into new commercial uses, while the Downtown Crossing project was merely an improvement to the pedestrian environment to encourage the economic revitalization of an existing commercial center. Even in terms of public funding, the $21 million of federal urban renewal funds for the Faneuil Hall Marketplace development considerably overshadows the $5 million of public funding for Downtown Crossing.

It is not reasonable to expect that the pedestrianization of a few blocks and the placement of benches and bushes there will in itself dramatically expand retail sales or spur immediate new private investment in downtown commercial expansion. However, when an ARZ is accompanied by other private investment downtown, it can represent an important contributing factor to an overall program of downtown economic development. In the case of Boston, there were measurable increases in pedestrian volumes and a measurable improvement in the retail sales trend since implementation of the ARZ. The Downtown Crossing project appears to be responsible for much of this change. At the same time, however, it must be recognized that these positive impacts critically depended on the existence of appropriate conditions in downtown Boston, including

1. The existence of a substantial potential market of office workers within easy walking distance to visit the ARZ during midday;
2. The high levels of transit use to downtown, so that the automobile restrictions and parking limitations were not a major concern for most visitors; and
3. The generally positive perception of the downtown area as a place where physical improvements

and substantial new development was already starting to occur.

The success of the Downtown Crossing project is also attributable to the multifaceted nature of the project. The extensive promotional program for Downtown Crossing, the improvements in police presence and traffic enforcement, and the improvements in the physical image of the area were important aspects of the project in addition to the automobile restrictions. The Boston experience shows that, under appropriate conditions, an ARZ project can be an important activity that contributes to the economic well-being of the CBD.

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