queue when an 11:00 a.m. arrival could be accommodated without delay on most days.

Unfortunately, it is not possible to generalize from the Knoxville experience about the relative merits of terminals with remote parking areas versus on-site parking. Such an analysis of cost-effectiveness must be site specific. Cost of land and improvements, minor capital item and equipment costs, and operating expenses for alternative configurations are the key variables in the equation, along with the demand to be accommodated. In the present case, the deciding factor turned out to be the unavailability of sufficient land adjacent to the Fair gates to even permit consideration of on-site bus parking. The terminal designs and operating plans used, although born of necessity, proved highly effective and are replicable.

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Assessment of Low-Cost Elevators for Near-Term Application in Transit Stations

KEVIN M. SHEA, M. RAY WHITLEY, BRAJA S. MAHAPATRA, AND JOSEPH S. KOZIOL

An assessment of low-cost elevators for use in existing transit stations, the supporting data for selecting the screw-column elevator for further evaluation, and an evaluation and assessment of the screw elevator design and operation are presented. This information provides data to authority representatives to enable them to make informed decisions regarding application of the screw-column elevator. The assessment team investigated screw-column elevator design, construction, maintenance costs, and actual use. On-site inspections were conducted at a manufacturing plant and at elevator installations. It was determined that screw-column elevators offer a low-cost alternative for vertically moving elderly and handicapped patrons in transit stations. Low capital expense, minimum time for installation, low cost for standard site preparation, and maintenance costs make the screw-column elevator attractive.

To comply with Section 504 of the Rehabilitation Act of 1973, which states that "no otherwise qualified, handicapped individual shall, solely by reason of his handicap, be excluded from participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving Federal financial assistance," transit authorities must make efforts to provide transportation that handicapped people can use. This may include providing access to existing systems. One element of accessibility is that of vertical movement in rapid transit stations. As past studies have noted, the problems and issues of providing vertical movement accessibility for transit are multifaceted.

To meet the significant problems imposed when locating an elevator in an existing station, the optimal unit will require minimum space, be relatively easy to install, and have an overall low cost. This study analyzed current elevator types to determine which type or types best satisfy these constraints and presents data for the screw-column elevator, which appears to offer important advantages. [The investigation is reported in its entirety elsewhere (1).]

ELEVATOR COMPARISON AND SELECTION

The issues and problems that surround the vertical movement of patrons in transit stations call for certain requirements in the design of an elevator. Issues associated with selecting a unit that will result in an overall low cost and satisfy structural, spatial, and security needs pose design problems for elevators. Each of these problems has been addressed, and a list of important requirements has been developed. These requirements pertain to elevator and station problems generally, but do not attempt to address site-specific problems that face the transit authority and architect or engineer at the time of planning and designing a specific installation.

The following requirements have been identified as necessary to evaluate elevators for transit use. The elevator should

1. Be capable of use by both the elderly and the handicapped and other transit passengers;
2. Have a capacity of no less than 2000 lb;
3. Be sized for wheelchair turnaround, which results in a net car dimension of 80x51 in or 68x51 in, depending on the location of the elevator door opening;
4. Be able to meet the expected vertical rise (nominally 20 ft);
5. Have a low life-cycle cost, which includes capital expense, installation, operations, and maintenance;
6. Be easily installed in existing locations;
7. Provide for passenger safety;
8. Provide for passenger security (such as against malicious attacks);
9. Give reliable service;
10. Meet and satisfy prevailing codes and standards; and
11. Be capable of operating in a transit environment.

These specific requirements set the conditions for any technical analysis of elevators. In addition, for purposes of this report, a nontechnical requirement has been identified: Material should be available that provides information needed by transit authorities to select, purchase, and install elevators that result in the lowest overall cost.

Discussions with manufacturers were conducted and elevator specialists were interviewed to select initial elevator candidates. Five types of elevators were identified and compared with the requirements: conventional electric traction, conventional hydraulic, holeless hydraulic, screw column, and vertical wheelchair platform lift. This comparison is

Table 1. Comparison of elevator and lift types.

Requirement	Conventional Electric Traction	Conventional Hydraulic	Holeless Hydraulic	Screw Column	Vertical Wheelchair Platform Lift
Provide for both elderly and handicapped and other patrons	Yes	Yes	Yes	Yes	No, designed and intended for use by handicapped only
Capacity (2000 lb minimum)	Yes	Yes	Yes	Yes	No, 500-lb nominal capacity
Size (80x51 in or 68x51 in)	Yes	Yes	Yes	Yes	No, nominal size 42x62 in
Vertical rise	Unlimited	Up to 60 ft	Up to 25 ft	Up to 60 ft	Nominal rise up to 10 ft (suitable for level changes within a single room or space)
Cost (total)	Highest	Medium	Low	Low	Lowest
Capital	Highest	Medium	Low	Low	Lowest
Standard installation[a]	Highest	Medium	Low	Low	Lowest
Operation and maintenance	-[b]	-[b]	-[b]	-[b]	-[b]
Retrofit capability	Most difficult due to machine room, pit depth, and heavy structural requirements	Difficult due to need for well hole drilling	Requires limited building modification	Requires limited building modification and no machinery room space	Easily installed
Safety	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	Safety mechanisms provided in accordance with equipment type	
Security (protection against assault)	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Enclosed cars of glass are available; closed-circuit television may be required	Open platform provides good security
Reliability	No specific differences can be identified	No specific differences can be identified	No specific differences can be identified	No specific differences can be identified	
Code satisfaction	Yes	Yes	Yes	Code currently being developed	
Effect of environment on elevator	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units	Environment should affect all units; no perceived difference can be seen between units

[a]Relative costs could vary due to specific site conditions.
[b]Data available for heavy-use office building environments only.

Table 2. Liaison Board for study of low-cost vertical elevators.

Member	Affiliation
George Wood	Foster Miller Associates, Waltham, Massachusetts
Edward Long	Special Needs Advisory Committee, Boston; and Boston Center for Independent Living
Thomas O'Brien	Massachusetts Bay Transit Authority, Boston
Melvin Sussman	New York City Transit Authority, New York
David Andrus	Port Authority Transit Corporation, Camden, New Jersey
Chris Kalogeras	Chicago Transit Authority, Chicago
Willard Pistler	Greater Cleveland Regional Transit Authority, Cleveland
Max Kroni	General Services Administration, Washington, D.C.
Braja Mahapatra	Southeastern Pennsylvania Transportation Authority, Philadelphia
Michael Tinnirello	Port Authority Trans-Hudson Corporation, Jersey City, New Jersey
George Strakosch	Jaros, Baum, and Bolles, New York
Dennis Cannon	Architectural and Transportation Barriers Compliance Board, Washington, D.C.
Charles Krouse	Professional staff—Committee on Public Works and Transportation, U.S. House of Representatives
M. Ray Whitley	Consulting engineer and chairman of ANSI Ad Hoc Committee on Screw Machine Elevators, Longwood, Florida
Patricia E. Simpich[a]	Project manager, Office of Technology Development and Deployment, UMTA
Theodore Gordon[a]	Senior engineer, American Public Transit Association, Washington, D.C.
Joseph S. Koziol, Jr.[a]	Project engineer, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts

[a]Ex officio member.

given in Table 1. It is assumed, for the comparison, that the site is an existing station that requires a 20-ft rise with openings at two different levels. (A review of the chain hydraulic type mentioned in a related report revealed that it is in the conceptual stage only. It is not immediately available and thus was not reviewed.)

From the data in Table 1 it was determined that

1. Conventional electric traction, due to overall high costs and problems in modifying the existing stations to accommodate the unit, will usually not be the best choice.
2. Conventional hydraulic, although lower in cost than electric traction, offers potential problems in modifying the existing stations to accommodate the unit, especially in the placement of the well hole for the hydraulic jack, and thus will usually not be the best choice.
3. Vertical handicapped platform lifts are strictly limited to transporting individual handicapped persons up or down for very low rises and as

such do not meet requirements. However, these units might be suitable for other, special handicapped-only level changes.

4. Holeless hydraulic and screw-column elevators will usually be the most appropriate types because of the overall lower cost and the fact that station alterations to accommodate their installation are less difficult. These units should therefore be considered the most applicable for vertical movement in existing transit stations.

With the selection of the holeless hydraulic and screw-column elevators as technically applicable elevators, a decision was made, with the assistance of the Low-Cost Vertical Elevator Liaison Board (see Table 2 for a list of members), to consider the additional requirement of this report--the need for information. This consideration was made with the realization that large American manufacturers are actively marketing holeless hydraulic elevators and that applicable information regarding these elevators is available from these manufacturers and consulting engineers. The screw-column elevator, which is considered to be an acceptable alternative, has the additional advantages of no machinery room and limited pit and overhead clearances, is new to the American market, and is currently being sold primarily in Europe; as such, information pertaining to screw-column elevators is limited. The need for information on screw-column elevator installation requirements, operation, and performance was confirmed by the Liaison Board, as it would present another option for transit authorities, with the potential result of lowering the overall cost of elevator installation.

SCREW-COLUMN ELEVATOR DESCRIPTION AND DATA

The screw-column elevator is a direct-drive unit that operates on the screw-lift principle. For elevator installations, a stationary screw-threaded column is located in the hoistway, and a rotating "nut" is driven around the threaded column, which provides the vertical movement. This drive mechanism and principle has been employed on elevators since 1965 in Belgium, where a total of 250 units have been installed by one manufacturer. Only recently have screw-column elevators been introduced to the American market.

This particular elevator has a well-defined market. The primary service for which the elevator is designed is for retrofit installation at relatively low rises. It has proved to be competitive where low rises (within 60 ft), lower capacities (up to 2500 lb), and retrofit installations have been required. The screw-column elevator is not competitive as a high-volume traffic elevator, such as those used in high-rise office buildings, because of the limited rise and also because the travel speed is slower than that of other elevator types.

The screw-column elevator, when compared with other available types, can be seen to have the following advantages and disadvantages.

I. Advantages
   - A. It requires less space in the building or structure than other elevator types that have the same capacity, size, and speed (it does not require an overhead machine room like the conventional electric-traction elevator or a machinery room outside the hoistway like conventional and holeless hydraulic elevators; also, lateral space requirements between the elevator car and hoistway are less).
   - B. It is usually easier to accommodate in existing buildings and structures than other types of elevators because it requires no machinery room and less space.
   - C. It adds less loading to the building and/or structures than do other types of elevators; furthermore, the loading is spread equally over an entire hoistway wall rather than concentrated overhead as with a conventional electric-traction elevator or concentrated at pit level as with a conventional hydraulic elevator.
   - D. It has good leveling accuracy with all load variations, which is especially important to persons in wheelchairs and other handicapped users.
   - E. It costs less, overall, than conventional electric-traction or conventional hydraulic elevators.

II. Disadvantages
   - A. It is designed currently for limited capacity (up to 2500 lb), limited speed, and limited travel installations (rises up to 60 ft).
   - B. It has a higher noise level (60 dBA) in the car than do other types of elevators (the motor and drive unit are mounted on the car).
   - C. It starts and stops somewhat abruptly.

To obtain the detailed information on screw-column elevators that would be valuable to transit authorities in assessing the applicability in existing transit stations, an assessment team was formed to study and evaluate screw-column elevators. The assessment was made of elevators manufactured by the Ebel Company of Belgium, which has installed more than 250 units.

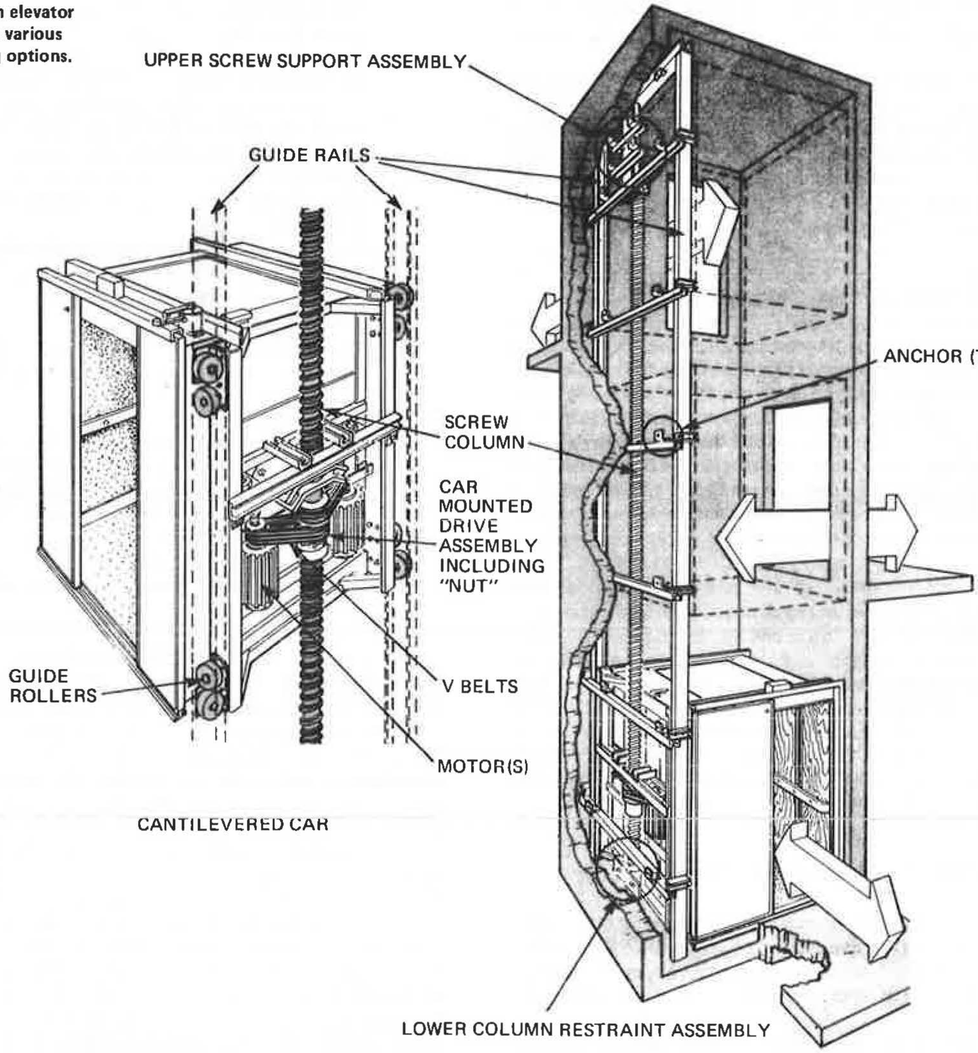
The manufacturer has installed these units in many varied locations, such as warehouses, offices, hospitals, apartment buildings, and private residences. As there is no current Belgium program that requires transit accessibility, no elevators of any type, including screw-column elevators, have been installed in transit locations specifically for handicapped patrons. Evaluation of the elevators took place in the manufacturer's plant plus seven locations in Belgium. These locations were chosen so that the assessment team could obtain a broad picture of the manufacturer's units and gather information that would be most appropriate for transit operation.

The screw-column elevator represents a simple, straightforward, and economical approach to providing basic vertical transportation service. Even with existing limits on capacity, speed, and rise of the unit, it appears to be ideally suited for the movement of handicapped persons in transit stations where large capacities, high speeds, and high rises are not needed.

The screw-column elevator uses a cantilevered car to which the drive mechanism is directly attached. The motor, which is connected to the nut by V-belts, rotates the nut on the stationary screw column and provides the power to move the car both upward and downward. The screw column is supported only from the top and thus is in tension. The belt drive permits desirable slippage should the motor continue to run because of a control malfunction. Movement of the car in the hoistway is stabilized through the use of permanently fixed guide rails.

The relation among the car, hoistway, screw column, drive mechanism, and guide rails, as well as other subcomponents, is shown in Figure 1. As each unit is engineered specially for the site, this manufacturer does not currently maintain detailed specifications or a technical data catalogue of pre-engineered or standard models. However, pertinent typical information for an elevator to be installed

Figure 1. Screw-column elevator schematic, which shows various automatic door opening options.



in a transit station was obtained and is presented below. In addition to the features listed below, the units can be designed for any door location (or with both entry and exit doors) and for various car interiors. All installations to date employ a manually activated swing door, which is the common European practice for small elevators. American standards call for automatic doors. The technical data for a typical transit station installation are given below:

1. Rise: 20 ft (two openings);
2. Rated capacity: 2000 lb;
3. Empty car weight: 775 lb (with no accessories);
4. Add for automatic door: 440 lb;
5. Car door: single slide type, 36-in opening, off center;
6. Car interior: 68x51 in; finished as specified;
7. Leveling tolerance: 0.25 in;
8. Normal velocity: 70 ft/min (approximately);
9. Safety provisions: safety nut and hand lever for manual movement of car;
10. Motor: two at 5 HP, 240 V, 3 ph, and 60 Hz;
11. Brake: internal motor brake, conical type; and
12. Drive mechanism: motor, V-belts, and nut.

FINDINGS AND RECOMMENDATIONS

Screw-column elevators appear to be an acceptable low-cost option for providing vertical movement for elderly and handicapped transit patrons, while providing transit authorities with minimal installation problems at existing transit sites.

Although limited to distribution primarily in Belgium, the market is expanding in various countries, including the United States, for this type of elevator. The manufacturer interviewed is the largest supplier of screw-column elevators and is currently establishing sales and manufacturing in the United States. Rise, Inc., of California is also supplying screw-column elevators and reports that only a few units have been installed in six years. Also, at the same time, code activity is being conducted to provide guidelines for installation and operation of these elevators. Differences between current European practices and anticipated U.S. guidelines are being investigated by the code committee and the manufacturer, and practical solutions are being conceptualized and tested. The manufacturer is committed to the U.S. market, and all units sold in the United States will be manufactured in the manufacturer's stateside facility.

It is the conclusion of this study that, for providing transit authorities with overall low-cost vertical elevators, the advantages of the screw-column elevator far outweigh the disadvantages. Because there is no need for high-capacity, high-speed transport, the primary source of concern is the noise level, which is slightly higher than that of other elevator types. As the patron is subjected to the noise for such a short time, it is considered to be more of an annoyance than a problem. However, the manufacturer is currently attempting to reduce internal car noise levels.

Also, the transit needs, guidelines for accessible design, and customer or patron demands will require modifications to the current design. These modifications may include: (a) provision of power-operated hoistway doors and car doors, (b) larger car size and capacity than the basic minimum elevator provided for handicapped persons in Belgium [1100x1400 mm (43x55 in)], (c) provisions to permit the rescue of persons (possibly severely handicapped) trapped in a stalled elevator by using outside help, (d) emergency voice communication system, (e) specially marked car bin operating panel that can be used by the blind, and (f) possibly an independent governor and safety device if the safety-nut principle used by this manufacturer is not accepted by U.S. code authorities.

It is recommended that, based on the data presented herein and on the observations made from the on-site inspection, a demonstration of screw-column elevators at an existing transit station should be considered. A demonstration will permit data to be collected that will identify how these elevators will perform in a transit environment.

REFERENCE

1. K.M. Shea, M.R. Whitley, B.S. Mahapatra, and J.S. Koziol. Assessment of Low-Cost Elevators for Near-Term Application in Transit Stations. U.S. Department of Transportation, Rept. UMTA-MA-06-0125-82-1, July 1982.

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Park-and-Ride at Shopping Centers: A Quantification of Modal-Shift and Economic Impacts

STEVEN A. SMITH

The purpose of this research was to quantify the effects of park-and-ride facilities at shopping centers on commuter travel and shopping behavior. A survey of commuters at three shopping centers in Montgomery County, Maryland, was conducted to estimate these impacts. The analysis demonstrated that there can be a significant economic benefit to shopping-center operators for allowing commuter parking to occur on their parking lot. Survey results indicate that between 25 and 45 percent of park-and-riders shop at the shopping center on a typical day on their way to or from work. Approximately two-thirds of this shopping activity is either diverted from other shopping locations or in newly induced shopping. For the shopping centers surveyed, the average increase in sales due to the presence of park-and-ride activity is $5/park-and-ride/day. Also, the presence of the park-and-ride facility, in itself, is responsible for 10-30 percent of the park-and-riders choosing to use transit or form a carpool.

Shopping centers have been prime locations for commuter park-and-ride activities for many years. Many such centers and retail sites are located along major public transit corridors and are ideal locations for catching a bus or meeting a carpool. Peak parking demands for shopping centers do not normally coincide with commuter parking peaks, and this creates an opportunity for more effective use of the parking supply. However, shopping-center operators are not generally enthusiastic about commuter parking on their property, perceiving that commuter parking can adversely affect business and the image of the center. In addition, there remain questions about how a park-and-ride lot influences travel behavior, and thus whether these facilities, in themselves, are responsible for including shifts to more efficient modes of travel (i.e., bus and carpool).

Although much of the park-and-ride activity takes place without any formal concurrence from the shopping center, there are also many examples of formal arrangements between shopping centers and local government agencies. This research was designed to quantify the potential benefits of commuter parking to shopping-center operators so that both the engineering community and shopping-center management can make knowledgeable decisions on this issue. Also, it may help the shopping-center management in dealing with problems perceived with informal commuter parking.

STUDY DESIGN

This study was one task of a larger study entitled Parking Policies Study for Montgomery County, Maryland, sponsored by the Maryland-National Capital Park and Planning Commission. Montgomery County is located to the northwest of the Washington, D.C., metropolitan area. It is a rapidly urbanizing suburban county with almost 600 000 residents and an employment of more than 300 000. The study of commuter park-and-ride activity was made to answer the following questions:

1. What modal shifts can be attributed to the presence of a park-and-ride facility at a shopping center? Would commuters simply park in other locations, or is there some actual diversion among alternate modes of travel?
2. What are the economic benefits of commuter parking to shopping-center operators?
3. Does the patronage of the shopping center by commuters divert shopping trips from a peak to an off-peak period, possibly justifying reductions in parking requirements for those centers that permit commuter parking?

To answer these questions, a survey was designed to question commuters on their travel and shopping habits at three commuter park-and-ride lots in Montgomery County. The three locations were Montgomery Mall, Wheaton Plaza, and Aspen Hill Shopping Center. Both Montgomery Mall and Wheaton Plaza are