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ASSESSMENT OF THE INCLINED ELEVATOR AND ITS USE IN STOCKHOLM

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16. Abstract

The Stockholm experience with operation of inclined elevators in subway stations is reported comprehensively to serve as a basis for judgment of the feasibility of inclined elevator applications in U.S. mass transit systems. An onsite investigation was conducted by a multidisciplinary team through direct observation of equipment; interviews of personnel concerned with the development, operation, and use of the elevators; and review of source material.

The inclined elevators are technically similar to vertical, counterweighted, mechanical traction-type automatic elevators, except for the inclined travel. Their installation within escalatorways integrates the travel path of elderly and handicapped elevator users with the escalator route of able-bodied passengers. Station arrangement is simplified where separate vertical elevator shafts and lateral connections to platforms can be eliminated. Inclined elevators are a possible alternative to vertical elevators in U.S. subway systems for new stations where escalator rise is greater than 40 feet, or greater than 25 feet and accompanied by a lateral displacement that prevents vertical connection.

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PREFACE

This study of the inclined elevators installed in the Stockholm mass transit system was commissioned by the U.S. Department of Transportation, Office of Technology Development and Deployment. During a two-week inspection of the Stockholm subway system, five specialists studied the inclined elevator and its setting, including planning and architectural aspects, design, construction, maintenance, costs, and actual use. The investigation included interviews with personnel representing the transit authority, the inclined elevator manufacturer, public safety agencies, the insurance underwriter, building and elevator code agencies, and handicapped persons. Firsthand experience was obtained by riding the elevators at most stations on the subway system, and elevator construction details were examined during tours of two factories and an installation site. Elevator usage was observed at several stations over extended time periods.

Gathering of information was assisted by the warm generosity of our many hosts and guides during the two-week period in Sweden, and the report was given form and direction with the help of the many interested persons who were interviewed in the United States. These contributors are listed in Appendixes A and B. We particularly thank Dr. Ernest Sohns, of the American Embassy in Stockholm, and Mr. Peter Bjorlin, of the Swedish Institute, for their assistance with the details of the itinerary. We also gratefully acknowledge the generous contribution of time and effort of Mr. Ingemar Backstrom and the Storstockholm Lokaltrafik staff; Mr. Kurt Hedstrom and the KONE Hissar AB staff; Mr. Leif Helenius of the Handikapp-institutet; Mr. Gunnar Johansson of De Handikappades Riksforbund; Mr. Tove Linderoth of Handikappforeningarnas Central Kommittee; Mr. Lars Nordquist of Statens Anlaggningsprovning; and, in Goteborg, Professor Sven-Olaf Brattgard of Avdelningen for Handikappforskning and Mr. Ake Hellman of Goteborg Sporvagar. Information sources and reference materials available in the United States were identified by Ms. Patricia Simpich of UMTA (Contracting Officer's Technical Representative) and Mr. Roger Masthagen of the World Bank.

EXECUTIVE SUMMARY

The Stockholm mass transportation authority (SL - Storstockholm Lokaltrafik) installed vertically operating hydraulic elevators for the use of elderly and handicapped people in the new passenger stations that opened for service in 1957. Inclined elevators were developed by 1964, and designed to operate adjacent to the escalators in the inclined shafts, which, in most of Stockholm's underground passenger stations, are the shortest paths from the shallow station entrance levels to the deep train room platforms. The first inclined elevators were installed in masonry-enclosed hoistways and were indistinguishable by the passenger from vertical elevators, except for the inclined acceleration.

The current model inclined elevator travels in an open hoistway, separated by an enclosure of open-mesh metal from the adjacent escalator. Windows in the elevator car allow observation of the interior from the escalator and from adjoining station areas and provide elevator passengers with an enhanced sense of security and of participation in the general flow of pedestrian traffic, as well as visual anticipation of the direction of motion.

Despite more than 20 years of effective development and construction progress, the legally required goal of total accessibility of the mass transit system to elderly and handicapped passengers has not yet been attained in Stockholm. Of the total 95 SL subway stations now in operation, approximately 20 are not yet equipped with elevators for the elderly and handicapped. In addition, the municipal bus system is not equipped with lifts, ramps, kneeling mechanisms, or loading platforms to accommodate the handicapped, although experimental systems are operational. Steps, curbs, narrow passageways, steep slopes, and rough pavement remain as barriers in some public outdoor areas and in many publicly used buildings and vehicles.

Until all public mass transportation systems in Stockholm are fully accessible, the transportation difficulties of the elderly and handicapped are being relieved by a special transportation system (Fardtjanst), operated by the SL. Fardtjanst provides a fleet of 200 lift- , or ramp-equipped vans for the more severely handicapped and subsidized taxi service for the moderately disabled. The service is door to door, with passengers being carried over barriers, if necessary, by the two-man staff on each van. In Stockholm County, with a population of 1.5 million, 70,000 elderly and handicapped people are entitled to Fardtjanst service.

Because of the excellence and broad availability of Fardtjanst, few moderately to severely handicapped people make use of the mass transportation system. Thus, the inclined elevators are used primarily as an alternative to escalators by the elderly; people burdened with carts, carriages, packages, or pets; and able-bodied people. Available data indicate that less than 1 percent (1.8 million elevator-using passengers per year) of total subway trips involve elevator use for level-changing in passenger stations. This low usage rate can be attributed to the waiting time, manual door operation, and isolation of vertical elevators, and the slower travel speed of inclined elevators as compared with instantly available escalators. However, the elevators are indispensable for the unsteady elderly and moderately handicapped who cannot cope with the relatively fast (.75 m/s; 2.5 ft/s) escalators.

The inclined elevator is generally selected as an alternative to the vertical elevator by the SL for new stations where the elevation change is greater than about 40 feet, or greater than about 25 feet and accompanied by a substantial horizontal displacement between the structures at the two levels. The cost ratio of inclined to vertical elevator equipment within the range of application in Stockholm (30 to 130 feet of rise) is about 2 to 1. A complete economic analysis must compare the site-specific costs of enlarging an escalator shaft with the cost of driving a separate vertical shaft and special lateral connecting facilities. The benefits of integrated passenger paths and visual surveillance associated with the inclined elevator are also significant factors to be evaluated in a cost comparison.

In both Sweden and the United States, elevator codes, which do not now include coverage of inclined elevator requirements, are being expanded to regulate special inclined elevator characteristics and to assure safety. The existing Swedish inclined elevator installations have been tested, inspected, and approved by the use of applicable vertical elevator codes, electrical codes, building codes, and technical judgment exercised by the inspectors. A fully developed U.S. inclined elevator code is likely to be more stringent in regard to overspeed testing, performance, and materials. Advance indications are that the developing U.S. code will probably require a protected elevator hoistway similar to that developed in Sweden, with the need for fire-rated enclosures within subway station escalatorways subject to the same exceptions that are applicable to vertical elevators.

Inclined elevator cars are similar to standard vertical elevator cars in size, control equipment, and arrangement. Dimensions, equipment arrangement, and facilities conform to the standards for accessibility that have been developed by Swedish organizations of the handicapped. Comparable U.S. standards developed by the GSA for U.S. government buildings differ only slightly in some dimensions and operational features.

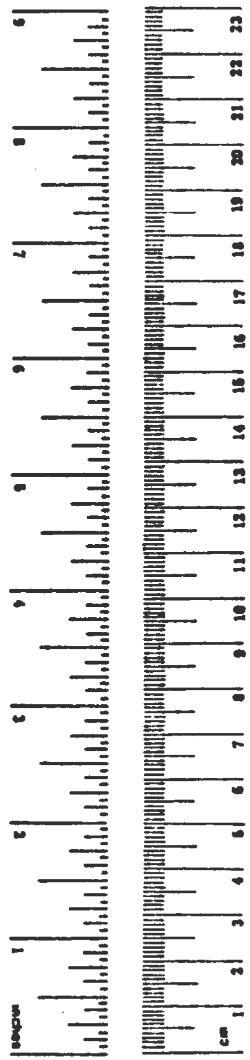
Factors that influenced the development of inclined elevators in Sweden were: the need to accommodate elderly and handicapped people, the presence of sound granite in which mining of deep stations and escalator shafts was the lowest cost construction method, the flexibility and willingness to innovate of both industry and the transit authority, the cooperation of elevator inspectors and certifying agencies in developing new standards, and the shift in emphasis from lowest cost to best method. Where most of these factors are present in new subway construction projects in the United States, the inclined elevator can be a feasible alternative to the vertical elevator.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

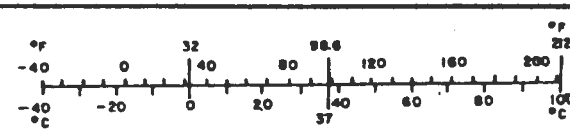
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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



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STUDY OBJECTIVE

The objective of this study is to investigate the development, technical characteristics, costs, and use of the inclined elevators provided for the elderly and handicapped in the Stockholm subway system, in order to benefit from the Swedish experience.

This report is intended to provide information for transit system managers who must decide whether or not to install inclined elevators in transit stations, architects and engineers who need technical information for feasibility studies of inclined elevators at specific sites, and concerned members of the public.

This report does not answer specific site-related feasibility questions for transit agencies; it does provide guidelines for assessment of the potential applicability of inclined elevators in U.S. transit systems.

THE INCLINED ELEVATOR IN STOCKHOLM SUBWAY STATIONS

BACKGROUND

During the early 1950's, the Swedish legislature established the principle that all public facilities shall be accessible to the elderly and the handicapped. The County Council's responsibility for ensuring accessibility of subway stations in Stockholm County was implemented by an addition to the building code (Byggnadsstadgans #42), which translates as follows:

> The spaces in buildings to which the public requires entrance or that constitute a place of employment shall be reasonably configured overall so that they are accessible to and

Vertical elevator and escalator entrances to Stadion Station.

can be fully used by persons whose abilities
to move or to orient themselves are decreased
as a consequence of age, disablement, or illness.

By 1957, the Stockholm County public transportation authority, Storstockholm Lokaltrafik (SL), had introduced elevators into all their new subway station designs. Subway stations that entered service on new subway extensions were equipped with vertical hydraulic elevators from street level to the fare hall area and from the fare hall area to the train room platform.

Much of the Stockholm subway tunnel is mined in sound rock strata lying, in some areas, as much as 130 feet below the surface. The travel paths of passengers on vertical elevators diverge from those of escalator passengers descending to the deeper stations, causing a confused passenger flow, extended routes, and potentially dangerous isolated elevators. SL designers improved the arrangement in many newer stations by replacing the vertical elevators with inclined elevators that operate beside the escalators in enlarged escalator shafts.

Development of the inclined elevator was undertaken jointly by SL and the Graham Elevator Company, a Swedish manufacturer of conventional elevators. The first generation of these specialized elevators appeared in segments of the subway that opened for service in 1964. A continuing program for adding elevators to older stations was not yet completed in 1977.

PUBLIC TRANSPORTATION IN STOCKHOLM

The Stockholm County public transportation network consists of a rail mass transit system (T-bana), a bus system, and a special transit system for the elderly and handicapped (Fardtjanst). The bus system provides downtown circulation, serves the two air terminals, and feeds T-bana stations in outlying areas. The T-bana also connects with two commuter railroad lines and the intercity railroad lines at a complex underground station interchange.

T-bana

In 1977, T-bana consisted of three incrementally constructed, integrated, heavy rail lines of approximately 61 route-miles and 95 stations. By 1978, T-bana will be extended to 70 route-miles and 110 stations, of which more than 60 percent will be underground and less than 10 percent, on aerial structures.

Fardtjanst

Until the Swedish mass transit system has been made fully accessible to persons with severe disabilities, the transportation of most elderly and handicapped persons is being provided by special vans, and by commercial taxicabs on a government-subsidized basis. In Stockholm, this special service (Fardtjanst) provides excellent door-to-door, on-call transportation that includes two attendants to carry handicapped persons, if necessary. Fardtjanst is so convenient and inexpensive that very few handicapped people avail themselves of the mass transit system. (Government assistance toward purchase of private vehicles with special controls is also a major inducement for the handicapped to rely on their own vehicles rather than the mass transit system.)

Although Fardtjanst projections for 1977 accounted for only 1.1 percent of all one-way trips on the public transit system, the operating cost of Fardtjanst was 15 percent of the total SL operating budget. The 1977 estimate of Fardtjanst trips was 4.78 million, while that for all forms of public transit was 432 million trips and the subway ridership was 185 million one-way trips.

Fardtjanst annual operating cost is projected for 1978 at $43 million, the major portion of which ($36.6 million) is for the subsidized taxicab service. The 1977 average costs per trip are $8.07 for the taxicab service and $16.20 for the specially equipped van, or an overall average of $8.79 per trip. In contrast, the overall mass transit system cost per ride is $0.65.

SL management predicted that the 80 percent of all Stockholm's handicapped who now rely on special transport for urban area trips can be reduced to 50 percent when total mass transportation system accessibility is attained.

Capital costs of adapting the mass transit system for the handicapped can be offset, to some extent, by the predicted reduction in Fardtjanst use and tend to be justified by the improved access to mass transportation for the encumbered passenger and the temporarily mobility handicapped.

FACILITIES FOR THE TRANSPORTATION-HANDICAPPED

In order to investigate and clarify the task of providing barrier-free access to public transit for the elderly and handicapped, in 1966 the Swedish government established the Committee on Handicapped Persons (HAKO-utredningen) to conduct a survey of the transportation-handicapped individuals in the population. The committee estimated that nearly 12 percent of Sweden's 8.5 million people, or 1 million persons, have intrinsic ambulatory handicaps that impede their ready use of the public mass transportation system.

Classification of the Transportation-Handicapped

Four categories of generalized functional disability were defined, and the number in each was estimated. In order of decreasing severity of handicap, the classifications and the approximate number of persons affected are:

- Severe ambulatory handicap: (20,000 individuals) Persons who require special vehicles or special service on standard vehicles, such as airplanes, trains, ships. This group includes persons who are confined to wheelchairs and stretchers; paralyzed, completely blind, or deaf and blind; some of the mentally retarded; and some of those with severe allergies.

- Severe ambulatory handicap of lesser degree: (230,000 individuals) Persons who usually require assistance at the start and end of a regional or inter-regional journey by standard rail, bus, or air service. Such journeys are undertaken with difficulty and personal sacrifice.

- Appreciable ambulatory problems: (250,000 individuals) Persons who experience various degrees of difficulty in using all the regular unadapted transport services and who are, therefore, disinclined to travel, except by private car.

- Ambulatory handicap to some extent: (500,000 individuals) Persons with general physical or mental restrictions who experience certain difficulties because of shortcomings presented by the public transportation systems.

Going beyond these four groups, the HAKO-utredningen defines a fifth category containing "probably at least 1 million additional persons who are transportation handicapped."

> These persons do not have intrinsic ambulatory problems, but the general handicaps associated with old age, or are young children, persons with prams or bundles--in general, all those who, in traveling situations, are at a disadvantage compared with fully mobile, unencumbered individuals.

Thus, the total number of transportation-handicapped individuals is estimated to be 2 million, or nearly 25 percent of Sweden's population!

The HAKO-utredningen summarizes its survey of the handicapped population as follows:

> A large number of handicapped persons are usually obliged to travel by public transport, either because they cannot or do not wish to drive a personal vehicle. A small percentage of the transportation-handicapped (severe ambulatory handicap), about 20,000 individuals, cannot travel by public transport at all, on their own, and to fully adapt public transport for this group will require technical research and development.

Statistics on Swedish wheelchair users are shown in Table 1.

Adaptation of Public Transit for the Handicapped

Although a great deal of progress has been made, Swedish planners and designers are still working to overcome the same types of technical difficulties that confront U.S. efforts to achieve barrier-free access to mass transportation systems. Development of techniques for complete accessibility of buses, taxicabs, railroad cars, ships, and airplanes is being pursued by industry in cooperation with government agencies, research organizations, and special interest groups.

Adaptation of the T-bana for use by the handicapped is evidenced by the widening of faregates and doors and by the existence of special toilet facilities in stations and reserved seats for the elderly and handicapped in vehicles. Because the rail vehicles have not yet been fitted with special provisions, such as wheelchair parking areas, tie downs, or handrails, passengers in wheelchairs remain in the entry areas adjacent to the doors, where stanchions are fitted and adequate space exists for other passengers to pass to the aisles.

Level-Changing Facilities

Various types of level-changing facilities in the T-bana include fixed stairways, ramps, inclined moving walks, escalators, vertical elevators, and inclined elevators. A ramp incorporated in a concrete stairway is shown on page 8. The elevators, both vertical and inclined, are more readily accessible to the elderly and handicapped than any of the other facilities, each of which has obvious disadvantages, such as the steepness of the ramps and the relatively high speed of moving walks and escalators. However, some elevators in Stockholm are difficult for some handicapped persons to use because of such characteristics as the heavy, manually operated double doors in the early models; nonuniform and isolated locations of some vertical elevators; and the visual, mental and manual requirements for operation of the elevator controls.

Table I

CHARACTERISTICS OF WHEELCHAIR USERS IN SWEDEN

Total Wheelchair Users in Sweden	(Approx.)	30,000
Wheelchair Dependent*	58%	16,500
Wheelchair Bound**	45%	13,500

WHEELCHAIR USERS' MANEUVERABILITY

Self-maneuvered Manual Wheelchair	22%
Self-maneuvered Electric Wheelchair	3%
Require Assistance	70%
Use Transport Chair Only	5%

SOURCE: Professor Sven-Olaf Brattgaard; derived from total Swedish population. Ratio applicable to Stockholm population.

* Employ wheelchair to varying degrees, but are semi-ambulatory.

** Permanently confined to wheelchair.

Dual track ramp incorporated in a concrete stairway.

Elevator Usage Rates

Inclined elevator use represents only a small percentage of total passenger trips on the T-bana and does not approach the maximum capability of the installed elevators. Data indicate that the inclined elevators, with an average of about six trips per hour, account for slightly less than 1 percent of all passenger trips. Data on the use of Fardtjanst indicate that a comparable percentage (1.1 percent) of all public carrier passenger trips are made on the special service vehicles. Assuming that the total number of trips made by elderly and handicapped persons does not increase radically, there appears to be ample elevator capacity for transferring the less seriously handicapped from the Fardtjanst system to the T-bana. This, of course, will be done over a period of time as the few inaccessible stations are retrofitted with elevators and the remaining barriers in public pedestrian areas and on the buses have been removed.

The small direct sampling of elevator user characteristics taken for this study indicates that about one-third of the users could be categorized in the two less seriously handicapped classes described by HAKO-utredningen: "appreciable ambulatory problems" and "ambulatory handicap to some extent." The remaining users were ambulatory elderly people or persons with packages, baby carriages, or pets--the large group described by HAKO-utredningen as not having intrinsic ambulatory problems, but general handicaps of youth or age, carriages or packages. While the inclined elevator appears to offer a better level of service for this group of marginally handicapped, presumably, many of these riders could use escalators should the more seriously handicapped increase their use of the subway and cause the elevators to be less readily available.

Implementation Measures

Adaptation of public transport for the handicapped is classified by the HAKO-utredningen into four groups of implementation measures that are differentiated by their relative ease of application:

- Immediate measures can be undertaken on existing vehicles and facilities without interrupting service.
- Overhaul measures can be undertaken on existing vehicles when they are withdrawn for inspection, overhaul, or repair.
- Procurement measures can be implemented when ordering new vehicles, constructing new stations, or remodeling existing stations.
- Developmental measures can be implemented only after research, development, and testing have been completed.

Within the context of these classifications, installation of inclined elevators is a procurement measure because, up to 1977, their installation in operating stations has been impractical, even though the developmental and test phases are completed. As of the present time, space limitations in existing escalatorways and the difficulties of mining inclined shafts, as opposed to vertical shafts, into existing stations have ruled out the installation of inclined elevators in operating stations.

Greatly improved access to passenger platforms could be accomplished by providing street-level passenger boarding platforms, from which the trains would descend to run in tunnels. Unfortunately, in Stockholm, as in most central city areas, large-scale surface disruptions for street-level platforms would be prohibitively costly and obstructive to surface traffic. The ease and low cost of mining in sound rock, the weather protection afforded by underground stations, and the closely built character of the old central city are factors that weigh against construction of street-level passenger stations in Stockholm. However, in other locations, city structure, climate, and geology may be more favorable to enabling universal accessibility to transit vehicles by means of street-level platforms.

Costs

The cost of adapting Sweden's total public transportation system, to the extent possible with current state-of-the-art hardware, was estimated in 1974 at 236 million kroner ($50 million). The proposed facilities for the handicapped are to be implemented in passenger stations, subway vehicles, railroad cars, buses, and taxicabs over a period of about 10 years. When this program is completed (about 1985), totally free movement will still be restricted by such barriers as steep slopes, steps, road crossings, and irregular pavement in general outdoor areas that are not part of the public transport system, and less readily overcome barriers that require research and development for elimination, such as access to and free passage within railroad cars and airplanes.

DEVELOPMENT OF THE INCLINED ELEVATOR

Development of the inclined elevator has been a cooperative effort of the SL and the Graham Elevator Company and its two successor entities, Graham-Asea and Kone, a Finland-based corporation. The direction taken by the inclined elevator development was influenced by Stockholm's unique requirements and characteristics.

- Because vertical level changes range from 30 to 130 feet, mechanical traction-type vertical and inclined elevators were installed at the larger level changes where the required length of hydraulic cylinder and piston is too great for practicality, while the less costly short-rise vertical hydraulic-type elevator was installed for smaller level changes.

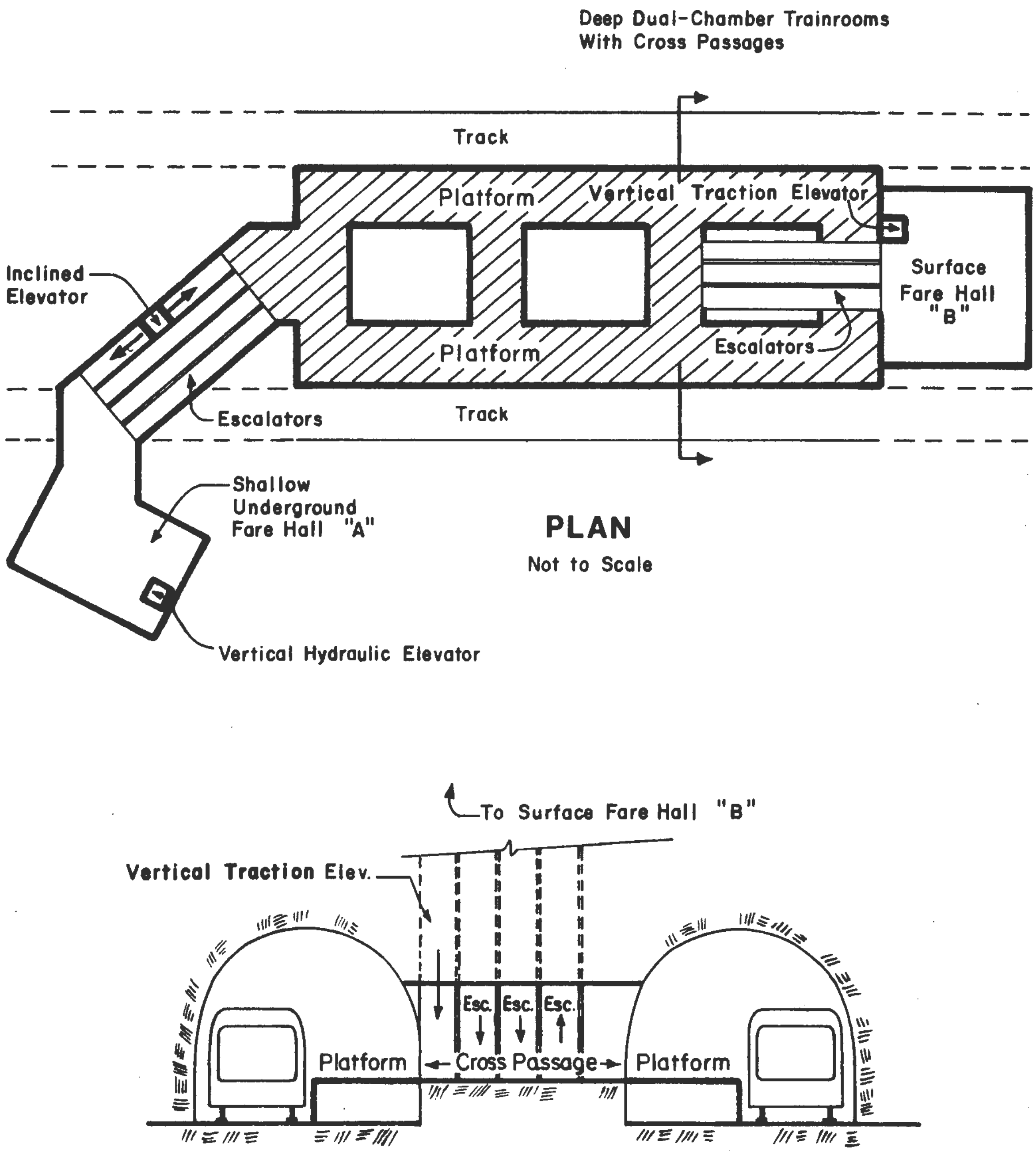
- All inclined elevators are either totally underground or protected from weather because of the long, severe winters in Stockholm.

- Stockholm is in an earthquake-free zone and underlain by sound rock that is readily mined at low cost for inclined subway access tunnels.

- Strictly economical choices between alternative design approaches are not of overriding importance; instead, emphasis is placed on selection of the best approach from an engineering, functional, humanitarian, and aesthetic viewpoint.

STATION CONFIGURATION

In general, the fare hall level in the T-bana underground stations is close to the surface, and the train room is usually two to three times deeper. A common station configuration is one in which the fare hall is horizontally displaced from the train platform, as shown in fare hall "A" of Figure 1. The direction of travel from the surface to the platform level can be freely selected to locate the entrance conveniently. The lower landings of escalators can be anywhere along the platform length or at a bridging, underpassing, or center concourse serving separate train platforms. The actual configuration becomes a site-specific



CROSS SECTION
Not to Scale

FIGURE 1

REPRESENTATIVE UNDERGROUND STATION LAYOUT

design choice, which is a direct function of major construction techniques and constraints of the geologic and urban surroundings. This type of station was the major inducement for Stockholm's development of the inclined elevator. Installing inclined elevators in the escalator shafts eliminates the need for separate vertical and horizontal passages.

A less common station configuration is one in which the fare hall is not significantly displaced horizontally from the platform, as shown in fare hall "B" of Figure 1. In such a configuration, there are no obvious advantages for a specific kind of elevator equipment, and design decisions must be based on cost comparisons, structural feasibility, or the constraints of local surface and underground structures and facilities.

Stockholm's Vastra Skogen Station train platform is approximately 130 feet below the surface fare hall, which is roughly centered above the platform. Cost analysis was a major influence on the decision to drive a separate vertical elevator shaft rather than to enlarge the exceptionally long escalator shaft. A separate passageway for the vertical elevator was not necessary because station components are arranged to allow the surface landings of elevators and escalators to converge in a compact hall. Combined costs of equipment, excavation, and structural provisions gave a distinct advantage to the vertical elevator alternative for this recently completed station. A disadvantage is that the escalator and elevator landings on the platform are widely separated.

Upper and lower landings of vertical and inclined elevators are shown in the photographs on the following pages. The first two photos were taken in an older station; the others illustrate the current model inclined elevator.

CRITERIA FOR ELEVATOR SELECTION

In determining the types of vertical transportation to be installed, SL planners have evolved a set of first approximations; although applicable in Stockholm, these approximations must be verified in light of unique local conditions. Briefly, these "rules of thumb" are:

- Hydraulic vertical elevators are warranted for rises up to 25 feet.
- Mechanical traction-type vertical elevators are preferable for rises greater than 25 feet at sites with no horizontal displacement.
- Inclined elevators should be considered for vertical rises greater than 25 feet at sites with a significant horizontal displacement.

Fare hall landing of masonry-enclosed vertical elevator.

Train room landing of vertical elevator, separated from foot of escalator and stairway, at end of short corridor.

Fare hall landings of escalators and inclined elevator enclosed with glass and metal mesh.

Fare hall landing approach to escalator and inclined elevator.

View from upper landing of escalator. Inclined elevator enclosure on right.

Train room landing of mesh- and glass-enclosed inclined elevator, coinciding with escalator landing. A member of the study team is at left.

Lower landing of escalators and inclined elevator in cross-passage leading to train room.

View of escalators and inclined elevator, showing scale of underground rock excavation.

Short rises from shallow fare hall levels to the surface are generally accomplished with hydraulic elevators, and the greater lift from train room to fare hall is usually made with traction-type elevators.

The final selection of vertical or inclined elevator installation is based on an evaluation of station configuration, pedestrian travel paths, and construction cost. Sound rock that is easily mined to form large escalatorways is a factor favoring the selection of the inclined elevator.

Conditions in other locations may dictate shallow cut-and-cover concrete box stations, with the fare hall immediately above the train room. In these cases, short vertical rises are most economically equipped with hydraulic vertical elevators, and the mainstream flow of passengers is not radically diverted. Architectural treatment may include open entrances with stairways and escalators exposed to the weather, which would require additional costs for weatherproofing the elevator car and the many exposed moving parts. High cost of forming large escalator shafts in difficult-to-excavate ground and near existing structures may preclude installation of inclined elevators.

The horizontal separation between fare hall and train room may be the result of surface constraints, depth of train room, irregular topography, or interconnections between separate transit lines. The inclined elevator can provide a positive solution to the problem of connecting these displaced underground structures.

ADVANTAGES OF THE INCLINED ELEVATOR

A major planning consideration, tending to supersede all other issues related to inclined elevators, is the desirability of channeling the flow of patrons through a station in a single simplified pattern. Where site conditions permit large escalator shafts or stairwells, the inclined elevator may be installed in a common opening, accommodating all traffic.

The following considerations summarize the factors favoring inclined elevators:

- The need for separate vertical elevator shafts and horizontal passageways may be avoided by placing inclined elevators adjacent to escalators.

- The personal security of elevator users is greatly improved by placing all patrons in the same traffic pattern, because occupants of the inclined elevator are clearly visible from the adjacent stair or escalator.

- Duties of station attendants, security guards, and maintenance personnel are simplified by integration of equipment and passenger flow, as opposed to separate and distant elevator shafts and passageways.

- Street or building configurations that are not directly compatible with installation of vertical elevators to serve underground transit lines may be more readily connected by the inclined elevator.

- The public preference for safe, convenient, fast and pleasing modes of vertical transportation is satisfied by the inclined elevator.

DESIGN OF THE INCLINED ELEVATOR

Essentially, the inclined elevator used in the Stockholm subway is a vertical elevator car, mounted at a 30° angle on a wheeled undercarriage, balanced by a counterweight, and moved by a conventional traction-type elevator hoist and cables along fixed, inclined guide rails.

The relationship between escalators and inclined elevator in a typical underground entrance shaft is shown in Figure 2. Some of the variable characteristics of the inclined elevators are location of doors, passenger capacity (6 to 12 persons), and angle of incline (25° to 35° from horizontal). Cars with doors located on the front and rear walls are applicable to two-landing installations; intermediate landings can be accommodated by cars with the door on the side wall.

Hoistway configuration and major components of the inclined elevator are shown in Figures 3 and 4. Details are illustrated in the following photographs.

Technical data for the early 8-passenger inclined elevator and the currently produced 12-passenger elevator are summarized below.

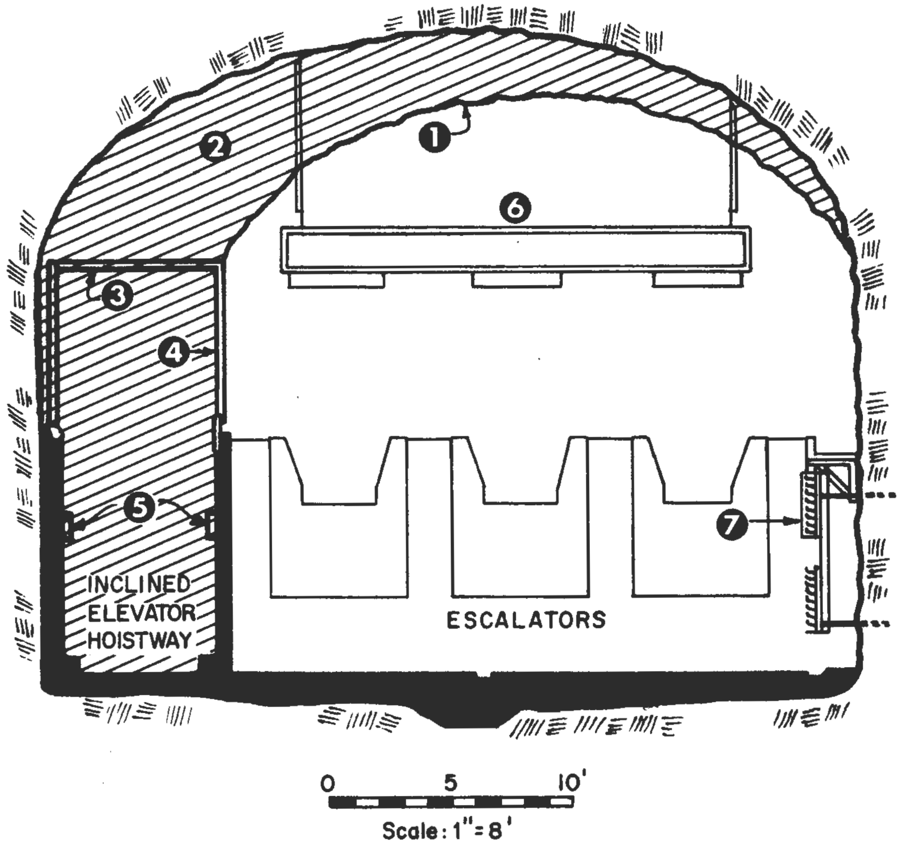
TECHNICAL DATA

<u>Eight-Passenger Car</u>

Rated car load:	600 kg (1325 lb)
Empty car weight:	1400 kg (3075 lb)
Counterweight:	1000 kg (2200 lb)
Vertical static load on one car guide rail:	1000 kg (2200 lb)

Twelve-Passenger Car

Car door:	Width	900 mm	(36")
	Height	2200 mm	(7'3")
Car interior:	Length	1500 mm	(60")
	Width	1420 mm	(57")
Control button height:		1170 mm	(47")
Control pressure:		2.5 Newtons	(.56 lb)
Control button diameter:		30 mm	(1-1/4")
Door-closing pressure:		3 kpm	(2 foot-pounds)
Safety edge tolerance:		50-75 mm	(2" to 3")
Emergency door width:		400 mm	(16")
Handrail:	Height	875 mm	(35")
	Diameter	41 mm	(1.6")
	Clearance	40 mm	(1.5")
Photo-electric door control height:		500 mm	(20")
Car interior illumination:		200 lux	(19fc)
Acceleration/deceleration:		.45 m/sec/sec	(1.5'/sec/sec)
Vertical leveling tolerance:		± 10 mm	(3/8")
Normal velocity:		.65 m/sec (Range 0.6-1.0 m/s)	(2'/sec)
Dwell time at landing:		20 seconds (Observed range 12-30 sec)	
Rated car load:		900 kg	(1980 lb)
Emergency controls:		Emergency stop; call for assistance (intercom to station attendant)	
Hoist machine:	modified, geared vertical elevator hoist		
Motor:	two-speed, 4.4 kw, 380 volts, 3-phase, 43.7A starting, 12.5A running		
Brake:	double block shoe and drum, spring-applied		
Flywheel:	on motor for damping acceleration/deceleration		
Driving sheave:	650 mm dia., four 12 mm cables (26", 1/2")		
Wormgear drive:	four-to-one speed reduction in cast steel housing		

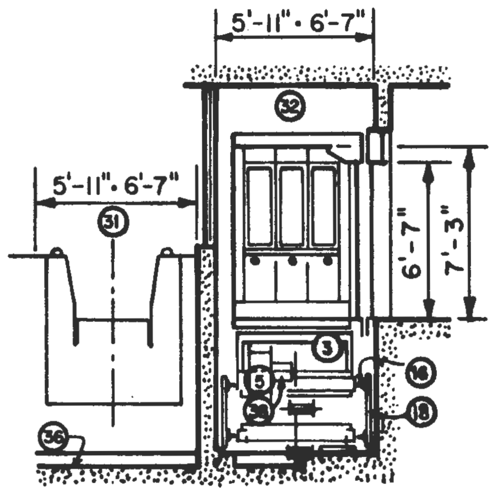


LEGEND

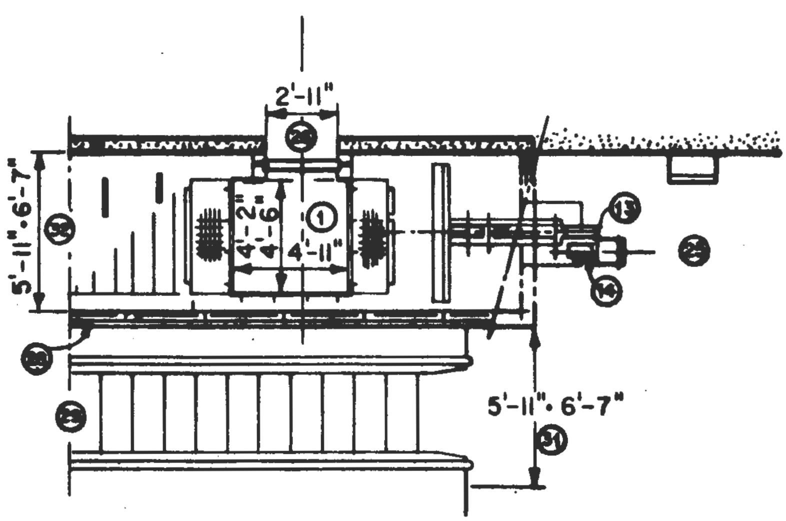
1. Excavation boundary w/o inclined elevator
2. Additional area of excavation with inclined elevator
3. Ribbed ceiling closure
4. Expanded metal partition
5. Inclined hoistway lighting
6. Noise baffles and lighting
7. Wiring and controls

FIGURE 2

ENTRANCE SHAFT FOR TYPICAL UNDERGROUND STATION



CROSS SECTION



PLAN

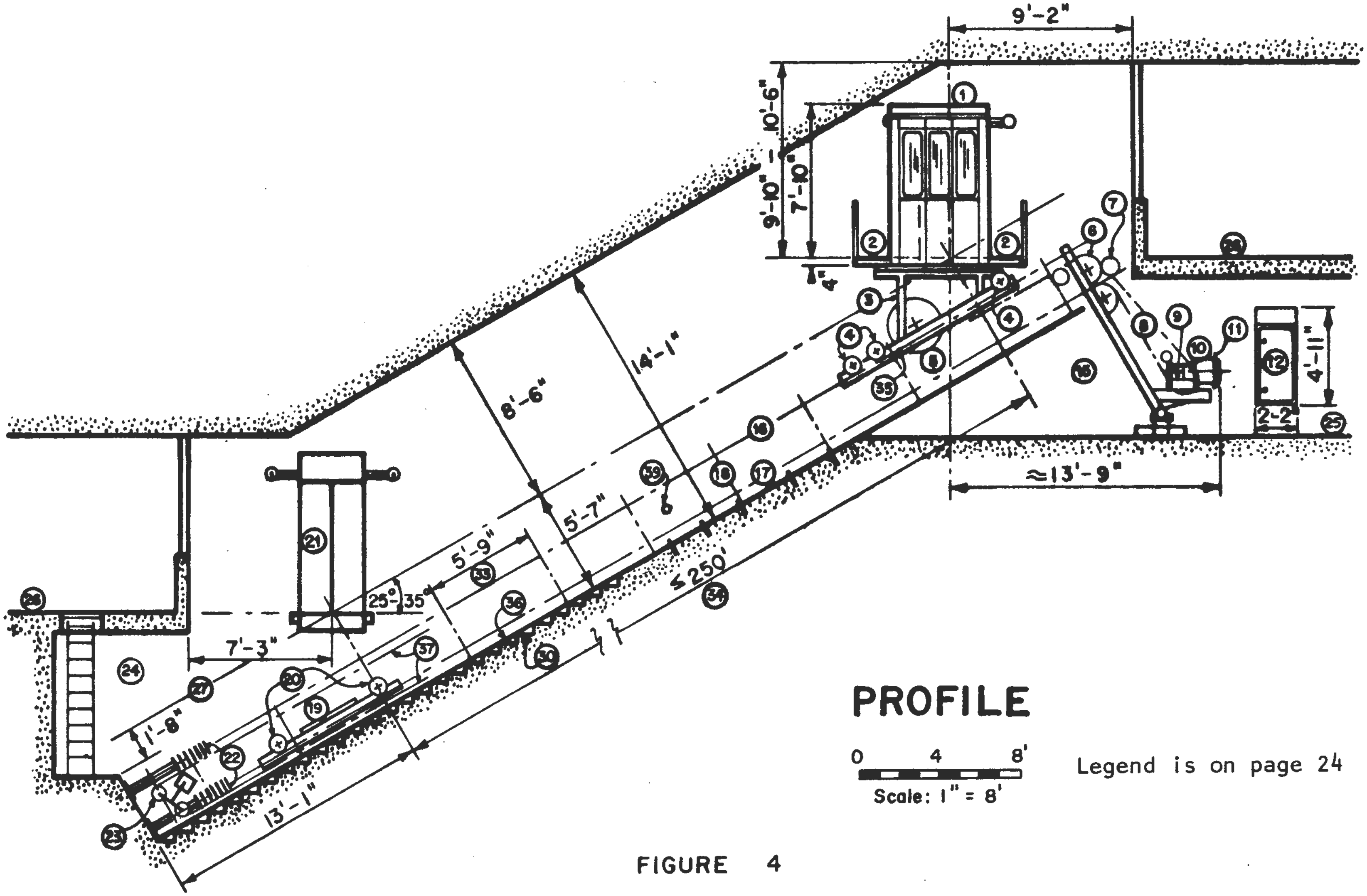
Legend is on page 24.

0 4 8'

Scale: 1" = 8'

FIGURE 3

TYPICAL SIDE-DOOR INCLINED ELEVATOR



PROFILE

0 4 8'

Scale: 1" = 8'

Legend is on page 24

FIGURE 4

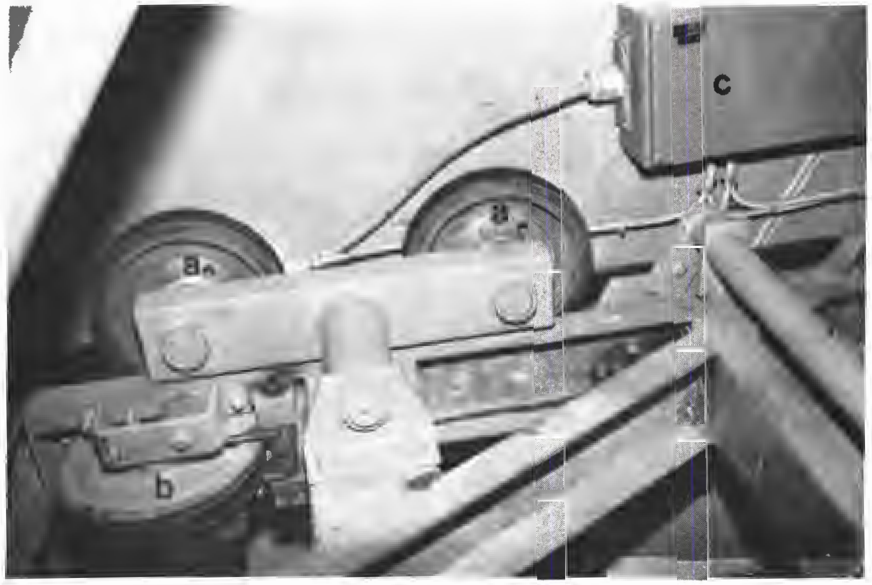
TYPICAL SIDE-DOOR INCLINED ELEVATOR

LEGEND FOR FIGURES 3 AND 4

1. Car
2. Emergency exit platforms
3. Undercarriage framework
4. Car roller guides
5. Drum reel for traveling cable
6. Deflector sheaves
7. Overspeed governor
8. Hoist cables
9. Worm gear drive
10. Drive motor
11. Flywheel
12. Control panel
13. Driving sheave
14. Operating brake
15. Hoist machine
16. Car guide rail
17. Counterweight guide rail
18. Inserts and rail brackets
19. Counterweight
20. Counterweight roller guides
21. Hoistway door to side entrance car
22. Spring buffers for car and counterweight
23. Tension weight and sheaves for overspeed governor cable
24. Hoistway pit
25. Machine room
26. Floor level landing for passengers entering/leaving car
27. Travel line for center of car floor
28. Expanded metal and glass partition
29. Escalators; bank of three is typical
30. Steps for hoistway maintenance and emergency egress
31. Escalator; typical gross width of one unit
32. Inclined elevator hoistway; typical inside clear dimensions
33. Spacing between guide rail support brackets typical for traveling cable-drum design
34. Maximum travel, suggested by manufacturer
35. Emergency brake, located on undercarriage frame with guide rail clamps
36. Lower floor of hoistway; common level with floor of adjacent escalator way
37. Governor cable, supported by rollers
38. Sliprings connecting traveling cable control circuits and service power circuits into car
39. Roller supports for traveling cable

View of inclined elevator shaft, looking upward toward car.

Undercarriage of inclined elevator seen from lower end of shaft. Spring buffer(a), carrying wheels on rails(b), and ladder to car(c) can be seen.



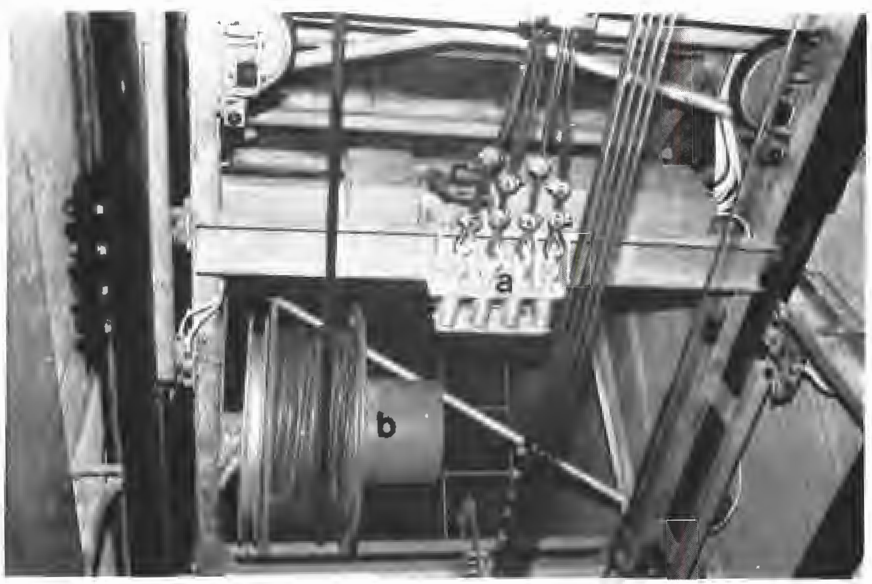
Carrying wheels(a) and side thrust wheel(b) on inclined elevator undercarriage. Control device(c) is mounted on wall of shaft.

Lower end of inclined elevator car, showing exterior platform and ladder used for maintenance and emergency evacuation.

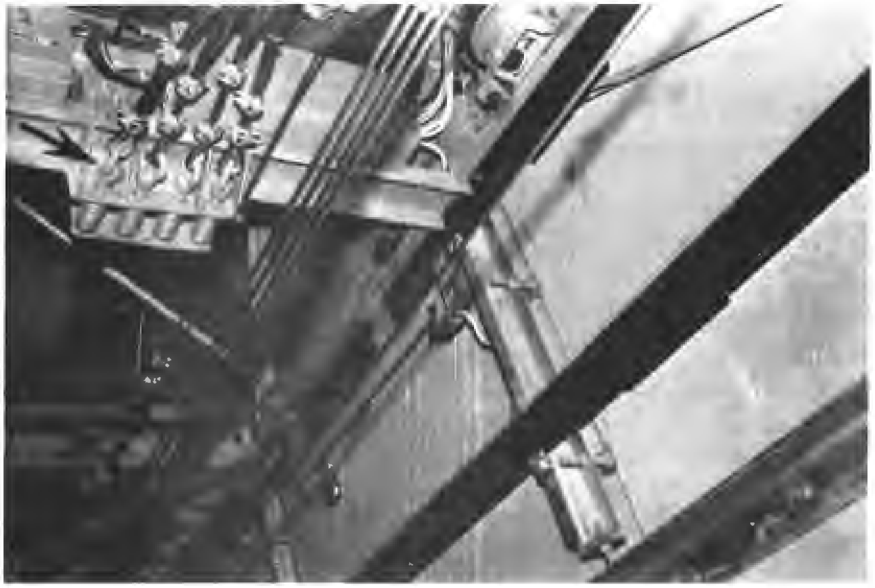
Upper end of inclined elevator car and carriage, showing exterior platform and ladder in use.

Upper end of inclined elevator car and shaft, showing car(a) and counterweight rails(b), steps(c), cable tray(d), car exterior platform, and ladder.

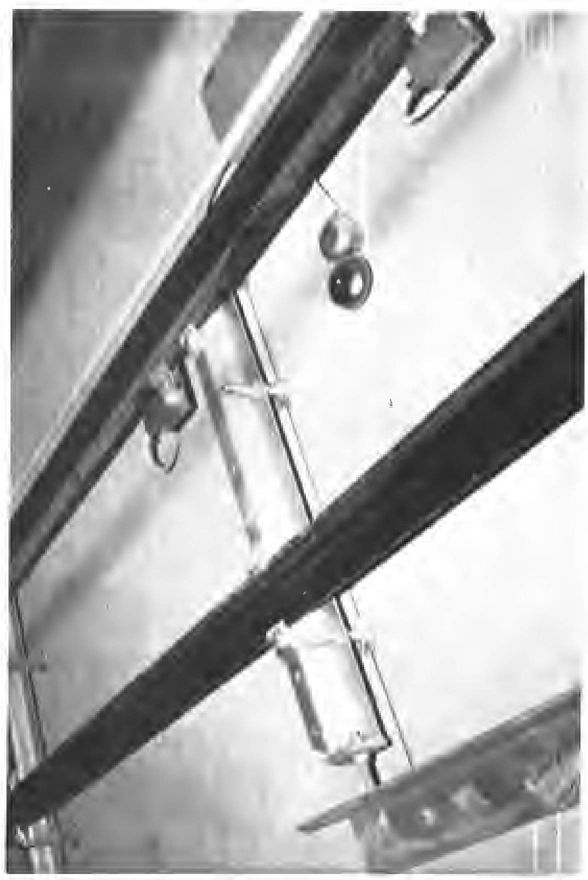
Hoist machine(a) and deflector sheaves for car(b) and counterweight(c) cables.



Inclined elevator undercarriage, showing traction cable connections(a) and control cable drum(b).



Detail of traction cable connection to undercarriage.



Detail of car and counterweight rail fastening to shaft wall.

Line-of-Travel Loading

The early, windowless inclined elevator cars were designed for loading and unloading at the front and rear in the direct line of travel, which required that the cars be fitted with two doors. This arrangement simplified passenger movement into and out of the elevator, no turn-around maneuver being needed, and minimized the amount of expensive excavated space devoted to the elevator and its landings. However, the passenger was concealed within the masonry-enclosed hoistway for a period of time sufficient to cause distress to some and an opportunity for vandalism by others.

Technical problems in attaining the high degree of stopping accuracy needed to align the car with the landing, while avoiding contact or large gaps, resulted in the change to single-door, side-loading elevator cars that are currently being installed. Continuing development by the manufacturer has resolved the stopping difficulty, and it was reported that future inclined elevators on the T-bana are likely to have two-door cars, in-line loading, and visually open hoistways and cars to combine the advantageous features so far developed.

Car Size

The current model 12-passenger inclined elevator is large enough to accommodate comfortably two wheelchairs, or one wheelchair accompanied by four ambulatory passengers--a size that the SL has fixed on as optimal. Although the high cost of underground space was a strong factor in the decision to install minimum-size elevators, especially in the retrofit of existing stations, six-passenger elevators were found to be too limiting in use.

Accessibility Standards

Swedish standards governing accessibility of buildings to the elderly and handicapped differ only slightly from those developed in the United States, most deviations probably being a function of the discrepancy between the metric and the English dimensional units. A direct comparison of major U.S. elevator requirements with corresponding Swedish standards is given in Table II. Selected U.S. criteria are taken from the GSA publication, Design Criteria: New Public Building Accessibility, which is derived from the American National Standards Institute publication ANSI A117.1. The Swedish design characteristics are those of the current model 12-passenger, side-entry KONE inclined elevator.

Minor differences between the two sets of standards are functionally insignificant, with the possible exception of the U.S. turning radius requirement of 60", which is not achieved in the Swedish design. Some minor shortcomings of the Swedish inclined elevator are: location of the controls on the same wall of the car as the door, which imposes on a

TABLE II

COMPARISON OF U.S. ACCESSIBILITY REQUIREMENT AND SL DESIGN

Automatic Elevators

	U.S. REQUIREMENT	SL DESIGN
Clear Space	1. Provide clear space within accessible elevators to allow wheelchairs a 180° turn (a 60-inch diameter circle is preferred).	1. Current design will not accommodate full 60-inch turn (interior dimension 59" x 56"). However, side pivot is possible. If "Direction of Travel" design is employed, turning requirements could be reduced or eliminated.
Doors	2. Minimum width, 36 inches	2. Door width in nearest metric, 900mm (35-1/2").
	3. Provide method to prevent doors from closing on passengers. A. Where photocell is employed, mount units at approximately 5 and 28 inches above floor.	3. Single photocell used, mounted at approximately 20 inches above floor.
	4. Kinetic energy of doors shall be no more than 7 foot-pounds.	4. Pressure tolerance, 3 kpm (2.016 foot-pounds).
	5. Doors must remain open at least 4 seconds.	5. Total dwell, 20 seconds.
	6. Provide safety shoe.	6. Safety shoe provided.

Table II (Cont'd)

	U.S. REQUIREMENT	SL DESIGN
Flooring	7. Minimum leveling zone, ±1/4 inch preferred.	7. Leveling, ±10mm (3/8").
	8. Provide non-slip flooring.	8. Non-slip flooring provided.
Handrails	9. Provide horizontal handrails on at least one side wall, 3 preferred.	9. Handrails provided on 3 side walls.
	10. Mounting height: 32-34 inches, 33 inches preferred; allow 1-1/2 inches clearance between rail and bottom of control panel.	10. Mounted at metric equivalent 875mm (34-1/2"). No rail under panel.
	11. Recommend vertical rail in addition to horizontal.	11. Not provided.
	12. Provide at least 1-1/2 inches clearance from handrail to wall.	12. Clearance, 40mm (1-1/2").
	13. Handrail shall have a horizontal cross section of 1-1/4 to 1-3/4 inches, with 1-1/2 inches recommended.	13. Handrail round, smooth metal, circumference = 130mm (5"), cross section = 1.46".
Hall Arrival	14. Arrival indicators shall be visible and audible from central points in elevator lobby.	14. Door opening is visible due to reduced size of lobby. Audible annunciation not standardized in system.
	15. Provide direction symbols of contrasting colors for upward- and downward-bound elevators.	15. N/A for two-point service.
	16. Provide two audible signals, one for each direction.	16. Audible signal not standard feature. Two signals not required for two-point service.

Table II (Cont'd)

	U.S. REQUIREMENT	SL DESIGN
Lobby Call Button	17. Provide at least one separate call button for every bank of four elevators in line.	17. N/A
	18. Center line button height: 40-48 inches from floor, 42 inches recommended.	18. Button height: 1170mm (46").
	19. Minimum size: 3/4 inch.	19. Button size, 30mm (1-1/4").
	20. Maximum depth, if recessed: 3/8 inch when operated.	20. Button raised.
	21. Provide visual indication of call registration.	21. Provided; visibility limited.
Elevator Car Controls	22. See Nos. 19, 20, and 21 above.	22. See Nos. 19, 20, and 21 above.
	23. Letters or numbers minimum 1/2 inch high and raised or depressed at least 1/32 inch, shall be placed adjacent to each control button.	23. Letters, minimum approx. 2/5", not depressed to required depth (some models also employ braille characters, but not standard).
	24. Mount with top and bottom button center limits between 30 and 48 inches from elevator car floor.	24. Top center line, 46"; bottom center line, 40".
	25. Recommend placement on side wall adjacent to entry	25. Mounted on same wall as entry.

Table II (Concluded)

	U.S. REQUIREMENT	SL DESIGN
Telephone and Intercom	26. Mount between 24 and 56 inches as near to control panel as possible.	26. Communication is by microphone-speaker.
	27. Equipment must be operable with a single hand.	27. Intercom initiated by pressing a button.
	28. Provide cord of sufficient length to avoid bending during use.	28. Initiation button mounted on control panel at 46". Once initiated, communication is constant without further manipulation.
Floor Identification	29. Provide visual car-position indicator above entrance door in car.	29. Not provided; of questionable value in two-point travel.
	30. Provide floor identification on jamb of elevator opening.	30. Not provided; of questionable value in two-point travel.

wheelchair occupant an awkward reach-over-the-shoulder or a complete about-face before the elevator can be started; a lack of tactile information on the controls; omission of a folding seat for persons who are unsteady; and omission of an audible "elevator arrival" and "door operating" signal for the blind.

Weather Protection

Although Stockholm inclined elevators are protected from direct exposure to sunlight, rain, snow, sleet, and dirt, they are designed to be tolerant of relatively large temperature differences since they are not always in heated areas.

The inclined elevator hoistway contains guide rails, rollers, electrical switches, moving parts, and clearances that would deteriorate or malfunction if directly exposed to outdoor weather. (Some of this equipment could be weatherproofed, but maintenance and repair would be more difficult and costly, and reliability of operation would be decreased.) The mechanical equipment that operates the inclined elevator is visible from the car as it approaches the upper landing and from both landings when the car is absent. Not only would it be difficult to conceal these moving parts, but any aesthetic screening or concealment would interfere with ease of maintenance and inspection. The bright yellow cars themselves are plainly visible behind the metal screen as they move within the moderately illuminated hoistway.

Capacity

The capacity of the current inclined elevator car is chosen to allow maneuvering space for two wheelchairs or for one wheelchair and four ambulatory passengers, which seems adequate to accommodate a rather larger-than-usual group of subway co-travelers. The space given over to the car, and indeed to the hoistway, will be less transportation-effective than the space allocated for moving peak-period passenger traffic on escalators or stairways. For example, an escalator carrying a crush load on a typical 140-foot travel distance can carry 30 times as many passengers as an inclined elevator operating at the same speed over the same distance. The total peak passenger flow in a mass transit station could not reasonably be accommodated by an installation of inclined elevators solely.

Speed and Acceleration

The speed and acceleration of T-bana inclined elevators are selected primarily to accommodate the physical limitations of edlerly and handicapped passengers. The velocity of a typical elevator is 0.65 meters per second (2 feet per second), and the acceleration/deceleration rate is 0.5 meters per second per second (1.65 feet per second per second). The horizontal component of acceleration of a 30° inclined elevator is a substantial part of the whole (.866 x .5 = 0.43 m/sec/sec, or 1.42 feet/sec/sec). Acceleration and velocity of the early inclined elevators was somewhat greater, but has been reduced because of the effect of the horizontal acceleration and deceleration on unsteady passengers. The inclined elevator, moving at a pace slightly slower than the adjacent escalator, is no great temptation for the hurrying, able-bodied passenger and is left in place to be used by those who cannot cope with the escalator or stairway.

The typical inclined elevator travel distance could accommodate an increased acceleration zone and greater operating velocity, with possibly some loss in ride quality due to slight irregularities of the guide rails that would become more noticeable at higher speed. An example of higher velocity operation is the atypical inclined elevator at the T-bana Liljeholmen Station, which is the sole means provided for passengers to reach the hilltop community above the station. This elevator operates at a 9° angle from the horizontal and travels 760 feet at 11.5 feet per second. It differs from the inclined elevators that serve as alternatives to escalators not only in higher operating speed, but also in larger car size, having attended operation, pneumatic wheels that roll on concrete tracks, overhead trolley wires and moving contact pick-up of control and signal circuits, and more complex accelerating and decelerating controls.

The two-speed squirrel-cage AC motors driving through the four-to-one speed reduction gearing provide excellent starting, accelerating, stopping, and leveling in the slow-speed elevator application. The flywheel on the extended double shaft of the motor absorbs jerks and smoothes the transition between low and high speed. The flywheel can be used as a handwheel for manually moving the elevator to a landing in case of equipment malfunction or power outage.

Control

Because the T-bana inclined elevators only operate between two landings, the operating controls are simplified to a single call button at each landing and two destination buttons in the car. Calls are automatically held until completion of the trip and expiration of the associated dwell time.

The undercarriage is equipped with a load-sensing device that prevents movement if rated load is exceeded. Safety factors governing structural design for the car undercarriage, supporting rails, and hoist machinery are determined by engineering judgment and are often as much as fourfold that required for the design load.

Support System

The forces of gravity, acceleration/deceleration, overspeed stops, buffer stops, and design speed and load acting on the car, undercarriage, and counterweight are transmitted to the structural hoistway by a pair of guide rails for the car and a pair for the counterweight, buffers at the bottom of the hoistway, and anchorage of the hoist machine at the top of the hoistway. The conventional elevator guide rails are bolted to metal inserts that are cast in the vertical concrete walls. Small-diameter metal wheels with plastic rolling surfaces are mounted on the car undercarriage and on the counterweight to contact the guide rails in two planes for support and steering guidance. The support system is accessible to inspection, maintenance, and repair by means of the stairway built into the sloping floor of the hoistway. The elevator hoist machine occupies much less space than the adjacent escalator machinery due to the smaller power requirements of the counterbalanced elevator.

Safety Buffers

Safety buffers absorb the kinetic energy of car or counterweight in case of overrun beyond the normal stop limits. Buffers are mounted on the lower hoistway end wall, aligned in the direction of travel, and centered on the car and counterweight framework. Retardation requirements are based on speed and weight of the car and counterweight.

Standard coilspring buffers, used for the side-entry elevator cars, are similar to vertical elevator hardware and are positioned to allow 300 to 400 mm of run-by clearance before a car or counterweight contacts the buffer.

Oil-filled buffers are used with the front/rear-entry elevator cars to provide controlled stops at top and bottom of the hoistway. Very small tolerance is allowed in the clearance between car and landing at the ends of the hoistway, because a slight underrun will leave gaps in vertical and horizontal alignment that will be difficult to negotiate with a wheelchair and a slight overrun will cause the car to strike the landing. The oil-filled buffer contacts the car or counterweight on every stop, withdrawing and easing normal stops. In case of overrun or overspeed, the oil-filled buffer is fully activated to serve its safety function. The oil-filled buffer requires more frequent inspection, maintenance, and replacement than the usual coilspring buffer because it is actuated at each elevator trip. Such buffers are commonly used in high-speed vertical elevators and are recognized by U.S. elevator codes for this type of service.

EQUIPMENT QUALITY AND CODE COMPLIANCE

Elevator equipment installed in Stockholm appears to be equal in quality and function to U.S. equipment, although there are superficial differences in materials, dimensions, and operating parts.

U.S. Elevator Code

Although inclined elevators are used in the United States for such services as mine lifts, hillside hoists, ski lifts, and residential lifts, none are comparable to the Swedish inclined elevator in commercial finish and duty. The current American National Standard Safety Code for Elevators, Dumbwaiters, Escalators, and Moving Walks (A17.1), which does not contain coverage for commercial duty inclined elevators, is being revised to include this class of elevator. The existing vertical elevator codes are being adapted to the inclined mode of operation and its unique applications within stairways or escalatorways.

Swedish Elevator Code

In Sweden, as in the United States, there is no official code setting forth standards or requirements for the inclined elevator. Swedish building and elevator inspectors apply electrical, building, structural, and vertical elevator code requirements directly to the inclined elevator installations, wherever these requirements are technically correct, create no safety hazards, and impose no undue hardship on the manufacturer and owner. Where existing code provisions are inapplicable to the inclined elevators, a series of improvisations have established precedents for their design, testing, installation, and inspection. The acquired successful experience with the installation of about 50 publicly used inclined elevators is currently being formalized into code.

In general, Swedish codes tend to be overall statements defining configuration, function, dimension, and standardization, whereas U.S. codes are more detailed in their treatment of performance and minimum safety requirements, materials selection, and testing procedures.

As an expedient toward a practical working arrangement in Stockholm, the inclined elevator manufacturer works directly with the local inspection authority and the equipment owner to obtain approval of the installed equipment. The process is generally as follows:

- Each elevator is designed for its site conditions and operating requirements.

- Vertical elevator code provisions govern certain car dimensions, components, and safety features when they are applicable. There is relative freedom in choice of materials and structural design.

- Where design features are unique to inclined elevator equipment, such as the forces and deflections on the guide rails, judgment and experience establishes the design approach, and empirical methods are used for design adequacy checks and equipment approval.

- Final inspection and approval of the installed equipment is made by the local authority, and it is then accepted by the owner as safe to operate. The final inspection includes empirical in-place testing.

- Routine inspections are made annually on a fixed schedule by the local office of the inspection authority. The procedure for routine inspections is similar to annual inspections in the United States.

Compliance with U.S. Standards

The Stockholm inclined elevator equipment could be manufactured to conform to a developing U.S. code, with perhaps only a minor increase in cost due to potentially more stringent requirements. For the most part, electrical and mechanical hardware and assembled components of the Stockholm inclined elevator appear to be compatible with U.S. standards. Changes, such as enclosing all wiring in conduit and defining test procedures acceptable to U.S. custom, could be accomplished without major investment of resources.

The existing U.S. vertical elevator codes define the properties of many of the components that are common to both inclined and vertical equipment. With the notable exception of car and counterweight configuration, most material, material assembly, and component arrangement for inclined elevators would require little change by the manufacturer of present U.S. vertical elevators. For example, the following components would need little or no modification: hoist machine, hoistway electrical hardware, hoisting cables and sheaves, buffers, car and hoistway doors, controller and its associated material, overspeed governor, and mechanical emergency brake. These components have well-established performance records and would be used under the same conditions that are now regulated by the U.S. elevator code.

Some of the inclined elevator features that are not commonly used on U.S. elevators are: traveling cable winding drum and slip rings; flywheel on the hoist drive motor; load bearing and guide wheels; tilted undercarriage and cable attachment; direction-changing sheaves for hoistway cables at the hoist machine; and roller supports for hoisting cables, governor cable, and traveling cable on the inclined hoistway floor. These and other innovations will have to be considered in the development of a code for inclined elevators in the United States.

Major Issues in Code Compliance

Several issues of Swedish code compliance that may create initial concern among manufacturers of U.S. elevator equipment and potential U.S. owners of Swedish equipment are discussed below.

Safety Equipment Testing

Most of the safety requirements for Swedish vertical elevators are similar to U.S. code requirements and are incorporated in the design and testing of inclined elevators. A major Swedish departure from U.S. practice involves the car overspeed safety test. Safety equipment for emergency stopping is neither type- nor field-tested by actual overspeed conditions as is customary in the United States.

The governor alone is tested to determine that it trips at the controlling preset overspeed, which is artificially imparted by a change of governor cable sheave size driven at the rated car speed. Tripping the overspeed governor causes application of the car's mechanical emergency brakes to the car guide rails. During this test, the car runs at rated design speed with a full load. While future U.S. test procedures may be expected to subject the equipment and structural supports to actual, all-systems emergency conditions, with a loaded car moving at overspeed down the guide rail to reach governor-tripping speed, the Swedish procedure tests only for safety component operability at design speed with rated load.

After visual inspection, the study team judged that the Stockholm equipment could probably pass a U.S. type test or field test. However, such tests have not been performed in Sweden because there has been no code or acceptance requirement or perceived need for subjecting the system to more severe conditions.

Guide Rail Dynamics

The Stockholm inclined elevator uses basically the same equipment and structural provisions as the vertical elevator. The main design difference is that inclined equipment exerts horizontal and vertical forces on guide rails, which vary with degree of inclination. Car body design and undercarriage detail also vary to accommodate these forces. Although U.S. Code provisions would normally govern performance characteristics, the sizing of members, and the selection of materials to safely accommodate guide rail dynamics, there appears to be an insufficient accumulation of data for these features in inclined elevators.

Standard T-shaped guide rails are used to support both car and counterweight in the Stockholm inclined installations. They are sized by designer experience and engineering calculations, which are not governed by code. The normal and abnormal dynamic interactions between moving body and structural support throughout the range of vertical to horizontal are known only theoretically.

The present U.S. code deals with vertical elevator rail deflections caused by unbalanced loading in normal operations and in emergency stopping conditions. A future inclined elevator code would be expected to govern the selection and installation of materials to accommodate the unique dynamics of inclined motion.

Firewalls and Passenger Evacuation

The inspection authorities in Stockholm determined that, when an inclined elevator is located in a common structural opening with escalators, firewalls are not required to enclose the hoistway. Indeed, a principal advantage of inclined equipment--clear visibility between elevator user and other patrons--would be lost if firewalls were imposed.

The open-mesh metal partition between car path and adjacent escalatorway can be readily disassembled for maintenance or emergency evacuation. As an added precaution against accidental contact or interference with mechanical parts, laminated glass panels back up the metal hoistway enclosure at landings.

An interesting SL ground rule for currently constructed vertical elevators requires two cars in an enclosed hoistway where the difference in consecutive landings exceeds 33 feet. Car body side panels can be quickly opened on hinges so that the second car can be used to evacuate passengers in the stalled car. When an inclined elevator is installed in a common opening with stairs or escalators, there is an inherently greater degree of accessibility to the occupant of a stalled car from any point on the adjacent stairway.

Miscellaneous Issues

The adequacy of Swedish requirements for safety devices in inclined elevators is testified to by the fact that there have been no recorded accidents with injury to passengers. Doors are equipped with photoelectric cells and safety edges to prevent closing against passengers. Emergency alarm and voice communication equipment can be operated from inside the car. Current installations have an array of safety devices similar to those in U.S. vertical elevators.

Swedish codes allow power and control lines to be exposed in the hoistway. The lines, which are insulated and jacketed, are firmly fixed, clear of moving parts. U.S. codes would require these lines to be enclosed in metallic conduits. This adaptation would slightly raise the overall cost of the installation, but would not require an increase in hoistway cross section.

Until inclined elevator provisions are written into U.S. codes, it appears that established practices for vertical elevators could also accommodate the exceptional features of inclined equipment. Type and acceptance testing procedures could be developed, considering the merits of each case, until sufficient data are accumulated to cover the practical range of inclined equipment that may be available for public use. This procedure has served the public interest in the past and appears to be the logical path toward U.S. standards. This has also been the process used in Sweden for generating information to support national code provisions.

OPERATION AND USE OF THE INCLINED ELEVATOR

Inclined elevators are immediately familiar to passengers who are acquainted with vertical elevators. Door operation, control device location, and interior arrangement of the car are similar to standard vertical elevators. Only after the destination button has been touched and the elevator has begun its diagonal trip does the difference become apparent because of the momentarily unsettling horizontal shift. This is especially marked in the early inclined elevators, which have no windows and give no advance clue to their motion; in the later elevators, the entire hoistway is visible from inside the window-equipped car, and the visual reference to direction of motion is an aid to stability. Because of the low acceleration rate, the momentary horizontal acceleration requires, at most, only a steadying touch on a handrail and may be unnoticed by a person seated in a wheelchair.

In the T-bana, inclined elevators generally operate between the fare hall and the train room platform, and the shorter rise from the fare hall to the street-level entrance is equipped with vertical elevators. The inclined elevator is usually located at one side of the escalatorway, immediately adjacent to an escalator. The metal mesh and car windows provide a full display of the interior when viewed from the escalator and, conversely, create a sense of exclusivity and privacy within the elevator.

After the initial acceleration, the speed transition and steady travel are jerk-free and smooth, comparable to a good quality vertical elevator ride. A single call button at the landing activates the elevator, opening the automatic doors or starting the cab toward the calling floor. The doors are automatic and bi-parting, with a safety edge and photoelectric device to prevent reclosing on passengers. The doors remain open for a dwell time of about 20 seconds before reclosing. The cab controls are mounted low for easy reach from a wheelchair and are functionally identified by incised lettering. Braille or raised letters are to be used on future elevator controls to improve their readability by the visually impaired. Car controls consist of two destination buttons and an emergency button that sounds an alarm bell and initiates communication between the car and the station attendant. Pressing of the appropriate destination button closes the doors and initiates the automatic trip to the opposite landing where the elevator stops and the doors open. The upper and lower elevator landings are immediately adjacent to the escalator landings and the two passenger routes merge with no apparent difficulty.

SAFETY

The safety of inclined elevators was vouched for by handicapped user groups, SL management, and the representative of the insurance company that provides liability coverage for the T-bana. No accidents involving passenger injuries or insurance claims have occurred during the operating history of the inclined elevators.

Of the insurance claims against the T-bana, approximately 20 percent have been for accidents occurring on escalators, and 80 percent of these involved elderly persons. The insurance representative voiced the opinion that total insurance claims could be substantially reduced if elderly and infirm passengers would ride the elevators rather than attempt to cope with the escalators.

The high order of mechanical safety of the inclined elevator stems from the conservative design, which is based on many years of development and experience with the vertical elevator. The sense of personal safety perceived by the passengers derives from the mainstream location of the elevator and from the open visibility of the cab interior, which enables previewing before entering and visual contact with others while moving.

ELEVATOR EVACUATION

SL reported that no emergency elevator evacuation had yet occurred. Should an emergency arise, evacuation would be accomplished by SL personnel entering the shaft, lowering a folding ladder that leads to a service platform on the elevator car, and removing the passengers through the emergency door (see photographs on pp. 25 and 26). The emergency access door can be opened only from the car exterior, and car operation is canceled while the door is open.

The narrowness of the access door (16") and steepness of the shaftway stairs requires that a nonambulatory passenger be evacuated and carried by means of a stretcher to the station exit--if prompt evacuation is necessary.

Normal operating procedure during an elevator breakdown calls for station personnel to contact maintenance staff, who are the only persons authorized to operate elevator controls manually. Should the elevator fail to resume operation, it is manually moved to the nearest floor and the passenger is removed through the normal access door. The elevator occupant remains in communication with station personnel by intercom.

MAINTENANCE AND RELIABILITY

Available SL maintenance records do not differentiate between the data for inclined and vertical elevators, which is an indication that no significant maintenance problems are unique to the inclined elevator.

The breakdown frequency of inclined elevators is estimated by the SL staff at four to eight times per year per unit. About once a year per elevator, a passenger will be trapped by a malfunction for a period greater than 20 minutes. About 80 percent of the elevator stoppages occur at a landing. Maintenance and repair of approximately 40 inclined elevators, 100 vertical elevators, and all escalators and moving sidewalks are performed by 35 mechanics, each working individually on routine maintenance tasks. It is planned to increase this staff to 42 to 45 mechanics for improved preventive maintenance.

Programmed maintenance for each inclined elevator requires 70 to 80 man-hours per year, including weekly 20-minute inspections. Unprogrammed troubleshooting and repair of inclined elevators requires an effort of 1.2 times the routine maintenance, or 85 to 95 man-hours per elevator, per year.

For comparison, hydraulic elevators require only 14 man-hours per elevator, per year, for routine maintenance, and a typical escalator requires 140 to 160 man-hours. Escalator troubleshooting and repair is also 1.2 times the routine maintenance, or 170 to 190 man-hours per year each.

In spite of a thorough preventive maintenance program, equipment failures occur. Most of the elevator malfunctions are attributed to vandalism, usually of the doors and controls, which are readily accessible and often not under direct surveillance by station attendants. The SL failure experience with elevators, which has not been differentiated between vertical and inclined types, is about 120 to 140 outages per year with passengers on board. The average elapsed time before release of passengers is 20 minutes. As the cabs are counterweighted, mechanical elevators are generally moved to a landing by releasing the brake and operating the manual wheel provided in the machine room. All stations are provided with stand-by diesel engine-generators that are capable of furnishing sufficient power to operate the elevators on an emergency basis when normal and emergency power sources are lost. Elevator car lighting and communication systems are supported by battery power as a last resort.

Elevator installations are maintained by the manufacturers' maintenance staff for the first two years of operation, after which the SL maintenance staff takes over. SL maintenance personnel receive two years of training at the manufacturer's school and additional on-the-job training by the manufacturer's engineers during start-up and testing of new equipment.

The SL staff has not reduced their maintenance data to derive numerical values of mean-time-between-failures, time-to-restore, and reliability.

USER CHARACTERISTICS

The majority of inclined elevator users are individuals with moderate physical disabilities or temporary handicaps, such as broken limbs, pregnancies, and illness, or persons transporting pets, children, packages, and carriages. Two-hour periods of continuous observation of inclined elevator users at each of three locations provided the data presented in Table III. The 20-to-40 year age group contains a large percentage of inclined elevator users--due, probably, to the higher degree of mobility of individuals in this age range.

Elderly persons walking without assistance also were observed to be frequent users of the inclined elevator--probably in preference to coping with the difficult transitions of boarding and leaving high-speed escalators. The number of male and female riders (46.6 and 53.4 percent, respectively) may be a function of the time of observation, but is probably influenced by the larger number of women traveling with baby carriages and packages.

Data on inclined elevator use for 1971 to 1976 were furnished by the SL from their maintenance record of the number of operations of each elevator. Inclined elevators in central business district stations received the most use--16.3 trips per hour at the Ostermalmstorg Station being the highest average--and suburban elevators the least--1.15 trips per hour at the low-volume outlying Nackrosen Station being the lowest. The overall system average is 5.9 trips per hour. Assuming that the observed use per trip by a single passenger is the usual case, just under 1 percent of the total T-bana riders make use of the inclined elevator.

The extensive special transit system, Fardtjanst, which offers door-to-door service by taxicabs or by vans equipped with ramps or lifts, and furnishes two-man portage service for the handicapped, is available to most elderly and handicapped persons at a very low cost to the passenger. Specially equipped private vehicles for operation by the handicapped are also available for purchase by individuals on a government-subsidized basis. These alternative, more attractive modes of transportation generally are preferred by the elderly and handicapped according to several handicapped persons who were interviewed by a team member and as indicated by the high use of Fardtjanst and the relatively small use of subway station elevators as reported by SL, and by the infrequent presence of handicapped persons in the subway, as seen by the team.

Table III

CHARACTERISTICS OF OBSERVED INCLINED ELEVATOR USERS

Types of Users	Percentage
• Ambulatory, without assisting device, but with visible difficulty.	27
• Traveling with pram.	27
• Ambulatory, with assisting device	7
• Ambulatory, without assisting device and no apparent difficulty (30% of this group classified as elderly).	20
• Ambulatory, encumbered with packages, animals.	13
• Pregnant.	7
• Wheelchair users.*	0
Estimated Age of Users	
• Under 20	13
• 20 - 40	47
• 40 - 60	20
• Over 60	20
Sex of Users	
• Male	47
• Female	53

*Although no wheelchair users were recorded during structured observation periods, 9 wheelchair users were noted during approximately 55 hours of casual observation of system use.

PATRON EVALUATION

Representatives of De Handikappades Riksforbund (DHR: The National Organization of the Handicapped) summed up the general opinion of users when they reported "no significant problems with the inclined lift. . . . it is a very positive solution." No critical comments were made about access, motion, or operation of the inclined elevator. Minor concerns that were expressed included fear of the possibility of excessive time to restore malfunctioning elevators, vandalism, and assault (especially in the enclosed elevator). Although criticism was leveled at the inaccessibility of sidewalks, the bus system, and the older T-bana stations, and the difficulty of using the manual swing doors on the older vertical elevators, the newest stations were generally praised as models of accessibility and design.

A Personal Experience

In addition to the Swedish organizations of the handicapped and incidental users who were interviewed to establish users' reactions to the inclined elevator, a special insight was gained by the direct experiences of a member of the study team who is employed by a major U.S. transit system and is a wheelchair user.

His personal statement was that the freedom of movement offered by the accessibility of SL was nothing short of exhilarating. Within the underground system, no accessible routes were appreciably longer than the routes used by the able-bodied traveler and, due largely to the inclined elevator, in most cases there was no deviation at all.

He reported that the elevator and cab controls were within easy reach and offered great simplicity of use. In this regard, the inclined elevator was easier to use than the vertical elevator due to the automatic doors--as opposed to the heavy manual doors on the vertical elevators.

The team member also had an opportunity to observe the SL response to a malfunctioning inclined elevator. While traveling alone, he entered an inclined elevator that stalled a short distance from the starting point. He reported that he was immediately in communication with station control personnel, who dispatched a maintenance team to the site. His apprehension was allayed by the constant visual contact with both station patrons and SL staff, which was possible because of the glass/mesh elevator enclosure.

Although he was initially skeptical of the attainability of the 20-minute average response time which SL management had cited for cases of elevator breakdown, he was pleasantly surprised to find that the response was even faster. The elevator was restarted and the trip was completed within 15 minutes.

Throughout this experience, the ability to maintain constant verbal and visual contact was reassuring and warded off the tendency to panic. He was enthusiastic about the benefits of the open visibility for other potential emergencies, such as incapacitation or distress of an elevator passenger. Observation of such an emergency by the escalator users would bring invaluable assistance and a degree of safety not otherwise obtainable.

His general comments included the opinions that the inclined elevator will accommodate all but the most severely handicapped persons, the cars offer sufficient maneuvering room, the controls are easily operated with only limited dexterity required, the quality of ride was generally excellent with slight bumpiness encountered on only one or two units, and siting of the elevator adjacent to escalators did not create conflict between wheelchair users and ambulatory passenger traffic patterns.

The accessibility of the Stockholm system, and the integration allowed by the inclined elevator, was far superior to that of any transit system in this team member's experience.

INCLINED ELEVATOR COSTS

Cost data for inclined and vertical elevators were obtained from the Swedish elevator manufacturer and confirmed by the SL as applicable in Stockholm for 1977. Costs cited below are for equipment and installation, including supporting mechanical and electrical systems. Costs for excavation, concrete framing, shotcrete support, auxiliary steel framing, and architectural finishes on surrounding areas are not included.

For a vertical rise of 10 meters (33 feet), an inclined elevator costs \$57,000 (\$1700 per foot of rise)--about twice the cost of a traction-type vertical elevator, \$28,000 (\$850 per foot of rise). For a vertical rise of 30 meters (98 feet), the inclined elevator cost is \$75,000 (\$765 per foot of rise), which is 2.3 times the vertical elevator cost of \$32,000 (\$325 per foot of rise). Note that this cost includes equipment and installation of equipment. The cost per foot of travel of the two elevator types is about equal, which underlines the basic similarity of construction.

Within the usual range of elevator application, the SL has found that the ratio of inclined to vertical installed elevator equipment cost follows the relationship:

$$\frac{\text{Inclined}}{\text{Vertical}} = 3.8 - \frac{240}{h + 125} \qquad \text{(h = rise, in meters)}$$

This relationship shows that, in SL's experience, the inclined elevator cost will always be more than two times the cost of a vertical elevator for the same vertical rise. Again, this relationship is based on equipment cost and installation, not including excavation, framing, and architectural finishes.

A typical inclined elevator installation in Stockholm, for which the SL has accumulated cost data for tunneling in sound rock, is illustrated in Figure 2 (p.21). The additional cost of widening a planned 24-meter (80-foot) rise escalator shaft by about 2 meters (6.5 feet) to accommodate an inclined elevator, is approximately \$60,000. The cost of the inclined elevator equipment is approximately \$65,000. The total inclined elevator installation cost, including architectural treatment, is approximately \$130,000 to \$150,000 for this specific situation in Stockholm.

SL calculation of the relationship between volume of excavation for an inclined elevator and for a vertical elevator with a horizontal connecting tunnel is:

$$\frac{\text{Inclined Elevator}}{\text{Vertical Elevator}} = \frac{18h}{13h} = 1.38 \quad (h = \text{rise, in meters})$$

Although the inclined elevator takes the shorter path, the volume excavated is 1.38 times greater because of the large corner-to-corner dimension of the car and the clearance needed for the undercarriage and counterweight (see Figure 4, p. 23).

This relationship may be useful for an approximate cost comparison between the two elevator types, but it is clear that the inclined elevator will be more costly than a vertical elevator in both equipment and excavation costs when it is assumed that the two types of excavation have equal unit costs for excavated material.

SL data on relative maintenance costs indicate that vertical elevators are 10 to 15 percent less costly to maintain than are inclined elevators. Their annual routine maintenance cost for inclined elevators is \$700, plus an average annual repair cost of \$1100.

Although inclined elevators are shown to be a more expensive alternative to vertical elevators, the SL will continue to install them because they "are the best solution" to the problem of transporting handicapped passengers into subway systems in situations where the change of elevation is greater than 12 meters or where direct vertical connection between levels is impossible due to lateral displacement or an obstruction.

The currently standardized "Stockholm Station" design is a single-chamber train room, mined in solid rock, with sprayed concrete lining and a center platform connected by an escalator-elevator way to the mezzanine fare hall near the surface. The SL gave a typical mid 1977 cost figure of 30,000,000 SK (\$6,250,000) for this type of station construction, not including station equipment and architectural finishes. The cost of a single inclined elevator to provide access to the platform from the fare hall is about 2 percent (\$125,000) of the station construction cost.

CONCLUSIONS AND RECOMMENDATIONS

Inclined elevators for the elderly and handicapped in conjunction with escalators for the mainstream of passengers in mass transit systems is a natural partnership of functionally related equipment. The advantages of uniformly directed passenger flow into and out of subway stations through common shaftways equipped with a choice of elevation change modes are readily apparent in Stockholm. The SL will have 41 inclined elevators installed by 1978, but a number of vertical elevators (114) have also been installed or placed on order for locations where they proved to be more applicable.

No iron-clad criteria have been defined by SL designers for determining the type of elevator to be installed at new stations, as each station presents a unique set of problems that must be studied thoroughly to find the best overall solution. However, the SL has developed a typical approach to underground station design and elevator choice.

Station fare halls are usually located at the surface or at a shallow depth of 3 to 4 meters, where they are served from the surface directly by a vertical hydraulic elevator and short-run escalators. Vertical elevators have an advantage over inclined elevators at these locations because lower cost, simpler, more reliable hydraulic elevators can be installed without causing elevator passengers to follow a path differing radically from that of the escalator passengers. Construction at shallow depths is usually in earth excavations, so there is no inherent advantage in combining elevator and escalators in a common shaft, as in rock excavations.

Because the T-bana train rooms are usually enlargements of the running tunnels in sound rock more than 4 meters below the fare hall, the advantage of unifying passenger flow is reinforced by the economy and simplicity of driving common diagonal shafts to contain all escalators and elevators connecting the fare halls with the train rooms. However, in some stations having the fare hall directly above the train room, the SL has elected the cost-saving approach of constructing a vertical elevator shaft from the fare hall to the train room rather than enlarging the inclined escalator shaft sufficiently to contain an inclined elevator.

The evolution of the inclined elevator, experience with its operation, and continuing development of improved station configuration has produced general guidelines for inclined elevator application. As expressed by a member of the SL staff, "inclined elevators are generally favorable for rises of 8 to 12 meters and greater, vertical elevators are generally preferable below 8 to 12 meters of vertical rise."

To further define the limits based on the Stockholm experience the inclined elevator, in conjunction with escalators, is a feasible alternative to the vertical elevator for elevation changes of 12 meters (40 feet) or more and also for elevation changes greater than 8 meters (25 feet) where these are accompanied by such a horizontal displacement that direct vertical connection between fare hall and train room is not possible.

Variations in sites and subway system configurations are likely to cause a different set of guidelines to be applicable. For example, a very deep station, beyond the practical reach of escalators, will be best served by vertical elevators for all passengers. Escalatorways that are exposed to the weather are unsuitable for installation of the inclined elevator as developed in Sweden. A subway station in a narrow right-of-way will not have enough space for an inclined elevator in tandem with the escalator system. Existing subway stations are best retrofitted with vertical elevators because of the simpler excavation required. Aerial mass transit stations generally are low-rise and much more readily served by vertical elevators. Very shallow subway stations may best be served by ramps for all passengers, eliminating escalators and elevators entirely.

For those subway systems in the United States where inclined elevator feasibility is indicated by the general guidelines, other concerns must be addressed before a successful installation can be completed. Among these concerns is the need to construct and test an imported elevator (since no U.S. manufacturer is available) that conforms to U.S. standards. The first installation will be a proving ground for mechanics, inspectors, code writers, and insurance underwriters. We conclude that the inclined elevator, as developed in Stockholm, can be readily modified in design, materials, and testing procedure, to be acceptable under existing and developing U.S. standards. The development cost associated with modifications to the existing Swedish design is difficult to predict, but may be substantial if the effort is extended over a long time. The alternative to importation of the inclined elevator--development by a U.S. elevator manufacturer--may result in development costs that exceed those for modification of an existing, operationally tested design. A well-known elevator manufacturer, when questioned as to his ability to develop and supply inclined elevators locally, responded that a firm order of 30 units would be necessary in order to make a development program feasible.

An alternative to this approach would be direct funding by UMTA of the development of a prototype inclined elevator and delivery of a small number (e.g., two) for installation at a selected subway station that can be designed to take full advantage of the inclined elevator attributes.

Because of the positive experience of the SL with the inclined elevator and its special applicability in certain station configurations, we recommend that the mass transit systems now being designed in the United States be surveyed to determine a favorable location for installation of an inclined elevator. Conceptual specifications and drawings for such a selected installation should then be developed. With the functional requirements established, elevator manufacturers, including U.S. firms and the foreign manufacturers currently producing inclined elevators, should be invited to submit proposals for development and fabrication of the prototype. We also recommend that a transit agency with an interest in equipping a favorable location with an inclined elevator submit a grant application for Federal assistance in funding the development and installation.

APPENDIX A: INDIVIDUALS INTERVIEWED

Listed below are the organizations interviewed or contacted by the study team. Representatives of these organizations contributed information or assisted with data collection and verification.

(1) AB Storstockholms Lokaltrafik (SL)
Tegnergatan 2 A
Box 6301
S - 113 81 Stockholm, Sweden
Ingemar Backstrom - General Manager
Archibald Rosenwald - Marketing Officer
Bertil Linner - Deputy Technical Director
Per H. Reimers - Chief Architect
Kjell Werner - Architect
Ingemar Berg - Director, Fardtjanst (Special Service for the Handicapped)
Mr. Christiansson - Deputy Director, Fardtjanst
Leif Almquist - Head of Electrical Section

Roland Pettersson - Mechanical Engineer
Lars Almer - Counsel
Leif Karlstrand - Vegete, Insurance Consultant to SL
Tage H. Lund - Commuter Rail Operations
Aake Renstrom - District Manager, Metro Operations
Allan Thulin - Head of Safety Section
Mr. Bergstrom - Fire Brigade

(2) The Swedish Plants Inspectorate (SA)
Ministry of Industry
Rolf Sanderborg - Administrator for Inspections
Lars Nordquist - Lift Inspector

(3) National Board of Occupational Safety and Health
Stockholm, Sweden
Bertil Ulfward - Chief Engineer
Carl-Otto Falk - Chief Fire Protection Officer

(4) Handikappforeningarnas Centralkommittee
Stockholm, Sweden
Tore Linderoth - Ombudsman

(5) De Handikappades Riksforbund (DHR)
(National Association of the Handicapped)
Stockholm, Sweden
Gunnar Johansson - Director

(6) Handikappinstitutet
Bromma, Sweden
Suzan Forsberg - Executive Staff
Leif Helenius - Executive Staff

(7) The Swedish Institute
Stockholm, Sweden
Peter Bjorlin - Study Visits Section

(8) American Embassy
Stockholm, Sweden
Ernest R. Sohns - Scientific Attache

(9) Goteborgs Spaarvagar
Goteborg, Sweden
Aake Hellman - Director of Operations

(10) Goteborgs Universitet, and Fokus Society Research Group
Avdelningen for Handikappforskningen (Department of Handicapped Research)
Goteborg, Sweden
Sven-Olaf Brattgaard - Director

(11) Volvo, Inc.
Goteborg, Sweden
Thore Brynielsson - Manager, Bus Division Development

(12) Kone Hissar AB
Sundbyberg, Sweden
Kurt Hedstrom - Managing Director
Alf Ekdahl - Sales Manager
Gunnar Fredriksson - Design Engineer
Karl-Axel Bolling - Civil Engineer
Denits Sjorstrand - Engineer
Ruben Karnfalt - Product Planning
Carl-Goran Karlsson - Plant Supervisor

(13) Kone Oy
Helsinki and Hyvinkaa, Finland
Pertti Makela - Director of Marketing
Matti Erkkila - Area Export Manager
Hyvinkaa, Finland
Erik Relander - Manager of Design and Production Planning
Feysal Samarhan - Section Manager, Fabrication Plant

(14) Kone Heiser
Oslo, Norway
Christian Viig - Director

(15) Schindler Auzuge Fabrik
Berlin, West Germany
Hans Arens - Technical Representative

(16) Orenstein and Koppel
Dortmund, West Germany
Fritz Querfurt - Technical Representative

(17) Flohr-Otis GmbH
Berlin, West Germany
G. A. Podszun - Marketing Services

(18) American National Standards Institute
A.17 Inclined Elevators Subcommittee
William J. Wheeler - Chairman
Long Island City, New York
Ray M. Whitly - Committee Member
Washington, D. C.

(19) Otis Elevator
Washington, D. C.
D. E. James - District Manager

(20) Noakes Associates Architects
Chevy Chase, Maryland
Edward H. Noakes - Principal
Kevin Rohrbach - Design
Brenda Sanchez - Planning

(21) Skidmore, Owings & Merrill
Boston, Massachusetts
Robert H. Henderson - Architect

(22) President's Committee on Employment of the Handicapped
Washington, D. C.
Edmond J. Leonard - Director of Information

(23) Architectural and Transportation Barriers Compliance Board
Department of Health, Education and Welfare
Peter Lassen - Director of Compliance Division

(24) Urban Mass Transportation Administration
U.S. Department of Transportation
Washington, D. C.
Ramon A. Lopez - Engineering Field Offices
Arlan D. Eadie - Third Party Procurements
W. H. Lytle - Third Party Procurements
Gilbert L. Butler - Rail Technology

Lawrence L. Schulman - Policy and Program Development
Michael S. Bates - Counsel, Elderly & Handicapped
Kathleen M. Koss - Planning, Elderly & Handicapped
Patricia Cass - Planning, Grants
Santo J. Gozzo - Support Technology (Boston, Massachusetts)

(25) Office of the Secretary, U.S. Department of Transportation
Washington, D. C.
Mildred Allen - International Cooperative Programs Division

(26) Washington Metropolitan Area Transit Authority (WMATA)
Washington, D. C.
Robert A. Pickett - Planning
Mark M. Akins - Planning
Melvin Siegel - Architecture
Herbert H. Saxe - Engineering
Marshall E. Greenspon - Engineering
Robert T. Keahon - Security
Peter J. Ciano - Counsel

(27) Metropolitan Atlanta Rapid Transit Authority
Atlanta, Georgia
William D. McEwen - Staff Consultant to General Manager

(28) Trade Commissioner for Sweden
Chicago, Illinois
Bjorn Bieneck - Project Manager

(29) The World Bank
Washington, D. C.
Roger Masthagen - Former Official, Storstockholms Lokaltrafik

(30) German American Chamber of Commerce
New York, New York

(31) Swedish Embassy
Washington, D. C.
Ulla-Britta Johansson - Press Assistant

(32) "Mass Transit"
Washington, D. C.
C. Carroll Carter - Publisher and Editor

APPENDIX B: REFERENCES

Foreign

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Suggested contact for data exchange:

The Swedish Institute
Hamngaten 27
P. O. Box 7027
S-103 82
Stockholm 7, Sweden

United States

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