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Measuring Attitudes of Ridership Regarding the Design of LRT Stations Using CAD and VR as an Assessment Tool

By

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Abstract

This Master's Degree Project presents the results of a stated preference survey that measures a sample population's preference regarding a number of design features in Light Rail Transit stations.

The specified design features that were tested in this study were escalators, ramps, enclosed waiting areas, signage, and platform types. In order to conduct the survey in a realistic contextual environment, virtual reality technology was applied to create interactive and real-time simulations of different LRT stations. The discrete choice method was used to evaluate the importance of each tested feature in influencing a rider's preference. The survey results were analyzed using a logit model and the utility function was used to explain the results.

This study found out that signage had significant positive influences on a rider's attitudes toward a LRT station, escalators had marginal positive effects, and ramps had marginal negative effects.

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Table of Contents

List of Tables

List of Figures

1 INTRODUCTION

Background

Light Rail Transit Rider's Preference and Station Design

In recent years, there has been a growing interest by cities in using Light Rail Transit (LRT, see page 6) as a means of providing public transportation (Schumann and Tidrick, 1995). As part of the planning process, cities need to obtain public acceptance of LRT as an acceptable form of mass transit. One of the major factors in developing favorable attitudes towards the use of LRT is the design of transit stations, which are the system's gates to its riders. Safety, clarity, accessibility, and convenience are among considerations to build a rider's preference for LRT.

Computer-Aided Design and Visualization in Contemporary Design

CAD and visualization technology have been employed in design and planning for decades. Not only do they reduce designers' workloads, they also provide a window for viewing the visual impact. A major strength of CAD and visualization technology in design is as a means of presenting design concept to the public who normally would be confused by technical drawings. Research projects have been done on the effectiveness and accuracy of CAD models reflecting reality with a conclusion of a high level of correspondence.

Definition of the Research

The Necessity for the Research

For governments and planners who are working on an LRT system, it is important to know which factors of station design influence people's preference. Planners can obtain this information by surveying riders using existing LRT systems. However, if a city does not have an existing LRT, or if new features are to be put into an LRT station design, it becomes difficult to gather those reactions. Also, results from survey based on existing LRT stations may be less credible, because it is difficult to find out which design features contribute to a person's general attitude to a station. Finally, the survey may be expensive in time and money because the researchers may have to interview people on a site.

For these reasons, the CAD and computer simulation technology may have advantages in testing preference to LRT station design. First, a survey can be conducted before real construction begins, and the study conclusion can be applied to that project. Second, such a survey can test riders' attitudes to new features that have not been built. Third, researchers can limit people's reaction to the factors that are of interest. However, although it is common for designers to employ CAD technologies to improve their designs, a literature review shows that they have not been commonly applied to gather users' reactions to designs. This study will consider an experimental stated preference study, using CAD and computer simulation technology as the medium, to measure riders' attitudes to a number of factors that might affect the LRT station design's popularity.

Assumption, Hypothesis and Research Objectives

The hypothesis is that virtual reality technology (see page 27) can be used to accurately simulate major design features in LRT stations and that stated preference studies (see page 18) can be used to determine the attitudes and sensitivities of various groups regarding LRT stations.

The objectives of this research are to:

- identify unique design features and lessons learned in CAD and virtual reality technology in assessing transportation station design,
- identify specific design features that affect rider's preferences with respect to LRT station features, and their relative importance, and
- present findings on the limitations of using CAD models in a VR environment as an assessment tool.

Research Methodologies

Literature Review

A review of literature on LRT systems, CAD and visualization, and public preference measurement was conducted, including books, professional journals, and unpublished research reports and theses. The literature review shows that in North America, LRT systems are playing more and more important roles in defining and transferring urban land use patterns (Bertini et al, 1995; Claflin, 1995; Cervero, 1985; Arrington, 1995). It also recognizes the effect of station design in the LRT's success. The literature review identifies available visualization tools in architecture and planning, the pros and cons for each, and the research conducted in this area. Finally, available public preference measurement techniques are identified in the literature review.

Virtual Reality Simulation of LRT Stations

This research is to conduct a public preference study using CAD and computer simulation as the medium. Recent studies suggest that appropriate visual cues are needed in order to let an audience perceive spatial relationships accurately in a computer-generated simulation (Wanger et al, 1992; Park, 1995). In order to achieve real-time and interactivity, this research uses virtual reality simulations constructed on top of the computer 3-D models. This research assumes that the virtual reality simulation can reflect the reality accurately.

Stated Preference Survey

From various techniques that can test public preference, a category named "stated preference" survey was selected to conduct the study. The stated preference is believed by transportation planners to be the most advanced structured survey method to measure public attitudes, and it is the most widely used technique in today's traffic studies. The method is also very suitable for testing public attitudes toward proposed polices and projects — in this case, the LRT station design (Pearmain et al, 1991).

Organization of the Thesis

Chapter One is the introduction. It includes background, research objectives and hypothesis, brief introductions of research methodology, and thesis organization.

Chapter Two is the literature review. It discusses the recent roles of Light Rail Transit systems in North America cities, and the importance of the station design, and then reviews the public preference studies. The last part of this chapter is a study of visualization and simulation tools in architecture design and planning.

Chapter Three details the research methodologies. It addresses how the CAD models of two basic LRT station types are built, and how they are translated to virtual reality simulations. The second part discusses in depth the design of stated preference survey: how the options are designed, how the survey is presented, the sampling theory, how each survey session is processed, and why the logistic model is chosen to be the analysis method. The last part is about the hardware and software used in simulation construction, survey presentation, and statistical analysis.

Chapter Four is the survey result analysis. It presents the survey data first, followed by the data analysis. It discusses what the survey found and not found, and the reasons for such results. This chapter finally discusses the limitation of the research and the validation issues.

Chapter Five is the conclusion of this research, with recommendations of further research areas and directions.

2 LITERATURE REVIEW

Light Rail Transit and its Station Design

Re-recognition of Light Rail Transit

There are various definitions of LRT; this research uses the definition from Transportation Research Board's definition:

> A metropolitan electric railway system characterized by its ability to operate single cars or short trains along exclusive rights of way at ground level or aerial structures, in subways or occasionally in streets, and to board and discharge passengers at track or car-floor level.

The origin of LRT can be traced back to subways and metros widely used in Western European cities since the nineteenth century. However, neither the subway nor the metro has ever played as important a role in American's mass transit as their European counterparts, although they were popular in America between 1890 and 1930. After World War II, there was a trend in North American cities to eliminate their electric rail vehicles — an example is Denver, Colorado (Claflin, 1995).

That trend has been reversed during last two decades. Increasingly, city governments believe that the private automobile is one of the major reasons for traffic and environmental problems, and they are looking for solutions in of public transit, particularly the proven safe, efficient and electric-driven LRT systems. At the same time, LRT development is also seen as an opportunity to optimize urban land use and re-develop of the decaying downtown areas (Cervero, 1985). Two cities well known for such successes are Toronto, Ontario and Portland, Oregon (Cervero, 1985) (Arrington, 1995).

Recent LRT's Development in North America

Before 1975, there were only ten North American cities that had LRT running, including eight U.S. cities, Toronto, and Mexico City.[1] However, by 1995, the number rocketed to twenty-three: the new LRT-running cities include nine in the United States, two in Canada (Edmonton and Calgary) and two in Mexico.

Although Canada has fewer LRT systems, in mileage, than the United Stated, Canadians rely more upon them. Table 2–1 summarizes the major LRT systems running in Canada and the U.S. for 1994.[2] Among those cities, Toronto had the largest car fleet, rides/weekday, and rides/km. Calgary had the second-largest rides/km and the third largest rides/weekday, which is close to San Francisco's. Edmonton LRT's ridership was also significant, considering that its line was among the shortest and car fleet the smallest. Its rides/km held fourth place.

Most employment in a typical Canadian city happens in its downtown core and is considered to be one of the major reasons for public interest in LRT systems. In the areas around the downtown core, there are normally medium to high rise apartments; an LRT system provides a more convenient and cost-efficient means than private cars for those apartment residents to get to downtown jobs. Also, unlike American cities, Canadian cities are less likely to get as much federal money for their urban highway expansion; LRT development is quicker, less expensive, and less troublesome. Another reason is public support: European and Asian immigrants have been accustomed to similar rail transit systems in their mother counties (Cervero, 1985).

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1. There have been debates about what rail system should be counted as LRT. Some articles also include Montreal's subway and Vancouver's streetcar as LRT.
2. Data Source: Schumann, J.W. and Tidrick, S.R., *Status of North American Light Rail Transit System: 1995 Update*, in Seventh National Conference on Light Rail Transit v.1, National Academic Press, Washington, D.C., 1995

City	One-Way Line km	No. of Cars	Rides/Weekday	Rides/km	Rides/Car
Baltimore	35.4	35	20000	565	571
Buffalo	10.3	27	28000	2718	1037
Calgary	29.3	85	114500	3908	1347
Cleveland	21.1	48	9900	469	206
Denver	8.5	11	15000	1765	1364
Edmonton	12.3	37	36000	2927	973
Los Angeles	35.4	54	42000	1186	778
New Orleans	14.0	41	26000	1875	634
Newark	6.9	24	16800	2435	700
Philadelphia	35.9	112	77500	2159	692
Pittsburgh	31.2	71	29000	929	408
Portland	24.3	26	24500	1008	942
Sacramento	29.5	36	24300	824	675
San Diego	55.4	71	45000	812	634
San Francisco	39.1	128	134300	3435	1049
San Jose	32.2	50	20000	621	400
St. Louis	29.0	31	40000	1379	1290
Toronto	75.5	267	307100	4068	1150

Table 2-1: Status of North American LRT Systems

LRT Stations

A literature review shows that ever since the LRT's value has been rediscovered, studies have been focused on a limited number of issues, including re-introduction of rail electrical transit systems, definition of LRT definition systems, planning and construction, system and vehicle design, LRT operation policies, system operation and management, and urban land use.

Discussions relating to stations are found in system planning, maintenance, and security literatures. However, the lack of designated articles for station design on LRT forums does not reflect the complexity of the issue. Recently, since the enthusiastic LRT development and expansion during the 1980s in medium and large cities, LRT operators and designers are realizing the important role played by stations in an LRT's success.

There are various reasons for LRT becoming popular again in North America. One is that LRT is a good alternative to other urban transportation – it has proved to be efficient and flexible in providing high-quality services at affordable prices (Schumann 1992). Another is that it has been regarded as a vehicle that has the potential power to move people, shape the region, defer highway investment, clean the air, and enhance quality of life (Arrington 1995). In fact, installing or upgrading an LRT system is a strategy employed by many cities to reshape their land use policies and revive decaying urban centers.

Many municipal governments plan to take advantage of LRT development, however LRT alone does not bring about a livable downtown. As planners of Portland's LRT observed, a LRT system was an effective engine to carry out land use reshaping by establishing a partnership between the city's LRT system and community buildings: one of the key actions to achieve that was called Transit Station Area Planning. It included determining market potentials, rezoning station areas, and performing station-related development. Another action carried out by the Portland LRT planning authority made even more direct use of LRT stations to create a positive relationship between transit and the city. That was to connect or integrate stations with access to malls and urban facilities, such as the Portland Transit Mall, Rose Garden Arena, Pioneer Place, and the proposed Winmar/Tri-Met Regional Mall (Arrington, 1995).

In St. Louis, the bi-state LRT construction authority expected to make its Metrolink Light Rail system more than just another form of public transportation, and with an approach very different from Portland's. St. Louis' plan was to create a series of museums within each LRT station along the lines: the Art In Transit (AIT) program. Guidelines for station design required that underground tunnel stations maintain the character of the historic space in a contemporary setting, and that the preservation of architectural remnants at some stations be undertaken.

It also formed design teams to direct station design, with each team including two architects and two visual artists working closely together (Amundsen 1995).

LRT Station Design Issues

After reviewing the literature, a number of LRT design issues were identified as of particular interests to LRT authorities, station designers, and researchers.

1. Loading System and Accessibility

There are basically two types of loading systems: center-load and side-load (Figure 2–1). In a center-load station, passengers normally access the platform through a footbridge, so they do not need to cross rail tracks or streets. In a side-load station, passengers approach a platform directly from street. If they want to get to the platform on the other side, they have to cross the track. In both cases, accessibility is a big issue (accessibility reflects how easily and how quickly a volume of passengers can get on the vehicles in an evenly distributed manner).

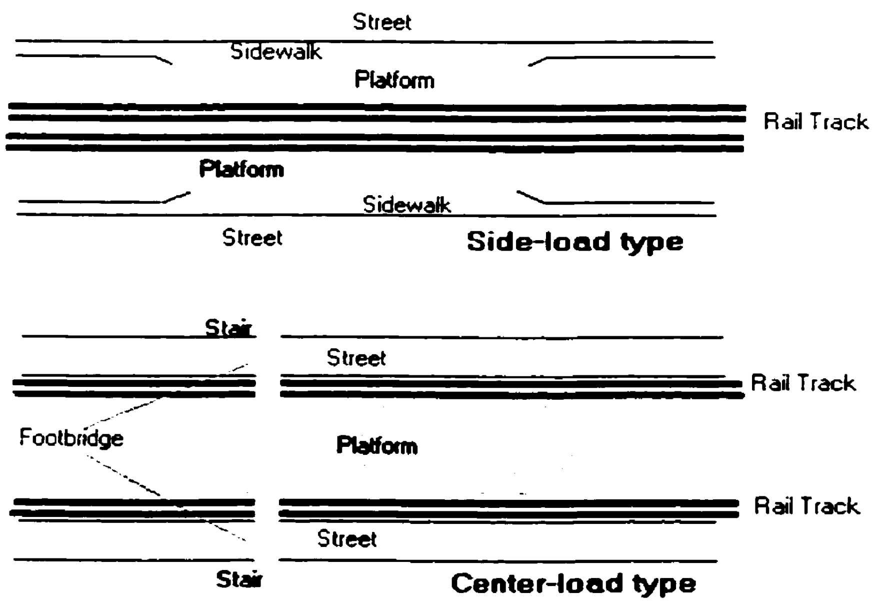


Figure 2–1: Basic LRT Station Loading Systems

Which loading system to use is determined by station site conditions, connections to existing transit facilities, cost, and type of vehicles. A center-load station needs a larger site, a more complicated building, and is more expensive.

2. Access Design for Disabled People

Many disabled and mobility-impaired people rely on public transit. The necessity of designing features to facilitate their access to LRT system is widely recognized by researchers in the U.S. and Canada, and is attracting attention.

3. Signage

Signage tells passengers where to go, and reflects how easily the facilities can be used. For people who do not use these facilities frequently, and for newcomers, signage is very important. Unfortunately, the literature review shows that there are not many studies on LRT signage. Calgary's LRT authority — Calgary Transit — realized the importance of this issue after years of operation. In 1996, they asked a graphic company to carry out a redesign of the city's LRT signage. Some of the stations (e.g. Chinook Station) have implemented the new signage system.

4. Safety issues

Passenger safety and security issues relate to the emergency exits, emergency communication, and lighting system.

5. Aesthetics issues

Many municipalities consider LRT station a gateway to show their cultural and historical characters. Each surrounding neighborhood would also like to see a station reflect its features.

6. Maintenance

Maintenance is a big issue for stations in extreme weather. It is costly and affects the system safety. Poorly designed stations often produce high maintenance costs. The most common high-cost maintenance items are escalators and tunnels.

7. Commercial development opportunities nearby

As a vehicle to reshape the urban land-use and carry on the downtown renaissance, an LRT system and its stations are highly connected with the surrounding commercial opportunities. Stations are often found connected to the entrance of a mall, commercial complex buildings, or a department store.

Research on Station Design

In the review of the Calgary LRT, Hubbell et al (1995) studied the lessons learned through the development of the city's three LRT lines. They compared different access and loading systems on the lines, and concluded that the station design should be simple to minimize the access time, and recommending grade-level access to platforms wherever possible. In center-load stations, two-end loading is preferred to one-end loading (Figure 2–2). With respect to successive one-end loading stations, alternate loading ends should be employed to balance the load between cars in a train. Station design that incorporates the local community's characteristics was encouraged, and integration of LRT stations with the community pedestrian-bicycle system was recommended.

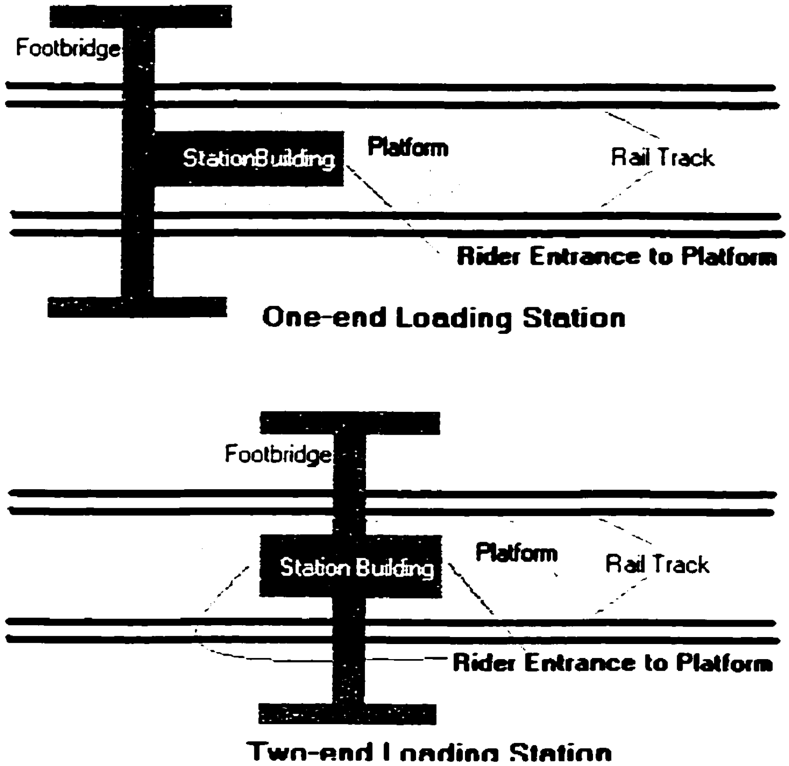
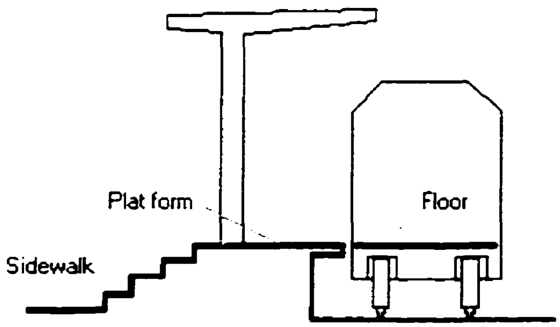


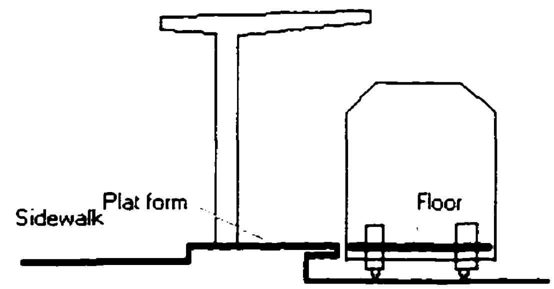
Figure 2–2: One-end and Two-end Loading Stations

Barnes et al (1995) studied how art could be integrated in the Santa Clara County LRT station designs. This project benefits from the Downtown Seattle Transit Project's experience in integrating art and local features in station designs. They detailed the process of defining the Integrated Art Program, the public support for this project, the founding of an Art and Aesthetics Committee, and the development of an Element Plan. They also addressed how the local segments and features were identified, and how the artists were brought in to integrate art in the station's design. This study reached the conclusion that involving artists early in the station design not only can improve the stations' aesthetics quality, but also could maximize the available budget and minimize the maintenance problems and costs.

Aurelius (1995) examined the issue of access for disabled person in his study. For high-floor vehicles, which are widely used in North America, the solution was a high-level platform. It provided level entry to the cars and could have ramps integrated with city side-walk systems, like those in Calgary, Edmonton, Long Beach, and St. Louis. If the transit line was largely inside a city core area, low-floor vehicles were recommended. Those vehicles were easier to find in European cities. The low-floor vehicles needed low platforms, which could be easily integrated with the street system, and provided easier access for disabled people. Figure 2–3 illustrates different vehicle types and platforms.



High Floor Vehicle and High Level Platform



Low Floor Vehicle and Low Level Platform

Figure 2–3: Vehicle Types and Platforms

McLachlan (1995) addressed the station maintenance issue in a study of Edmonton LRT, which had six underground and four surface stations. The average maintenance costs for underground station was $300,000 (CND) annually. He found that the major problems were with the escalators, as a result of poor station design that used regular escalators for the heavy-duty traffic that occurred in public transit use. Underground stations were also affected by water leakage, which caused structural damage. Seepage and freezing temperatures in winter impaired the operation safety and resulted in discomfort for customers.

Public Preference Studies

Methods Available for Evaluating Public Attitude

In designing LRT projects, it is important to measure the public attitude of potential riders and to gauge public reaction. When options exist, there is also a need to assess the public preference with respect to specific solutions: such attitudes are crucial to a project's acceptance and utilization. Although there are a number of methods to identify factors affecting the public preference and measure the factors' comparative importance, it is not always straightforward to select one. Each method has its advantages and weaknesses, and would be more suitable in particular cases than others. Five general methodological approaches identified by Hunt et al (1995) are:

- public meetings
- revealed preference
- psychometric analysis
- direct questioning or contingent valuation, and
- stated preference.

Table 2–2 lists the pros and cons of major aspects of each method (Hunt et al, 1995a):

	Public Meetings	Revealed Preference	Direct Question	Psychometric Scoring	Stated Preference
Able to minimize selection bias	--	++	++	++	++
Able to control data structure	--	--	++	++	++
Able to avoid manipulation by respondents	--	++	--	--	+
Able to quantify results	--	++	+	-	++
Able to consider non numeric attributes	++	--	-	++	+
Respondents able to perform familiar tasks	+	++	--	-	++
Ease of understanding of results by laymen	+	-	-	+	-
Ease of understanding of process by laymen	++	--	+	+	-
Acceptance/ Precedence / Tradition	++	-	--	+	-
Causal / Behavioral link	-	--	++	++	++
Based on actual behavior	--	++	--	--	--
Able to illicit behavior in context	--	++	-	--	+
Able to anticipate public acceptance of plan	-	++	++	++	++
Profile / Public relations	++	-	+	+	+
Able to allow free-form responses	++	--	--	-	--
Able to minimize cost to prepare / execute	--	--	++	++	+
Able to minimize actual time to prepare / execute	--	--	++	++	++
Able to simplify role of interview / respondent	-	++	+	+	-

Key: ++, very good; +, good; -, poor; --; very poor

Table 2-2: Public Preference Evaluation Methods (Hunt et al, 1995)

Public meeting

A public meeting can give members of a community an opportunity to present their opinions about a public project. It is often an open discussion, where the citizens are informed about the issues and have a chance to have their concerns heard. Although easy for the public to access, these public meetings can hardly achieve significant results. The opinions presented in a public meeting cannot represent all the community population. Quite often, only individuals or groups who are sufficiently motivated would participate. An experienced participant can easily dominate the meeting, leaving other individuals unheard. Thus, the conclusions in the meeting tend to be biased. Also, the comments are often difficult to quantify. The value of public meetings is that they can generate a list of concerns that will be used as a clue for further studies in a more objective and controllable manner (Yukubousky, 1973).

Revealed Preference

Revealed preference allows the researcher to observe people's actual group behavior and deduce attitudes: it is widely used to study the behaviors and attitudes with respect to elements of travel (Altman et al 1981). While its advantage is the observation of real behaviors, it encounters difficulties in allocating root causes of real behaviors because of possible correlation among possible causes (Kroes and Sheldon, 1988; Bates, 1988). Using this method requires measuring the physical factors and relevant psychological factors, and developing statistical models between them. This results in extensive and costly data collection job (Kroes and Sheldon, 1988; Pearmain et al, 1991). As it is based on real-world observation, it cannot be used to study potential public reactions to situations that do not exist (Pearmain et al, 1991).

Psychometric Analysis

A survey utilizing this method often asks respondents to evaluate the importance (by ranking or rating) of a list of elements, each of which is considered separately (Decision Data, 1993). Then, a psychological measurement model is developed to evaluate people's preferences. Its strong points include the ease of understanding the entire situation, ease of execution, and ease of data collection. Unlike public meetings or revealed preference, it is structured and controlled. Its major shortcoming is that respondents consider each variable in isolation rather than in a context. This leads to the fact that the variables are judged to be more important than they really are (Patterson, 1997).

Direct Questioning and Contingent Valuation

Surveyors who carry out this method ask respondents to indicate explicitly how much they would be willing to pay for a particular item (Boyle and Bishop, 1988), and is likely to be used by economists (Adamowics et al, 1994). Its major drawback is validity: a subject may indicate a high willingness to pay when he is not really going to pay. Also, it normally can only deal with one or two issues within a given context, and cannot achieve multiple trade-offs (Patterson, 1997).

Stated Preference

By definition, stated preference refers to a number of different approaches, all of which use people's statements on how they would respond to different situations (Pearmain, et al. 1991).

The most widely used stated preference techniques are those known as "conjoint analysis". A series of situations are constructed, and people are asked how they would respond to those situations if they faced them in reality. These techniques have been developed from market research (Green and Srinivason, 1978) and are now widely used in transportation related studies.

Selection of Stated Preference in This Research

Advantages and Disadvantages of Stated Preference

The advantages of using stated preference in public preference studies are:

1. A stated preference survey is less costly.

Because the stated preference interviewer asks each respondent to react to a number of situations, multiple observations are generated from every interview. This means that sufficient statistical data can be collected from a smaller sample population than an ordinary survey or interview.

2. Stated preference offers a realistic scenario to make users' choices more likely to be the same as what they would do in real life.

The purpose of doing an interview or survey is to find out what a sample population thinks about a situation. In an ordinary survey, this task is done by asking structured questions or through open responses on a specific issue. However, people's reactions to an abstract situation may be different from their real behaviors. The context created in a stated preference is to provide respondents with a situation much more similar to the reality so their responses would more likely to be realistic.

3. Stated preference make it easier to quantify and equalize responses from different individuals.

In order to compare different evaluated features, an ordinary survey is likely to use a quantified system to measure the preference. An example is to use a 0 to 10 scale, with 10 the most preferred and 0 the least. However, each individual has a different scale in evaluating preference, that is, one person might only give his best preference an 8, while the other gives it a 10. Since the stated preference techniques present a respondent with options that are combinations of different features, it lets him evaluate one feature against others. Because each respondent makes evaluations based on comparing options and state their preference in choosing options, instead of making individual scores on isolated features, the evaluating result is comparable between different subjects.

4. The ease in isolating factors.

The designer of a stated preference survey has precise control of the options he offers to respondents, so he can isolate factors and efficiently identify those that affect the design's preference.

5. Enable the researchers to test only the factors of interest.

Because of the reasons stated above, a designer can isolate those factors that are of interest.

However, it also has drawbacks. The major one is that although given a realistic context, the respondents' preferences are still likely to be different from their behaviors in the real-world. This potential problem suggests the importance of presenting the testing environment as realistically as possible. Another shortcoming of stated preference is that it is not easy to understand and needs a lot of effort in the designing of the survey.

Based on the nature of this research and the available resources, stated preference was selected for conducting the public preference survey regarding LRT station design. The reasons were:

1. The researcher is interested in only a limited number of factors in LRT station design. Stated preference survey can isolate the factors that the research is interested in from other features.

2. The researcher is interested in the comparative importance among the chosen design factors. Stated preference survey evaluates factors against each other.

3. The researcher is interested in how riders would react if a design factor is changed. Stated preference is a technique that provides alternative options and lets respondents react to the imaginary context.

To address the major drawback of the selected survey technique, a realistic context must be provided. A number of fully rendered interactive virtual reality simulations were developed to achieve such a context. From this perspective, virtual reality is an ideal tool to conduct a stated preference survey and an ideal tool in pre-construction evaluation.

Use of Computer-Aidded Design and Virtual Reality as a Tool in Testing Design Solutions

Visualization Tools to Test Architecture and Urban Design Solutions

Architects and planners have traditionally used technical drawings in plan, elevation, and section to communicate with other professionals. It is accurate and efficient so long as all the people speak the same professional language. However, when it comes making the designs understood by laymen, those tools become inadequate; people without special training cannot easily build a three-dimensional (3D) image from the information they receive in two-dimensional (2D) drawings. Unfortunately, to communicate with people who do not have professional training is an inevitable and a crucial part of an architect's or a planner's responsibilities. Those individuals can be the clients, the investors, and or end-users. If the design is for a public project, it can include all of the citizens of a community, as a successful design solution must meet a wide range of needs. An efficient method is needed to enable designers to assist with non-professionals to visualize designs.

Traditional Rendering

Traditional renderings refer to drawings in charcoal, pencil, pen, ink, or paint. This method implies that the drafter has to define the viewpoint position and light source position in the beginning, and involves a technique of generating perspectives based on the dimensions provided on plans, elevations, and sections. It also demands a method of calculating the shades and shadows from the light source. This method normally results in a beautiful hand drawn image, reflecting the drafter's skill and artistic preferences (Park, 1996). Before computer graphics became widely used, such rendering had been the most popular visualization tool for architects and planners. Its advantages include the fact that it often leads to artistic productions, and it has developed over many centuries. The primary disadvantage comes from the fact that it requires high-level skills and experience, and much time to generate a single rendered picture. Secondly, the drafter has to create many sketches before he can find an ideal viewpoint. Finally, the images are single images: if the project requires views from various positions, many images have to be drawn, and it is extremely time-consuming to generate animation by traditional rendering. An example is shown in Figure 2–4.

Figure 2–4: Traditional Architecture Rendering (Wang, 1995)

Physical Model

An option is to build a physical model. People have built architectural and urban models from all kinds of materials, including wood, paper, and plastic. Once a model is built, it can be viewed from any viewpoint, and it can be lit from any direction. Using a medical optical probe, people can "walk into" the model and take eye-level view photos of a design (Appleyard and Craik, 1979). However, to build a model is time-consuming, and a scaled-down model normally lacks fine details. Figure 2–5 is an example of a physical model.

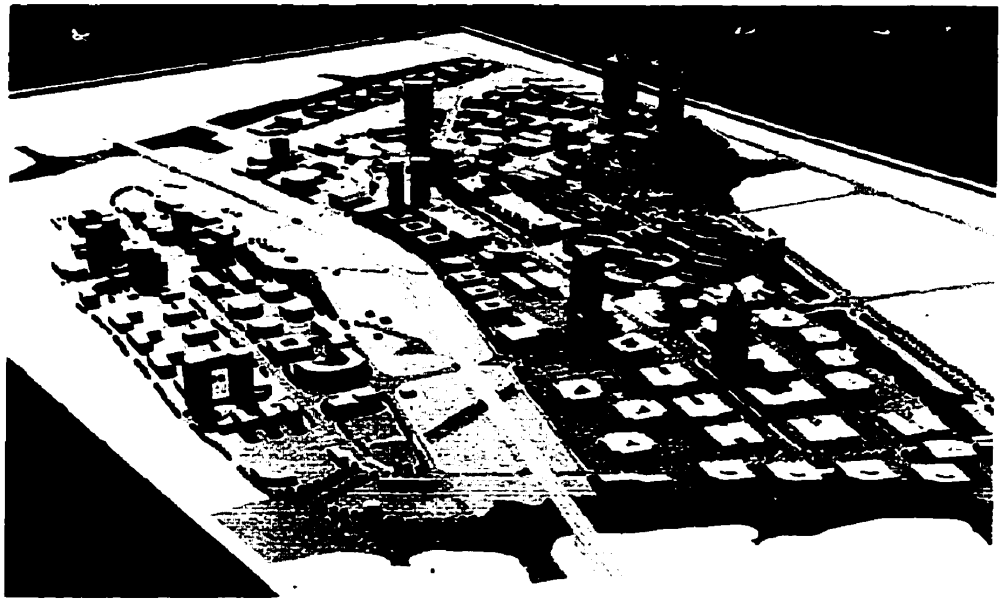


Figure 2–5: Physical Urban Design Model (Wang, 1996)

Computer-Aided Design and Computer 3D Models

Computer-aided design has been used for more than two decades. While the earlier packages lacked capable spatial modeling functions, it was possible to draw 3D "wire-frame" models in a CAD package, providing a solid object representation by "hiding" invisible lines or even "shading" the surfaces. Computer processor speed at that time greatly limited CAD's 3D functions' usefulness and practicality (Rahmat, 1996). For that reason, and for a long time, architecture and planning professionals only regarded CAD as a 2D drafting package (Novitski, 1998). In the past, architects used it as a replacement for traditional pen and board, but CAD is not as good as pen and board because of a lack of flexibility and abstraction (Novitski, 1998).

Recently, advances in computer hardware and software have brought much more powerful CAD packages to the market. Processing time has been substantially reduced, 3D modeling functions have been significantly improved, and the user interface has become much easier to use. It is now possible to make photo-quality images and animations affordable even on a desktop computer. After years of hesitation and resistance, architects and planners have begun to embrace CAD (Mahoney, 1997).

Using CAD in design involves several steps. First, a 3D model must be designed on the computer. Then, the model is brought into a rendering program such as 3DS MAX, where each object of the model is assigned a material. When necessary, and in order to achieve high levels of realism, images are applied to the object surface in predefined mathematical ways called mapping. Finally, light sources and viewpoints (cameras) are defined, and images are generated. An example is displayed in Figure 2–6. If desired, designers can also define a path along which the viewpoint (camera) travels. This enables the program to generate a set of successive images that will form the animation.

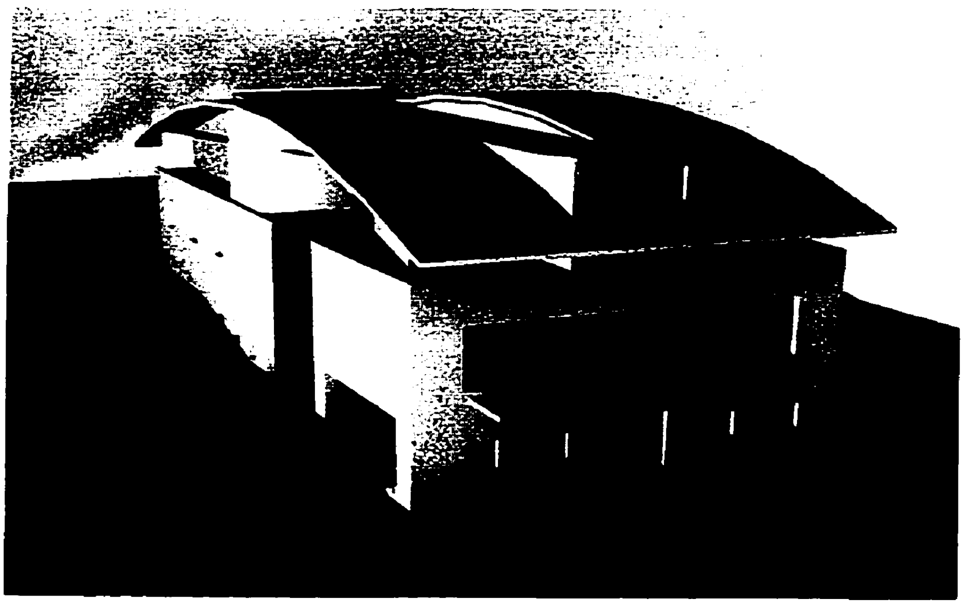


Figure 2–6: Computer-Generated 3D Image (Wang, 1998)

Features

Several features underline the popularity of computer 3D modeling these days.

1. Flexibility

From a 3D computer model, it is possible to generate images from a variety of viewpoints. The designer can adjust the model, seeing the effects of applying different colors and materials. In order to see the result of a revised design, the designer only needs to change the model on where the design changes, instead of creating a new drawing from scratch.

2. Realism and Accuracy

With the hardware and software widely available, there are few difficulties in generating realistic photo-quality images from 3D models, including textures and colors. Computers can calculate the exact shades, shadow, reflection, and opaqueness/transparency, based on the light source and material information provided by the designer. It is not only possible to apply images on model surfaces and give senses of material textures, but also to produce a sense of atmosphere, such as fog. More advanced programs with appropriate databases can let the designer define the time of day and day of the year, creating a "real" sun in the model. All these contribute to a much more accurate image than that generated by traditional rendering or modeling.

3. Fly-bys and Walk-through Animation

Playing a number of successive pictures in a short time produces OK. Many computer visualization programs enable the designer to define a path that a camera moves along and the number of images that should be generated during a specified period of time. This guarantees that the images are consecutive. The program then renders each of the image frames. The capacity of making fly-bys and walk-through animation of a design solution increases the value of a computer 3D model as a visualization tool (Elliott et al, 1994), because it gives viewers an experiential quality not available from traditional renderings or scale models.

Shortcomings of Computer 3D Modeling

Hall (1993) stated that the disadvantages of this visualization media includes steep learning curves, increased processing time if animation is required, and lack of ability to move around the model in "real" time.

Virtual Reality

In "Silicon Mirage" (Aukstakalnis and Blatner, 1992), virtual reality (VR) is defined as "virtual reality is a way for humans to visualize, manipulate and interact with computers and extremely complex data." The visualization part refers to the computer-generated visual, auditory, or sensual output of a virtual world (Isdale, 1993). The world can be a 3D model, a scientific simulation, or even a database. In this research, the virtual world refers to the 3D simulation of LRT station designs.

Virtual Reality Systems

A variety of systems can be called "virtual reality systems". The most common one is the **Window on World** System. This system uses a conventional computer monitor to present the virtual world and has existed since the birth of computer graphics. The computer pictures must look and sound real, and objects act real, in order to make a virtual world on a desktop computer (Sutherland, 1965).

Video Mapping merges the video input of a user's silhouette with a 2D computer graphic (Isdale 1993), so that the user can see his body's interaction with the video on the monitor.

A more advanced VR system is the **Immersive System**. In this system, a user normally wears a helmet that holds the visual and audio displays (also known as Head-mounted display). It gives a very realistic sense because it completely immerses a user's viewpoint into the virtual world. Another form of this system is to use a number of projections in a room where the user is standing.

Telepresence is a system that lets people do their job remotely. The system has remote sensors (e.g. video cameras) on the working end and is linked to the control end by cables. The operator can see the real world through these sensors and conduct his work by controlling the working-end devices, such as a robot.

Mixed Reality is a system that merges VR and Telepresence. It combines the information coming from the **Telepresence** remote sensors and the computer-generated virtual world to present a virtual reality reacting to the real world activities (Isdale, 1993).

In this research, the virtual reality system means a **Window on World** System (see page 27) using a computer monitor as the display device. Because this system is less costly and the required devices are easy to obtain, **Window on World** was selected as the VR equipment in the study.

This system lets users view, sense, and interact with these simulations in real time. The final result of this simulation is not a single image or animation; instead, it generates a virtual space where users should be able to "walk in," as they will walk in the real space after it is built. Besides a monitor, it also requires input devices through which a user can control his movements and actions in a virtual world. This can be a mouse, joystick, steering wheel, or pair of gloves with motion-detection sensors. In this research, a mouse is used as the input device. The virtual simulation is supposed not only to represent realistic images, but also to interact with the user by responding to users' actions (Sutherland, 1965).

The advantage of using virtual reality in design assessment is its interactive and real-time environment, which is not available in any other visualization tool: the only alternative is a mock-up. In this sense, it is simulating the design solutions, instead of only visualizing them. It provides a closer-to-reality way for people to experience the design result before it is actually built.

VR, although good in simulating reality, can be expensive in equipment. The intensive computing work demands a higher-speed processor, expanded memory, and faster video cards. Until recently, VR simulations of urban environments had to be constructed at higher-end workstation level computers, which implies a significantly higher cost than a personal computer (PC). Now, a PC equipped with a Pentium II or III processor, sufficient memory, and a fast video card can do this job. VR simulations that run on a PC do not display realistic color, shade and shadow, reflection and transparency, thus they cannot compete with images generated from 3D models in the sense of visual realism. However, one should remember that until recently, the images from 3D computer models were only "shaded in" wire-frames, hardly to be compared with hand-drawing perspectives. With greater processor speed, future PC-generated VR simulations will have video-quality realism.

An even bigger obstacle for VR's use in architecture and planning is the steep learning curve. VR programs treat individual geometry as an object that is supposed to behave as its counterparts in the real world. People who construct the simulation need to program each object's associating properties, making it respond to a user's action as in the real world, which involves a significant amount of programming. Actually, the idea of treating each entity as an object with properties and behaviors is the conceptual basis of Object-Oriented Programming Languages (Lemay et al, 1998). Essentially, VR software is a programming environment that associates Object-Oriented Programming with spatial geometric objects. A 3D model can be built in a variety of CAD and computer modeling software. The task of VR application is to associate properties and behaviors with the 3D model. It is this part of the work that creates difficulties for design professionals who normally do not have software-programming background.

Research on Using Visualization to Evaluate Design Solutions

The primary reason for visualization is that designers want to evaluate a concept before spending the money to construct it. A consequent question is how effectively and accurately can those tools reflect the design concept.

Early research by Schomaker (1979), Killeen and Buhyoff (1983), and Collins(1970) on visualization focused on the effectiveness of static simulations in reflecting reality. They were interested to know whether certain method could simulate environmental sense accurately, and compared audience responses to various artificially-made static images versus real environmental photos.

Stamps (1993) also compared audiences' preferences for a housing project's line drawing proposals, with the post-construction evaluations. He found large agreement in preference despite of the different media.

Janssens and Kuller (1986) conducted a study to compare different simulation media's capacity in representing real environment. They used plans, perceptual drawings, slides, and movies taken by a medical optical probe in a scale model. They conclude that the dynamic simulations (the scale model movies) generated the fewest errors.

A recent study conducted by Park (1996) focused on comparing animations generated by computer 3D models with the video taken on-site. Within this study, a detailed 3D model of a site in Kirkland, WA was constructed. In order to achieve high realism, most texture mappings in this model were photographs taken on site, including building surfaces, street furniture, planters, light stands, and news stands. A light source was added in this model based on the site's geographic location and the time of day. Several cameras were defined to move in a similar way as the real video camera did. The animation was then rendered frame by frame, and transferred to a VHS videotape. Fifty subjects were used in the study. Half of them were shown the real video, and the other half were shown the animation. Then they were asked about fifteen pairs of criteria pertaining to the site. Park concluded that "response equivalence was observed between a dynamic visual simulation and video imagery of an urban environment." Out of fifteen pairs of semantic differentials used, there was no statistical difference between the two groups in thirteen differentials. Another importance observation is that a moderately detailed photo-realistic animation, although not as detailed as the video, did not generate difference in responses from the audience.

Conclusion

Recent technology development and urban problems make more and more cities interested in LRT, and since the 1970s, North America has seen a stable growth in LRT development. It is not strictly mass transit, but also an engine for re-developing a city's urban land. One of the key issues in building a successful LRT system is to make its stations attractive to its riders. In order to know riders' attitudes to a LRT station's design, it is necessary to conduct public preference surveys. There are a variety of methods to conduct such a survey, and stated preference is selected in this research because it can evaluate only the factors that are of interest here, it can evaluate the features that do not exist, and it is comparably inexpensive in both time and money.

In recent years, CAD has become more important in visualizing architectural design concepts. VR, a more demanding technology, cannot only visualize the design concept, but also let users to "walk in" and "experience" the design in a virtual space through multi-media. A user not only views the virtual environment, but also is "inside" it and is "using" it virtually. VR technology transforms the designer's proposal into a more realistic simulation than any other visualization tool. In measuring public attitude using stated preference survey, a key issue is to create a context as realistic as possible: VR is the means to achieve this goal.

3 METHODOLOGY

This chapter details the methodology used in designing the LRT CAD models and building the VR simulations, followed by a description of the software and hardware needed. The third section discusses the design and implementation of a stated preference survey, and finally, the analysis strategy of stated preference survey results is introduced.

Model Design and Building

CAD Model Design Methodology

Basic Models

Two distinct types of LRT stations have been identified (see Chapter 2). One of them is a station that has two platforms, with the rail tracks located in between them (side-load station), the other station has the platform located in the middle of rail tracks leading to opposite directions (center-load station). In a side-load station, passengers approach directly from streets or sidewalks, and can only go to the other platform by crossing the rail tracks. It is a simple one-story station, a few steps above street or ground level.

A center-load station is more complicated. Most riders need to reach the platform via a footbridge, which connects the street sidewalk with the station crossing a rail track, and is normally a two-story building. As the platform is in the middle, riders can take trains going in both directions from the same platform (see Figure 2–1). Each station design has unique design features that affect riders' acceptance. For example, design features associated with footbridges, such as ramps and escalators, are likely to impact a center-load station's acceptability, but they irrelevant to a side-load station. Having two station types requires the building of two basic CAD models; one for each type. Within the two basic types, design features that may affect the design's popularity are further examined, and variations can be generated from the two parents.

In order to define the basic characters of those two station types, a senior LRT Planner from Calgary Public Transit and the researcher reviewed all the Calgary LRT station design blueprint together. It was decided that the two basic station models could be built based on the design of University and Lions Park stations in Calgary because:

- the design information is easy to access.
- the stations have typical features of the two basic stations,
- they meet the specified LRT station design guidelines, and
- time is saved in creating and testing the models.

The two design plans are shown in Figures 3–1 and 3–2.

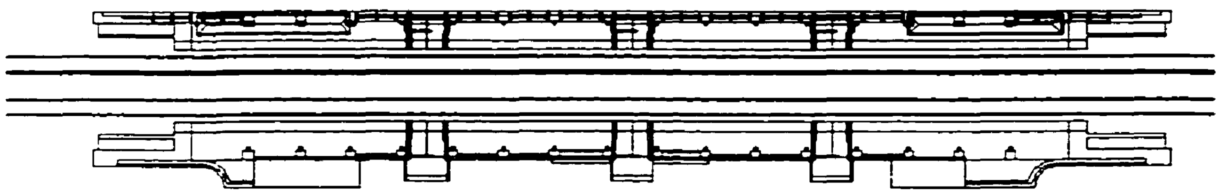


Figure 3–1: Plan of the Basic Side-Load Station

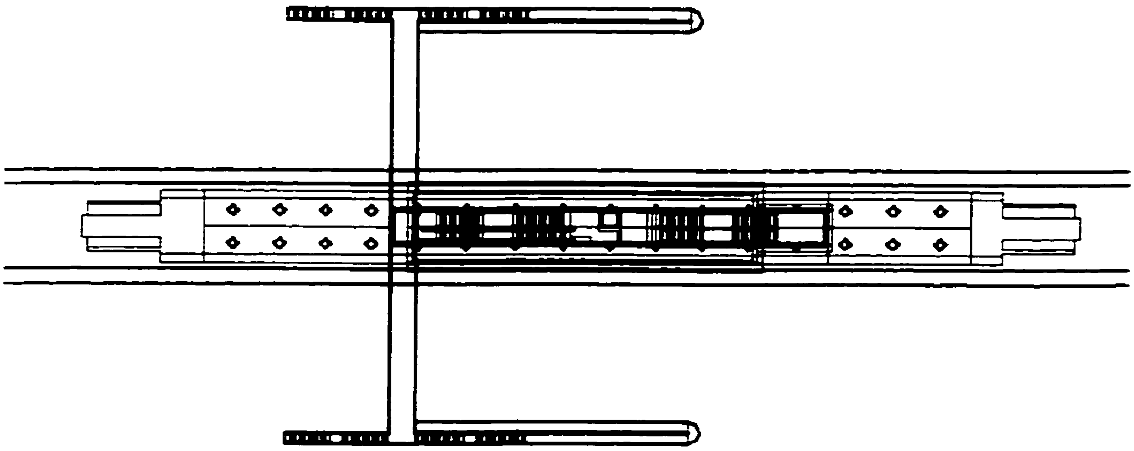


Figure 3–2: Plan of the Basic Center-Load Station

Model Variations

A list of design issues was generated through discussion with transportation and architecture design professionals (Appendix 2) and from readings in the literature.

1. Loading system: the relationship between rail tracks and platforms.

2. Accessibility: how to reach the station, platform, and LRT vehicles.

3. Design for disabled persons: how disabled persons can use the LRT facility.

4. Signage: how a passenger to find his way in the station.

5. Safety, security, and lighting: passenger safety and security, particularly at night.

6. Enclosures: waiting areas.

7. Aesthetics: decoration, local community characteristics.

8. Maintenance: cost in time and money.

9. Commercial development: opportunities in the surrounding area.

The loading system (side-load or center-load) is generally determined by the site conditions and how the station is connected to the surrounding area, hence in this research, stations with different loading systems will not be compared. Instead, a variation of each type will be built and compared within each basic loading system. Since a center-load station will normally have walls and roofs, the enclosure can only be a variable for side-load stations. Among the factors, accessibility is regarded as one of the most important. Since the function of a LRT station is to transfer people from street to the train, riders need the shortest, quickest way to their trains or buses. Signage is also assumed to be one of the most important features, because it lets riders know where to go, thus making the system easier to use. There are different opinions on lighting and enclosure: because they increase security at night, and protect waiting people from wind, some people think they are desired; others do not agree. However, it is generally agreed that lighting and enclosure are not as important as accessibility and signage (see Appendix 2). With respect to the other issues addressed above, the maintenance and commercial operations are beyond the scope of this research, and the aesthetic issues depend on the context of a local community's culture and historical heritage, which would require a separate study.

These factors are generated from professional experience, observation, and logic; and are subject to the findings of the stated preference survey. However, not all the features can be simulated effectively in the VR environment. Based on the available resources and the design features suitable for VR simulations, the researcher decided to assess five design features: the signage and enclosures of side-load stations; and the ramps, escalators, and signage of center-load stations.

Translation to Virtual Reality Environment

VR Simulations and Conventional Computer 3D Models

In a VR environment, what the viewers see, hear, and sense is what is happening within the simulation (virtual world) instead of pre-made images, actions, or sound tapes. A user, represented by an avatar, can walk through a virtual environment in any valid direction and at any reasonable speed, with full control of actions. However, in conventional computer generated 3D animations, the walking path and speed are pre-defined, leaving no control for the viewers. In the virtual world, a user can interact with the model in real time, e.g., open an elevator door by clicking the elevator button. In 3D animation, although a series image can be generate to achieve the sense of opening a door, it cannot be driven by the user's action. "Interactive" also means that a user can interact with objects in a virtual world. In the real world, if a walking person hit an obstruction, he stops, and so is his avatar. In the real world, when a person gets into an elevator, presses a button, he is taken to another floor; the same thing happens in a virtual world. The only difference is that in a VR world it is the avatar that moves (Sense 8 Corp., 1997). All of those interactions are impossible in conventional 3D images or animations.

An avatar is always needed in a VR simulation; it represents the user in a virtual space. What it sees is what the user sees; what it does is what the user does. When a VR simulation is running in a network, each user is assigned a different avatar. If more than one user logs in the system at a same time, they can see each other, and interact with each other in the virtual world (Sense 8 Corp., 1997).

Building Virtual Reality Simulations

In order to build the LRT station simulations as realistically as possible, a five-criterion guideline from Sheppard (1989) was applied here:

1. Representativeness: a simulation should show important and typical views of a project.

2. Accuracy: the simulation should compare well with the project.

3. Visual clarity: the level at which the detail and overall content of the simulation can be clearly recognized.

4. Interest: the level at which the simulation captures the attention of the viewer.

5. Legitimacy: the extent to which the accuracy of a simulation can be defended by the person or agency who created it.

In building the VR simulations, all of those criteria have been carefully considered. Of these criteria, the most effort has been put into making the model accurate; to look and act like the real world.

The real-time navigation lets the user go anywhere he wants in the simulation, and what he sees in virtual world is subject to navigation. Thus, all the features of the station design are revealed to the user: what he sees in the virtual world is very similar to what he would see in the real world if the station was built.

Visual clarity is concerned with the details of the design. With today's hardware and software, mapping texture images on a single 3D image can be done in a fairly short time and leads to a detailed, photo-quality image. However, for animations, it normally takes hours to apply the texture mapping to all the images involved. Obviously, this amount of time is not practical in a large VR simulation. Because a VR simulation is real-time — which means that the model is rendered at the time of playing — a large number and size of mappings will slow down the processing time for each frame of image. Since approximately twenty frames per second will need to be processed to get a smooth navigation (Sense 8

Corp., 1997), a walk in a VR simulation with many mapped surfaces will become jerky. Also, a slow video card may mix the mapping images together, and may even damage the visual clarity. Given these problems, the researcher decided to use as little texture mapping in the VR simulations as possible. The realistic sense of detail can be largely fixed by careful choosing of colors, light, reflections, opaqueness, and self-illuminations of an object's materials.

Since the user has full control of where to go or what to do, the simulation can be very exciting. In order to achieve an immersing experience, a "real-life" task is given to the user: find a train leaving for Anderson, the stop at the end of the line, starting from the sidewalk.

Creating Accurate VR Simulations

Navigation Control

A user navigates the VR environment by using a mouse to controll the direction and speed of his avatar. If the mouse is in the upper half of the window, the avatar goes forward; if the mouse is in the lower half, the avatar goes backwards. The avatar turns left when the mouse is in the left half of the window, and turns right when mouse in the right half. Forward and backward can be combined with turning left or turning right, e.g., an avatar can go forward while turning to the right. The moving and turning speed is determined by the proportional position of a mouse pointer related to the window height and width, which means the further up the mouse pointer is, the faster the avatar moves forward (see Appendix 3).

Following Terrain

When a person walks over terrain in the real world, his eyes (viewpoint) move up and down with the flow of terrain. What he sees also changes, depending on the elevation of his position. In a virtual world, the avatar should also move up and down relative to the terrain surface, and with the viewpoint following it. To achieve this, a ray is projected from the middle of avatar, directed downwards. A ray is an origin point and a direction (Sense 8

Corp., 1998). When it detects a surface defined as terrain, the ray reports the distance between the bottom of Avatar and that surface. The simulation then adjusts the avatar's elevation (Z value in 3D coordinator system) to make it touch the bottom of the surface (Sense 8 Corp., 1997) (see Figure 3–3 and Appendix 3).

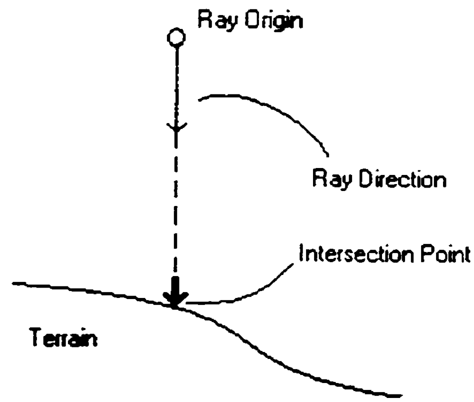


Figure 3–3: Projecting a Ray to Follow the Terrain

Collision Detection

Two rays are projected from the center of the avatar, one forward and one backward. When the avatar is going forward, if the first ray detects objects which are closer than the avatar's radius, the program will move the avatar back until the distance between them is equal to the avatar's radius (Sense 8 Corp., 1997). When the avatar is going backward, the second ray will perform a similar task; those operations are done in each image frame. As approximately twenty frames per second are rendered, the avatar will never get a chance to step into or cross another solid object. When it hits an object, it stops or passes around, depending on whether it is turning at that moment.

Triggering Events

In the real world, we can interact with objects: pressing a button may let an elevator door open, and stepping on an escalator may move the user to the next floor. In a VR environment, this kind of process can be divided into two phases: a predefined action (the elevator door opens) and an event to trigger (pressing button) it (Sense 8 Corp., 1997). To imitate these interactions, a number of actions are predefined and applied to an object; for example, doors opening and closing, elevator car going up or down, escalator steps moving up and forward. Next, the necessary triggering objects are created, such as elevator buttons and escalator steps and each is assigned special properties. When a user initiates a special event on the screen — clicking an elevator button, stepping on the escalator — the object's special properties will call up their reactions, which will either open the door or lift one up with the escalator (see Appendix 3).

By implementing these methodologies within a limited environment like a train station, it is possible to make the simulated space not only look, but also act, like the real space. The avatar can go in any direction, at any valid speed; go up and down stairs; and use an escalator, if the station has one. The avatar can take an elevator, but will not be able to cross a wall, column, handrail, or any other solid object. This accuracy achieved in VR simulation on top of an accurate CAD model is much more than visual accuracy.

Design of State Preference Survey Using VR as the Media

Design Options

The stated preference survey was designed to test five features in LRT stations: the signage and enclosure of side-load stations, and the ramps, escalators, and signage of center-load stations. Each possible combination of feature options within a basic station type defines an optional station design. An optional design may or may not have a design feature. In total, twelve simulations are required to represent all the possibilities, which are detailed in Tables 3–1 and 3–2.

Station ID	Ramp	Escalator	Signage
Lrt_1.5	Yes	No	No
Lrt_1.6	Yes	No	Yes
Lrt_1.7	Yes	Yes	No
Lrt_1.8	Yes	Yes	Yes

Table 3–1: Side-Load Station Options

Station ID	Escalator	Ramp	Signage
Lrt_2.1	No	Yes	No
Lrt_2.2	No	Yes	Yes
Lrt_2.3	No	No	No
Lrt_2.4	No	No	Yes
Lrt_2.5	Yes	No	No
Lrt_2.6	Yes	No	Yes
Lrt_2.7	Yes	Yes	No
Lrt_2.8	Yes	Yes	Yes

Table 3–2: Center-Load Station Options

Design Presentations

Pairs

To reduce the number of options, and interviews needed, the discrete choice method is employed. That method presents to respondents two VR simulations at one time, and asks them to select the one that they prefer most. For example, if a respondent is shown the following two simulations:

Simulation 1: no escalator, no ramp, prominent signage (Lrt_2.4)

Simulation 2: no escalator has a ramp, no signage (Lrt_2.1) and prefers the first one (Lrt_2.4), it can be concluded that he prefers prominent signage to ramps, because neither of them has an escalator.

The advantage of this presentation method is the simplicity and realism: with this approach, selecting a preferred choice from two options is much easier than ranking a series of options, hence the result is of greater validity. Furthermore, it is possible to assume that a respondent will always choose the dominant option from each pair. For example, he would always prefer a station with an escalator to a station without an escalator. He would also prefer a station with a ramp to a station without a ramp, and a station with prominent signage to a station without prominent signage. The researcher therefore needs only to present pairs in which no option is obviously dominant (Pearmain et al, 1991). Thus, the simulation numbers can be further reduced by eliminating the following two options from testing list:

Simulation 1: no escalator, no ramp, no signage (Lrt_2.3)

Simulation 2: has escalator and ramps prominent signage (Lrt_2.8)

Based on the above assumption, the first option (Lrt_2.3) will be the least favored, and the last one will be the most favored case. Applying this logic to the first type (side-load station), it is possible to further reduce the number of simulations by eliminating the station with no enclosed waiting area and no signage, and the station with both the enclosed waiting area and signage. Thus, in total, only eight simulations remain.

By testing those eight simulations, the researcher is actually testing the user's preference with respect to four pairs of design features. They are:

1. Enclosure against Signage (for side-load stations)

2. Ramp against Signage (for center-load stations)

3. Escalator against Signage (for center-load stations)

4. Ramp against Escalator (for center-load stations)

However, this discrete choice approach also has its disadvantages. For example, out of the following two options:

Simulation 1: no escalator, no ramp, prominent signage (Lrt_2.4)

Simulation 2: no escalator, has a ramp, no signage (Lrt_2.1)

If a respondent selects Simulation 1, this method cannot reveal the reason he does this. It may be that he does not like ramps, or he likes signage, or both. Instead of saying that he likes signage or dislikes ramps, a valid conclusion can only say that he prefers a station with signage to a station with a ramp.

Another limitation is that it does not give any indication on how much a respondent prefers one feature to another. This results from the way that discrete choice is implemented in this study: a simulation must either have a feature or not. That means the value of an independent variable, such as, must be either 0 or 1. There is no value in between to indicate how much a feature is preferred. The purpose of using a binary system (0 or 1) to describe the options is to simplify the survey process.

Packages

There are seven valid pairs of station simulations, which evaluate four pair of design features, as illustrated in Table 3–3.

Evaluated Features	Valid Pair	Station Model	
Enclosed Waiting Area vs. Signage	Pair A	Lrt_1.6	Lrt_1.7
Escalator vs. Ramps	Pair B	Lrt_2.2	Lrt_2.5
	Pair C	Lrt_2.4	Lrt_2.7
Escalator vs. Signage	Pair D	Lrt_2.3	Lrt_2.5
	Pair E	Lrt_2.4	Lrt_2.6
Ramps vs. Signage	Pair F	Lrt_2.2	Lrt_2.3
	Pair G	Lrt_2.6	Lrt_2.7

Table 3–3: Valid Station Simulation Pairs

Except for the case of the enclosure versus signage, each of other features has two valid test pairs, and so for each factor to have the same number of evaluations, there are four packages. Each subject completes one package as survey session. The testing is done as follows:

1. Package one tests for Enclosures/Signage and the first variant of Escalators/Ramps.

2. Package two tests for Escalators/Signage and the first variant of Ramps/Signage.

3. Package three tests for Enclosures/Signage and the second variant of Escalators/Ramps.

4. Package four tests Escalators/Signage and the second variant of Ramps/Signage.

Upon completion of the four packages, each set of tested features has been evaluated twice, and each station simulation has been run twice. An illustration of the packages is contained in Table 3–4.

Package 01	Pair A		Pair B	
	Lrt_1-6	Lrt_1-7	Lrt_2-2	Lrt_2-5

Package 02	Pair D		Pair F	
	Lrt_2-5	Lrt_2-3	Lrt_2-3	Lrt_2-2

Package 03	Pair A		Pair C	
	Lrt_1-6	Lrt_1-7	Lrt_2-4	Lrt_2-7

Package 04	Pair E		Pair G	
	Lrt_2-6	Lrt_2-4	Lrt_2-7	Lrt_2-6

Table 3–4: Survey Packages

This process guarantees that each set of features will be evaluated and makes sure that each simulation will have an equal opportunity to be played. The latter is important in this logic: although Pair B and Pair C both evaluate the importance of escalator against ramps, pair B is without signage while pair C has signage. The existence of irrelevant features is necessary in stated preference, because it insures an unbiased approach (Pearmain et al, 1991).

Sampling

The ideal group to interview in this experiment are current users of LRT services. First, LRT station design will be of interest; second, they have enough experience to make a connection between what they see in the virtual world with the real world. It is generally accepted in practice that thirty interviews per segment are sufficient for such of experiments. There is no theoretical basis for this, and some scholars argued that seventy-five to one hundred should be interviewed rather than thirty (Pearmain et al, 1991; Bradley, and Kroes, 1990). However, seventy-five to one hundred subjects was impractical in this research because of the time frame and financial conditions. Because this research was a pilot study, the sample size was targeted at twenty-eight.

Survey Session Process

The experiment began with an introduction to the objectives of the study and a consent form was presented. The test administrator briefly instructed the respondent on how to navigate and interact through the VR simulations, and the respondent was given several minutes to practice a simulation that would not be used in the test session. When the respondent felt comfortable with the simulation, he or she was given an answer sheet with the test instructions. There was also a task assigned: go to the train and return to the starting point. The respondent played the first station simulation, and then the second. After finishing the first pair, the respondent was asked to choose the preferred design, and then moved on to the second pair. The process is diagrammed in Figure 3–4.

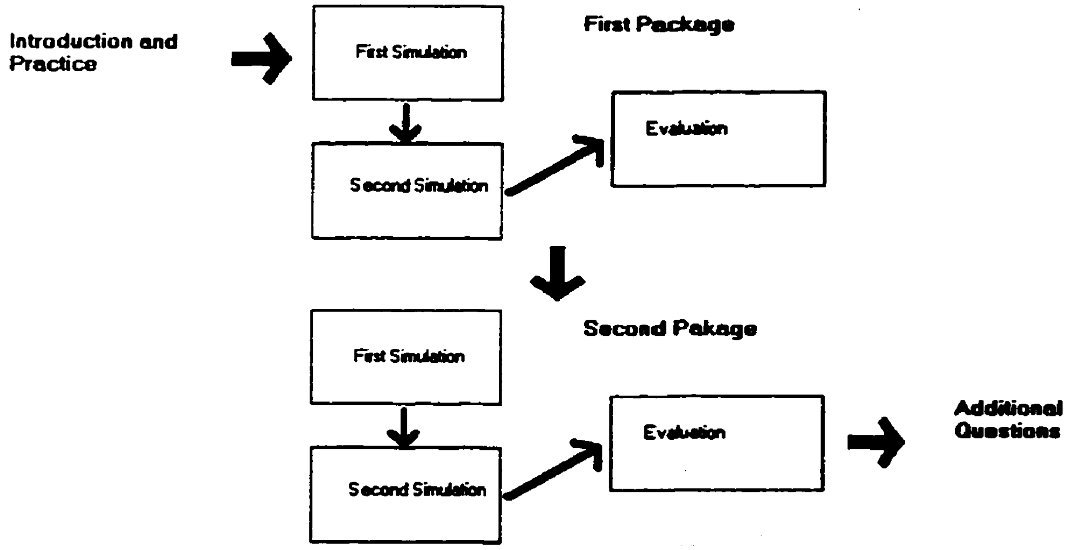


Figure 3–4: Survey Session Process

Analysis Using A Utility Model

There are various analysis methods that can be applied to the stated preference survey results.

Utility Model

In a utility model, "utility" refers to the satisfaction or benefits a consumer gets by spending his or her resources on different things. The model is constrained by the consumer's resources (Hensher et al, 1988). For example, one might prefer air travel to rail travel, but because of financial constraints, the former is not practical. The overall utility of a product is determined by its various attributes. Each attribute contributes to the utility on different levels (Jones, 1989). The utility is commonly depicted in the linear model shown below as Formula 3–1:

$$U_i = a_1 + a_1X_1 + a_2X_2 \ldots\ldots\ldots\ldots\ldots a_nX_n$$

Where

U_i	= utility of product i
$X_1 \ldots X_n$	= production attributes
$a_1 \ldots a_n$	= model coefficients
a_0	= model constant

Formula 3–1

The model coefficient, often also referred as "preference weight," represents the relative importance of each attribute. The model constant is a basic bias that an individual has towards or against that option (Pearmain et al, 1991).

In reality, an individual might respond to an option considering factors outside of the survey designer's perception. If an individual chooses option A from a set of alternatives, an assumption can be made that this option was selected because the person believes option A can provide more utility than any other options: the choice is a result of rational thinking. This assumption is called "Theory of Rational Choice Behavior", it implies that an individual always selects the option with highest utility. If this assumption is accepted, it is possible to calculate the utility associated with each option. Using the utility function, it is possible to predict which option a consumer will choose. However, human behavior is extremely complex and, sometimes, not always rational: a subject may not select option A every time. Thus the Rational Choice Behavior theory cannot accurately describe the nature of human choice (Hunt).

An alternative to the Rational Choice Behavior theory is the assumption that there are two components within the utility of a product. One of them is a measurable conditioning component, and the other one is the error component, which cannot be measured directly. This is what described in Formula 3–2, where Ui is conditioning component of the product i's utility, and ei is the immeasurable error component (Hunt).

The error term is the expression of that part of utility function that is not understood. It is added to the formula to establish equality. It can only be correct as long as all the individuals who will make the choice face the same set of alternatives and constraints (Hunt). This can be achieved by splitting them into groups. However, this is not practical in the real world. People with different constraints and choices are always put together in a survey. That situation makes the Random Utility Theory assume the error (ei) is a random variable with a certain distribution. With the ei is a random variable, the selection of any option by an individual is a chance thing. That means, when option A's measurable utility is greater than other options', there is a probability – instead of a certainty – that option A is selected. The probability can then be calculated mathematically.

Random Utility of Product i = Ui + ei

Where

Ui = utitlity of production i

ei = random error term

Formula 3–2

Available Analysis Approaches

The analysis of a stated preference data is to estimate the value of a_0 to a_n in the linear utility model (see Formula 3–1). By reviewing the available analysis tools, four approaches have been identified. Several techniques include the random error estimation, which leads to a more realistic statistical result.

1. Naive or Graphical Methods

This technique is based on the principle that each level appears equally in the experiment. By comparing the mean averages of each option at the same level, and comparing the mean averages, the designer can get some indication of the relative utility for that level. These methods don't have a statistical basis, neither do they provide any statistical significance of the data.

2. Monotonic Analysis of Variance

This technique applies an iterative algorithm to each of the responses separately. The first iteration is the solution provided by the Naive method. If part utility obtained by Naive can predict an identical rank order given by the respondent, that solution will be applied for all the responses. Otherwise, the part utilities are systematically altered in order to achieve a better correspondence, and the process is continued until an optimum situation is reached (Kruskal, 1965). This method is suitable for analyzing responses in rank orders. It cannot give an overall idea of the survey accuracy or develop reliable predicting models. Currently, this method is not widely used.

3. Regression

Regression is a commonly used statistical analysis method, applied to results obtained from a number of survey methods. When employed in stated preference, regression uses the least square method to decompose the rating or rank orders. It can provide measures of the significance of the model and its overall "goodness-of-fit" (Neter et al, 1989). A number of stated preference applications employed this technique (Kocur et al, 1982; Hensher and Louviere, 1983), however, it cannot analyze a random utility model.

4. Logit and Probit Analysis

The logit and probit analysis techniques were developed for analysis of discrete choice data (Ben-Akiva and Lerman, 1985). They can also be applied to other types of preference measures, such as rating and rank orders, by transferring those results to choice data format. These techniques can provide measures of the significance of the model and the "goodness-of-fit" of the model, as well as the tests for comparing alternative model specifications. They can handle the random utility model, and are widely used and preferred in stated preference analysis.

Selection of Analysis Tool in This Study

In this study, the stated preference survey is presented in discrete choices. The results can only be properly analyzed using logit (logistic) and probit analysis model (Pearmain et al, 1991). The logit and probit analysis are also the most accurate and desired analysis techniques for stated preference (Kroes and Sheldon, 1988). Between logit and probit, logit is simpler and more commonly used. In this research, Hague Consultant Group's ALOGIT was selected to perform the logit analysis.

Hardware and Software

Pentium and Pentium II NT workstations were used in the process of model building and virtual reality environment programming. AutoCAD R14 (Autodesk Inc., Sausalito, CA, USA) was utilized to generate two basic 3D LRT station models. Those models were then brought to 3DStudio VIZ (also from Autodesk Inc.) for material editing and mapping. During this process, several images were generated in Adobe PhotoShop 5 (Adobe Systems, Inc., Mountain View, CA, USA), which were used as texture mapping in the 3D models. WorldUp R4 package from Sense 8 Corp., (Mill Valley, CA, USA) was used to create the VR simulations. This package is a VR programming environment, utilizing object-oriented programming concept on 3D objects, taking the geometric objects from the 3D models and mapping textures from the generated images. Adding or subtracting geometric objects in WorldUp generates variations in the design of the LRT stations. A script language similar to Microsoft Visual Basic is used to write all of the coding for the virtual reality simulations. Finally, these VR simulations are compiled and exported as WUP files (a proprietary Sense 8 format), to be played with a viewer supplied by WorldUp.

Running the virtual simulations demands powerful graphics workstations. As approximately twenty frames per second must be rendered to get smooth navigation, the workstation needed to run the simulation must have a fast video card. Through experimentation, the Intergraph (Huntsville, AL, USA) TDZ-2000 GL2 machines available at the Learning Commons of the University of Calgary (AB, Canada) provided satisfying navigation for running the VR simulations. Most of the stated preference surveys were conducted on those computers. The VR simulations were played with OpenGL player supplied by Sense 8 Corp., (Mill Valley, CA, USA).

In the analysis stage, ALOGIT 3F/2 (Hague Consultant Group, The Hague, Netherlands) package was used to run logit analysis of the survey data.

4 STATED PREFERENCE SURVEY DATA ANALYSIS

Respondent Summary

Overview

Respondents

A total of twenty-eight subjects participated in the survey. Each one evaluated two simulation pairs for a total of fifty-six evaluations. The characteristics of all the respondents are summarized in Table 4–1.

Age	Average age	31.8	
	Number of subjects between age 20–29	10	35.7%
	Number of Subjects between age 30–39	13	46.4%
	Number of Subjects between age 40–49	5	17.9%
Gender	Male	17	60.7%
	Female	11	39.3%
Education	Design education background[3]	17	60.7%
	Non-design education background	11	39.3%
Occupation	Professional	14	50%
	Non-professional	14	50%

Table 4–1: Summary of Survey Respondents

The respondents were students, staff, and faculty from the Faculty of Environmental Design and University of Calgary at large. Though not randomly selected, respondents were fairly evenly distributed among different groups, in terms of the categories of age, gender, education background and occupation.

3. Design education background is defined as environmental design education, like planning, architecture, industry design

LRT Usage

Among the respondents, eleven percent take LRT every day, eighteen percent at least once a week, and thirty-five percent at least once a month. Thirty-six percent of the respondents use LRT less than once a month (Figure 4–1). They represent the population whom Calgary Transit would like to attract by improving LRT services.

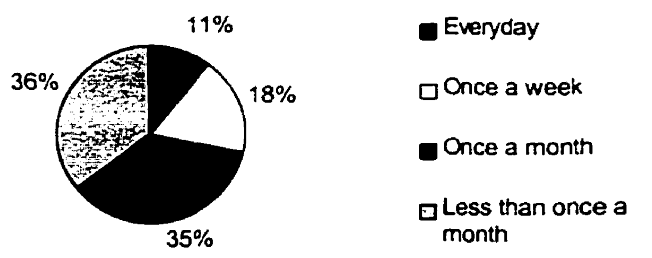


Figure 4–1: Respondent Use of LRT

When asked why they use LRT, forty-three percent of the respondents said they take LRT to work or to school. Among the rest, thirty-nine percent used it to go downtown, and fourteen percent for shopping (Figure 4–2).

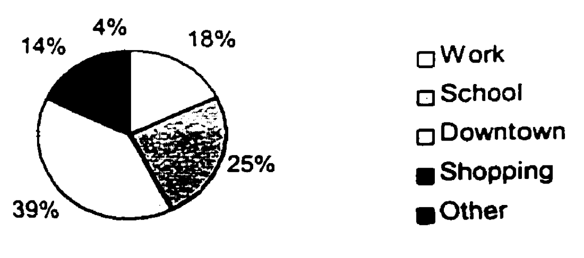


Figure 4–2: Reasons Respondents Use LRT

Simulations

Most respondents found using the virtual reality simulations was very easy (forty-two percent) or easy after practice (fifty percent) as illustrated in Figure 4–3.

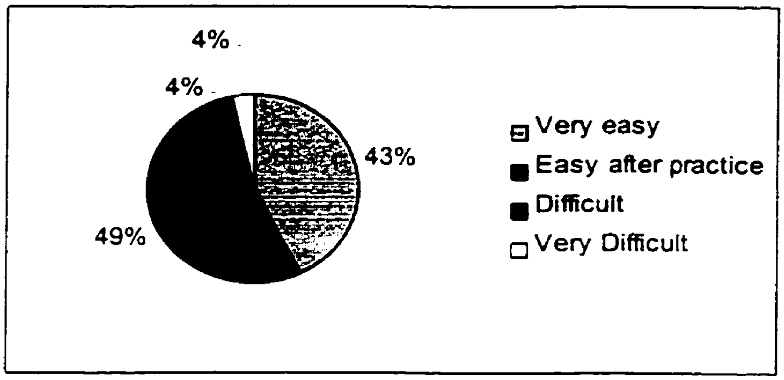


Figure 4–3: Ease of VR Simulation Use

More than two-thirds of the respondents also thought the virtual reality simulations represented the real stations realistically. Seventeen percent of the respondents said the simulations are very realistic, and fourteen percent said not realistic (Figure 4–4).

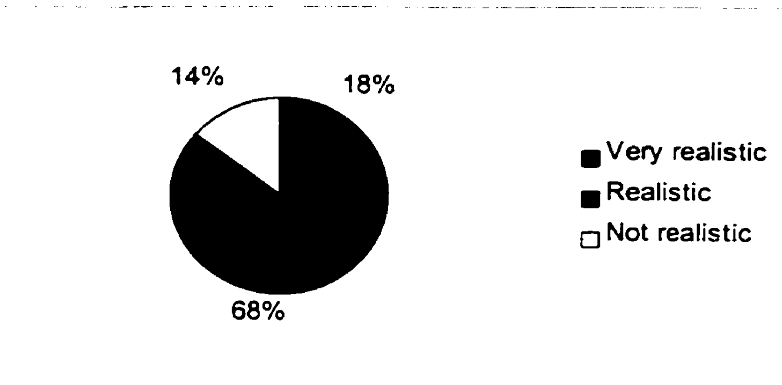


Figure 4-4: Realism of the Simulations

The four respondents who did not think the VR simulations were realistic were Faculty of Environmental Design architecture students. Through oral and written comments, they pointed out that these VR simulations lacked texture mapping and context environment, such as an urban surrounding area, which led to the unrealistic feelings. These students had training in 3D-computer modeling and were accustomed to photo-quality images with texture mapping, which suggests a possible rationale for their reactions.

Statistics Analysis

In this research, the statistical observation is not of each respondent, but is each pair of station simulations played by the respondents. In this experiment, there are twenty-eight respondents who each played two independent pairs for a total of fifty-six observations.

There are four tested design features in this study: escalator, ramp, signage, and enclosure. Additionally, the fifth independent variable added in the data analysis stage is the platform type. They are all binary variables: station simulation has escalators or not, ramps or not, signage or not, enclosed waiting areas or not, and is a side-load or center-load platform. In the input files, 0 and 1 are used to represent the status of an independent variable; the station simulation that has an escalator, no ramps, no signage, enclosed areas, and a center-load platform is represented as:

1 0 0 1 1

An analysis input file is actually a table in which each row represents an survey observation, and each column represents an independent variable. Because each observation includes two stations, there are ten independent variable columns in each row: the first five columns represent user-preferred station features, and the last five represent the other station's features.

After several trials, it turned out that the analysis program could not estimate the enclosure or platform coefficients because:

1. Throughout the survey observation, there were not enough variations of enclosure features to make the ALOGIT recognize them as independent variables.

2. The two station groups (center-load and side-load) were tested separately, and each of them had special tested features, so the ALOGIT could not recognize them as independent variables for all the observations.

Therefore the final analysis was performed only against three variables: escalator, ramp, and signage. The analysis shows that the estimated coefficient of escalators is 0.2140, of the ramps is –0.2528, and of the signage is 1.792. The 95% confidence intervals for escalators, ramps, and signage are 0.958, 0.976, and 0.764 respectively. The utility function for center-load station thus can be written as:

$$Ui = 0.2140 * Escl + (-0.2528) * Ramp + 1.792 * Sign$$

Where

Ui	= utility of station i
Ecsl	= escalator attributes
Ramp	= ramp attributes
Sign	= signage attributes

Formula 4–1

Formula 4–1 suggests that for a given LRT station, escalators will increase its utility and ramps will decrease it. However both of their influences are marginal. It also suggests that signage is a far more important feature in affecting a station's utility and a rider's preference. In order to further confirm that signage is a significant feature, the analysis process was performed again, but only with signage as an independent variable. This time, the analysis shows that estimated coefficient of signage is 1.792, and its 95% confidence interval is 0.764, which are identical with the first analysis results. The analysis also generates a T Ratio of 2.3 for signage, which indicates a very significant variable.

The coefficient for enclosure cannot be estimated by ALOGIT. In this study, it was a test feature only in side-load stations. Out of fourteen side-load station observations, there are only two that prefer enclosure to signage. Therefore, the ALOGIT cannot recognize the enclosure as an independent variable, and the logit analysis cannot be performed against it. However, all the side-load stations are identical in that they all have ramps and lack escalators. These simulations are only different in enclosure and signage. Within the fourteen observations related to side-load stations, the fact that twelve cases prefer stations with signage to stations with enclosure implies that eight-seven percent of the respondents think that signage is more important than enclosure in a side-load LRT station.

Limitation of the Research

In this research, design features that might affect riders' preferences with respect to LRT stations have been examined by conducting a stated preference survey using virtual reality simulations as the medium. The limitations of this research come from the virtual reality simulation construction, survey sampling, survey administration, and final statistics analysis.

Possible Source of Errors

Sampling

In this research, the sample size is small, resulting in higher likelihood of sampling errors. The reason for small sample size is the limitation of time and number of subjects, and the preliminary nature of the study; a total of twenty-eight subjects participated in this survey. In stated preference literature and practical research, a "rule-of-thumb" based experience suggests that a sample group of approximately thirty subjects is adequate. However, systematic research shows that a much larger sample (seventy to one hundred subjects) is usually needed to guarantee valid statistical analysis (Pearmain et al 1991). The fact that some of the statistical analysis procedures cannot generate valid results is the result of the small sample size.

Effect of Respondents

Unrealized by a respondent, he or she may tend to present himself or herself positively when participating in the survey. For example, when asked to find his way to a certain platform in the VR simulation, she or he may unconsciously try to show superior navigation skills. The respondent may want to influence the survey results in a certain direction, so she or he makes statements intentionally not based on what is seen in the experiment, but on personal experience. Because this survey used computer VR simulations, the respondent's skill in using a mouse is also a potential source of errors. Subjects who are not familiar with mouse operation may encounter difficulties in using the ramp facilities in the simulation, which could bias them against this feature, even though ramps are much easier to use in the real-world.

Media

The introduction of VR simulations as the survey medium brings more sources of error. Although great effort has been taken to simulate the LRT stations as realistically as possible (see chapter 3), there are many aspects on which a subject cannot have the same experience as in reality. For example, a subject cannot tell the physical difference between riding an escalator and walking up stairs, as there is no gravity involved in the VR simulation. A VR simulation can simulate the gravity by having proper equipment, but that is also much more expensive.

Validation Issues

Validation issues are of particular interest for stated preference research. A major argument against stated preference techniques is that a person's behavior is different from what they indicate in stated preference tests. The validity of stated preference research has three aspects (Pearmain et al, 1991):

1. Reliability: how reliably the same measured preference can be reproduced.

2. Internal validity: the descriptive quality of the model.

3. External validity: the ability to predict actual behavior using the model.

The literature on validation for stated preference research is very limited. Much of the validation research has been carried out as a by-product of practical stated preference studies. Although further systematical validity research on stated preference needs to be done, the evidence available now suggest a high level of validity of stated preference data (Pearmain et al, 1991).

In this research, care has been taken to increase the descriptiveness by controlling extraneous factors that might affect the respondent's reactions. For example, most respondents did the survey in the same room, on the same computers, and with the same administrator. All the VR simulations shared the same schema of colors, brightness, and materials; the respondents were given the same instructions, and when starting the VR simulation, the avatars were positioned in the same place to achieve the best internal validity.

The external validity can be impaired by a number of factors, including the lack of ecological validity, lack of population validity, and lack of temporal validity. Ecological validity means that the study is conducted under specific environmental and psychological conditions. In this research, the survey was done in a computer lab with subjects knowing that they were doing a test. These physical and psychological environments are believed to have some effects on the survey results.

Population validity questions if the study results can be generalized to the larger population from which the sample is drawn. This research sample represented a wide variety of population groups; ages varied from twenty to forty-nine, the male/female ratio was 3:2, and the respondents were equally divided between professionals and non-professionals. The variety of respondents increased population validity of this research; They were not selected on a random basis, but rather on an availability basis. This impaired the population validity.

The temporal validity means whether or not research results are still valid as time passes. In this research, the tested object was human behavior, which changes over time. It would not be surprising that the same person behaves differently in the afternoon than the morning.

5 CONCLUSION

The conclusions stated here are based on the survey observations made in this study. Two considerations should be applied to all the conclusions and explanations made in this chapter:

1. The survey sample is small, so the liability of statistical analysis is limited. The conclusions drawn from the statistics analysis are not definitive. More survey works are needed to bring more data for definitive conclusions.

2. The reasons proposed to explain the survey results were the researcher's suspects, not proven analysis.

Conclusion on Features

Signage

Statistical analysis shows that signage is a very prominent feature in affecting user's preference. The analysis reveals that signage is the only independent variable out of the five (escalator, ramp, signage, enclosure, platform) in logit testing. It was true that signage is more influential than any other tested design features; of fourteen cases, twelve preferred stations with signage to stations with enclosure in the side-load station group. Of forty-two cases in center-load station group, eleven preferred stations with signage to stations with ramps, and thirteen cases preferred stations with signage to stations with escalators.

These results were expected. The researcher thinks that the reason why signage is important to riders is because it tells them where to go—and "going somewhere" is the primary reason why riders use the LRT. In the survey, a task was set up for each respondent to help simulate actual actions in real LRT stations. The researcher believes this task also reminds a rider of the signage's function.

The design of the VR simulations may have also encouraged the respondents' to prefer signage. Because those simulations did not present an existing surrounding area, with which the respondents might be familiar (i.e. downtown Calgary), there were no landmarks to identify. Presence of landmarks was not a factor in this research, but it would have an impact on a rider's sense of direction. And leads to two further questions on signage:

1. If both landmarks and signage are presented within an LRT station (and its surrounding area), which one is more important to a rider in finding his or her way?

2. Not every station (and its surrounding area) has significant landmarks. For riders using the same station frequently, he or she may develop his or her own landmark system to identify the direction. However, non-frequent riders and newcomers (e.g., tourists) rely more on signage. It is interesting to know how big an impact signage has on those two groups.

Enclosure

Results of the survey show that enclosures, such as walls and kiosks, are relatively unimportant in affecting riders' preference for an LRT station. This was expected. People are at an LRT station for a short period of time. The enclosure is only good in inclement weather, when the waiting riders need a shelter to protect them. The function of the enclosures is not directly related to that of an LRT station, so it is reasonable that it received a low preference rate. However, a major negative consideration is that the VR simulations could not show the enclosure's advantages as much as they could for signage. When playing the VR simulations, the respondents were sitting in a lab and had no need of a shelter to protect them. That is believed to contribute partially to the large preference difference between signage and enclosures.

Escalator

Before conducting this experiment, it was speculated that escalators were an important feature. However, the logit analysis of survey data suggests that while escalators may have a positive influence on a rider's attitude, they are not a significant factor. This could be the result of:

1. An escalator is not so important for most LRT users. Riders rarely have heavy luggage, and most of them have full mobility. Unlike signage — without which a rider might get lost — an escalator is a courtesy, but not a necessity, for LRT stations.

2. In the VR simulations, the escalator's speed is about walking speed, but the maximum speed that an avatar can get is about running speed. For simplicity, the simulations are programmed so that when a person steps on the escalator, he or she loses control of direction and speed; he or she can only go up at the escalator's speed on the upper floor. However, in the survey, many respondents tended to maximize their speed when going straightforward or going upstairs. Thus, it seemed that taking the escalator is much slower than climbing stairs.

3. The advantages of escalators, such as convenience and reduced physical activity, cannot be reflected in the VR simulations.

Escalators are not as important as signage in the users' consideration. However, taking consideration of the above facts, one cannot conclude confidently that escalators are not significant in the choice of one design for an LRT station over another.

Ramps

The coefficient of ramps is –0.2528, and its standard error is 0.979, which means that one can be ninety-five percent confident saying that the ramp's coefficient can be anywhere from -1.2318 to 0.7262. This means that it is possible that ramps have both negative and positive influence on a rider's preference, with the negative one more likely. Regardless, the influence of ramps is marginal. The researcher believes that, in reality, the ramps are rarely used. Riders with reduced mobility prefer to use the ground-level access at the end of a center-load station, such as Chinook station in Calgary. It appears that most ramp users are cyclists. If signage is a necessity in LRT stations because it is related to the core function of the station, and an escalator is a convenience to the public, a ramp is only a courtesy to a limited number of users.

Recommendations

Based on the conclusion regarding each design factor, it is not difficult to find the order of relative importance in defining the public acceptance of LRT station design. Within the side-load station category, signage is much more important than enclosures. Within the center-load station category, signage is also the most important factor, escalators are the second, and ramps are not desired in LRT stations.

In an LRT station, a prominent signage system is always welcome. It is cost-effective and provides riders with the information they want most, improving service and efficiency. From the survey results, it is clear that a good signage system also largely increases the design's acceptability. If the station has a center-load platform and the budget permits, it is desirable to have escalators. However, LRT station designers should be informed that this recommendation is made only from the perspective of public acceptance. Not only are escalators expensive to install, but maintenance costs are high. When access for cyclists and disabled individuals to center-load stations is required, ground-level access at the end of the platform instead of ramps should be considered. A ramp to a footbridge is costly, and a long steep one is difficult for people with reduced mobility to use. From the public perspective, a ramp to the footbridge in a center-load station does not provide greatly improved service, and is rarely used.

Further Research

This research is an experiment using VR technology to test public attitude to LRT station design. VR is a relatively new technology, compared to other visual simulation methods, but it has shown promise in many ways. Further research should be conducted on the capacity of VR applications in simulating environmental reality and comparison with other simulation methods. In a broader view, research should be conducted on how to simulate the environment beyond visualization, such as simulating the sense of touch and gravity, to see how that affects VR's capacity to create a sense of reality for proposed designs. As Internet technology grows and improves, it will become a promising place to play with VR applications. The Internet has adopted and continues to develop a Web-based VR standard in Virtual Reality Modeling Language (VRML). It will become interesting to see how feasible Internet VR technology will be to test the public attitude to proposed public projects. The Internet promises to give the public a wider access to the design's VR model.

Research on LRT station design is also a relatively new topic. The design features studied in this research were very limited and there are many other issues that need to be addressed. Further research topics include safety and security, aesthetics, and access design for disabled people.

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APPENDIX 1 CONSENT FORM AND QUESTIONNAIRE

UNIVERSITY OF CALGARY CONSENT FORM

RESEARCH PROJECT TITLE: Measuring Attitudes of Ridership Regarding the Design of LRT Stations Using CAD and VR as an Assessment Tool

INVESTIGATOR: Zibin WANG, University of Calgary, Faculty of Environmental Design (General Program)

This consent form, a copy of which has been given to you (if requested), is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

In recent years there has been a growing interest by cities to use light rail (LRT) as a means of providing public transportation. As part of the planning process, cities need to gain public acceptance of LRT as an acceptable form of mass transit. Safety, convenience, access are some of the issues transportation planners face in developing LRT systems. One of the major factors in developing favorable attitudes towards LRT transit is the design of the public stations. This study will use interactive CAD (computer aided design) and VR (virtual reality) technology to assess ridership preference of major design features so as to figure out guidelines useful to transportation planners in LRT station designing.

You have been contacted because you are the resident of Calgary, and you are a rider or a potential rider of Calgary LRT. I will describe interview process to you and request your consent. You will be asked to use VR device to experience the existing and/or proposed LRT design in three-dimensional sense. Afterwards, a variety of questions will be asked regarding the safety, accessibility, and convenience. I will also ask for your ideas about how the CAD and VR technologies help you to understand the design proposals. The results of the interview will help to provide qualitative information that will aid in future LRT station designs, and present public attitude towards the present designs. It will also be used to assess the CAD and VR technology in aiding public transportation planning. The interview results will be kept confidential and only be referred to in a general sense. For example, it may state in the research report that of the X number of riders or potential riders interviewed, only x intend to have a certain feature in the LRT stations.

The interview is expected to take 30 minutes of your time. Your participation in these is voluntary and you have the right not to answer any questions or stop the interview at any tine. The interview results will be securely stored for 2 years following the completion of the research, at which time they will be destroyed.

Your signature acknowledgment indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

Zibin WANG at 210-1299 or
Email: wangz@acs.ucalgary.ca

If you have any questions concerning your participation in this project, you may also contact the Faculty of Environmental Design Local Areas Research Ethics Committee and ask for Prof. Thomas L. HARPER, 220-3629.

Participant Date

Investigator Date

A copy of this consent form has been given to you to keep for your records and reference.

Package ID: Package_____ Date: ___/___/___

Welcome to the LRT Station Virtual Reality Survey!

Please Note:

The survey result will be kept confidential and only be referred to in a general sense. A consent form is available upon request.

On the following table, you will find one highlighted Package. Please open the first model of that package and test it, then close it and test the second model. When you finish, please select the station you like most from the two. Next, do the same thing to the second pair of that package. For example, if Package01 is highlighted, test Lrt_1.6 first, and then Lrt_1.7, and make your selection; then test Lrt_2.1 and Lrt_2.5, and make your selection. Finally, please answer the questions on the next page.

Task: imagine you are a rider heading for Anderson. When you start, you are on the street sidewalk. Please go to find your platform. After you get there, please imagine yourself as a rider just got off the train. Please find your way to get out of the station.

Package 01	Pair A		Pair B	
	Lrt_1.6 ☐	Lrt_1.7 ☐	Lrt_2.1 ☐	Lrt_ 2.5 ☐

Package 02	Pair D		Pair F	
	Lrt_2.5 ☐	Lrt_ 2.4 ☐	Lrt_ 2.4 ☐	Lrt_ 2.1 ☐

package 03	Pair A		Pair C	
	Lrt_1.6 ☐	Lrt_1.7 ☐	Lrt_2.2 ☐	Lrt_ 2.6 ☐

Package 04	Pair E		Pair G	
	Lrt_2.2 ☐	Lrt_2.7 ☐	Lrt_ 2.7 ☐	Lrt_ 2.6 ☐

Please answer all of the following questions to the best of your ability. The answers you provide will be helpful in advancing transportation building design and planning. All responses will be strictly anonymous

1. How often do you take LRT?
   a) every day b) at least once a week c) at least once a month d) rarely

2. Why do you take LRT?
   a) to work b) to school c) others, please specify ________________

3. How easy do you feel navigating the VR models?
   a) very easy b) easy, after practice c) difficult d) very difficult

4. How well do you think the VR models represent real environment
   a) very realistic b) realistic c) not realistic

5. Any general comments on the VR models?

____

____

____

____

____

6. Your age: ______________

7. Gender
   a) Male b) Female

8. Do you have any design related background (architecture, planning, industry design, and environmental design)?
   a) Yes Please specify _______________ b) No

9. Your Occupation(s), including part-time work:

   ____

THANK YOU FOR YOUR PARTICIPATION!

APPENDIX 2 DISCUSSION WITH LIGHT RAIL TRANSIT PROFESSIONALS

In order to find the desirable features in an LRT station, and the comparative importance between them, the researcher discussed with professionals working in the areas of transportation and architecture. The following section lists the notes from those discussions:

A Senior Planning Officer of Calgary Transit

1. Whether the platform is between the tracks (center load) or outside the tracks (side load) is more a function of the surrounding area and how the station relates to the surroundings. A center load platform is safer if access is at grade because pedestrians only cross one track at a time. Also, a center load platform is easier if access is from above because then only a single set of stairs/escalators/elevators needs to be provided.
2. Access is the all-important issue for customers. People want the shortest, easiest access to the train. This is the number one priority. If vertical access is involved, escalators are the preferred choice.
3. Enclosures - I understand this to mean walls. Protection from the wind is appreciated but I would only rank this as number 4.
4. Coverages - A roof is also appreciated, but in Calgary's relatively dry climate, I would only rank this as number 5.
5. Light - This is important. The perception of personal safety, particularly at night, is greatly enhanced with a brightly-lit platform and an absence of shadow or dark areas. The use of indirect light is discouraged because it is a high maintenance item. Typically indirect lights have the lenses pointing up towards the ceiling and as such they readily accumulate dirt, bugs, garbage etc, and quickly loose their effectiveness. Lighting ranks as number 3.
6. Signage - Wayfinding through a station is very important. If you can't figure out how to get to where you want to go, it is tough to use the system. We would rank this as number 2.

7. Seats on platforms - While it is nice to be able to sit down, the majority of passengers prefer to stand. Seats may not always be clean, and the wait is usually only a few minutes for a train. This ranks as number 6.

A Faculty Member in Civil Engineering, University of Calgary

1. The Location of platform, or loading system depends more on factors other than riders' preferences.
2. The most desirable access (to platform) method is stairs plus escalators. However, it also depend on the loading system.
3. The ideal station should be an enclosed environment – meaning has walls
4. The ideal station should have regular roof
5. Indirect lighting is desirable in stations, but it also depends on station locations, underground or surface.
6. Prominent Signage is desirable in stations
7. The ideal station should have designated seats
8. Among those features, the most important one is the Prominent Signage. Designated seats and 'stairs plus escalators' access hold second importance. The enclosure and roof are least important.

A Senior Faculty Member in Architecture and Planning, University of Calgary

1. Prominent signage, map and schedule is one of the most desirable features
2. The access method to platform(s) is also one of the most important features. It is best to have stairs, escalators and elevators.
3. Roof and enclosure are good to have, but not as important as the first two
4. Seats are not important.
5. Not sure what options a station can have in lighting

APPENDIX 3 WorldUp(TM) R4 Basic Script® CODE

Script Name: StartUp.ebs
Function: To start the simulation and set the Avatar in the initial position. This script is used only in side-load station simulations with escalators.

```
' Startup Script
sub main( )

	dim av as Avatar
	set av = getAvatar("Avatar-1")

	dim avbody as Cylinder
	set avbody = getCylinder("AvatarBody")

	dim pos as Vect3d, ori as Orientation

	pos.X = 0
	pos.Y = 0
	pos.Z = 0
	'
	ori.X = 0
	ori.Y = 0
	ori.Z = 0
	ori.W = 1
	'
	avbody.SetTranslation pos
	avbody.SetRotation ori
	'
	'
	pos.X = 900
	pos.Y = -11.0482
	pos.Z = -125
	'
	ori.X = 0
	ori.Y = 0.355
	ori.Z = 0
	ori.W = 0.935
	'
	av.SetTranslation pos
	av.SetRotation ori


end sub
```

Script Name: StartUp.ebs
Function: To start the simulation, set the Avatar in the initial position, and start the escalator. This script is used only in center-load station simulations with escalators

```
' Startup Script
sub main( )
	getpath("GoEscLowSteps").Play
	getpath("GoUpEscSteps").Play
	getpath("GoEscHiSteps").Play
	'
	dim av as Avatar
	set av = GetAvatar("Avatar-1")
	'
```

```
        dim pos as Vect3d, ori as Orientation
        pos.X = 490
        pos.Y = -12.463
        pos.Z = -140
        '
        ori.X = 0
        ori.Y = 0.68
        ori.Z = 0
        ori.W = 0.72
        '
        av.SetTranslation pos
        av.SetRotation ori
end sub
```

Script Name: StartUpNoEsc.ebs
Function: To start the simulation and set the Avatar in the initial position. This script is used only in center-load station simulations with escalators.

```
' Startup Script
sub main( )

        dim av as Avatar
        set av = GetAvatar("Avatar-1")
        '
        dim pos as Vect3d, ori as Orientation
        pos.X = 490
        pos.Y = -12.463
        pos.Z = -140
        '
        ori.X = 0
        ori.Y = 0.68
        ori.Z = 0
        ori.W = 0.72
        '
        av.SetTranslation pos
        av.SetRotation ori

end sub
```

Script Name: ControlAvatar.ebs
Function: To control the direction and speed of the Avatar

```
sub task( obj as Avatar )
        dim MousePos as Vect2d
        obj.ControllingWindow.GetMousePosition MousePos
        '
        dim WindowWidth as Integer, WindowHeight as Integer
        WindowWidth = obj.ControllingWindow.ClientWidth
        WindowHeight = obj.ControllingWindow.ClientHeight
        if WindowWidth = 0 or WindowHeight = 0 then
              Exit Sub
        end if

        MousePos.X = MousePos.X / WindowWidth
```

```
        MousePos.Y = MousePos.Y / WindowHeight
        '
        dim code as integer
        if MousePos.X > 0 and MousePos.X < 1 and MousePos.Y > 0 and
MousePos.Y < 1 then
                if MousePos.Y < 0.4 or MousePos.Y = 0.4 then
                        obj.Speed = 10 - 25 * MousePos.Y
                        code = 1
                end if
                '
                if MousePos.Y > 0.4 and MousePos.Y < 0.6 then
                        obj.Speed = 0
                        code = 0
                end if
                '
                if MousePos.Y > 0.6 or MousePos.Y = 0.6 then
                        obj.Speed =  9 - 15 * MousePos.Y
                        code = 2
                end if
                '
                if MousePos.X < 0.3 then
                        obj.Turn = - 15
                        code = code + 3
                end if
                '
                if MousePos.X > 0.3 and MousePos.X < 0.7 then
                        obj.Turn = 0
                        code = code + 0
                end if
                '
                if MousePos.X > 0.7 then
                        obj.Turn = 15
                        code = code + 6
                end if
                '

        else 'if mouse is out of the window
                obj.Speed = 0
                obj.Turn = 0
        end if
        '
        dim u as universe
        set u = getuniverse("The Universe")
        '
        'the motionlink can be disabled when the cursor on triggers
        if GetMotionLink("MoveAvatar").Enabled = False then Exit Sub
        '
        if obj.Turn <> 0 then obj.Yaw obj.Turn/u.framerate
        obj.Translate 0,0, obj.Speed/u.framerate
        '
        '
        Select Case code
                case 0
                        setCursor("ARROW")
                case 1
                        setcursor("FORWARD")
                case 2
```

```
                setcursor("BACKWARD")
            case 3
                setcursor("TURN_LEFT")
            case 4
                setcursor("FORWARD_LEFT")
            case 5
                setcursor("BACK_LEFT")
            case 6
                setcursor("TURN_RIGHT")
            case 7
                setcursor("FORWARD_RIGHT")
            case 8
                setcursor("BACK_RIGHT")
        end select
end sub
```

Script Name: FollowAvatar.ebs
Function: To enable viewpoint follow the Avatar

```
sub task( obj as FollowViewpoint )

        dim av as Avatar
        set av = obj.ControllingAvatar

                dim pos as Vect3d, ori as Orientation
                av.GetGlobalLocation pos, ori

                pos.Y = pos.Y - 7 'in the height of human eys
                obj.SetPosition pos
                obj.SetOrientation ori

end sub
```

Script Name: FollowTerrain.ebs
Function: To enable the Avatar follow terrain

```
sub task( obj as Avatar )

        dim Pos as Vect3d
        obj.GetTranslation Pos
        '
        dim Start as Vect3d
        Start = Pos
        Start.Y = Pos.Y - 9 'start point is on avatar top

        'we want to look for intersections with terrian
        dim TrStable as node
        set TrStable = Getnode("Terrian-1")
        'we also want to look for intersections with Ele and Esc
        dim TrMovable as node
        set TrMovable = Getnode("TerrianMovable-1")

        ' Create a vector looking down
        dim Dir as Vect3d
        Dir.y = 1
```

```
        dim GeomStable as Geometry
        dim GeomMovable as Geometry
        dim PolyStable as long
        dim PolyMovable as Long
        dim DisStable as Single
        dim DisMovable as Single

        ' Test for intersection, disable this object so we
        ' won't find ourself
        obj.Enabled = FALSE
        PolyStable = RayIntersect(TrStable, Start, Dir, GeomStable,
DisStable)
        PolyMovable = RayIntersect(TrMovable, Start, Dir, GeomMovable,
DisMovable)
        obj.Enabled = TRUE

        if not(PolyStable = 0) then 'if stable detected
              if PolyMovable = 0 then 'but movable not
                    obj.GeomName = ""
                    Pos.y = Pos.y + (DisStable-18) 'distance is of avatar
top and the terrian
                    obj.SetTranslation pos
              else 'both detected
                    if DisStable > DisMovable or DisStable = DisMovable
then 'Movable is closer
                          obj.GeomName =GeomMovable.Name
                    else 'if Movable is farther
                          Pos.y = Pos.y + (DisStable-18) 'distance is of
avatar top and the terrian
                          obj.SetTranslation pos
                          obj.GeomName = ""
                    end if
              end if
        else 'if stable not detected
              if PolyMovable = 0 then 'movable not detected
                    obj.GeomName = ""
              else 'movable detected
                    obj.GeomName = GeomMovable.Name
              end if
        end if
end sub
```

Script Name: CollisionRevised.ebs
Function: To detect collision between the Avatar and other objects and set Avatar back if collision if collision happens

```
Declare Function MinDis(Dis1 as Single, Dis2 as Single, Dis3 as Single)
as Single
'
sub task( obj as Avatar )

        'define the projection origin, the height should be able to
detect frame and seat
        dim Pos1 as Vect3d
        dim ori as Orientation
        dim u as universe
```

```
        obj.GetTranslation Pos1
        '
        dim Pos2 as Vect3d
        Pos2 = Pos1
        Pos2.Y = Pos2.Y + 8
        dim Pos3 as Vect3d
        Pos3 = Pos1
        Pos3.Y = Pos3.Y - 8
        '
        obj.GetRotation ori
        set u = getuniverse("The Universe")
        '
        'get a foward vector
        dim DirF as Vect3d
        DirF.Z = 1
        Vect3dRotate DirF, ori
        '
        'get a bakward vector
        dim DirB as Vect3d
        DirB = DirF
        DirB.Z = -DirB.Z
        '
        dim Br as Node
        Set Br = GetNode("Barria-1")
        '
        dim Geom as Geometry
        dim DisF1 as Single
        dim DisB1 as Single
        dim PolyF as Long
        dim PolyB as Long
        '
        dim DisF2 as Single
        dim DisB2 as Single
        dim DisF3 as Single
        dim DisB3 as Single
        '
        dim DisF as Single
        dim DisB as Single
        '
        if obj.speed > 0 then
              obj.enabled = false
              PolyF = RayIntersect (Br,Pos1,DirF,Geom,DisF1)
              PolyF = RayIntersect (Br,Pos2,DirF,Geom,DisF2)
              PolyF = RayIntersect (Br,Pos3,DirF,Geom,DisF3)
              obj.enabled = true
              DisF = MinDis(DisF1,DisF2,DisF3) - obj.Radius/2
        elseif obj.speed < 0 then
              obj.enabled = false
              PolyB = RayIntersect (Br,Pos1,DirB,Geom,DisB1)
              PolyB = RayIntersect (Br,Pos2,DirB,Geom,DisB2)
              PolyB = RayIntersect (Br,Pos3,DirB,Geom,DisB3)
              obj.enabled = true
              DisB = MinDis(DisB1,DisB2,DisB3) - obj.Radius/2
        end if
        '
        if DisF < 0 then obj.Translate 0,0, - obj.Speed/u.framerate,
LocalFrame
```

```
      if DisB < 0 then obj.Translate 0,0, - obj.Speed/u.framerate,
LocalFrame

      '
end sub

Function MinDis(Dis1 as Single, Dis2 as Single, Dis3 as Single) as
Single
      if Dis1 > Dis2 then
            if Dis2 > Dis3 then
                  MisDis = Dis3
            else
                  MisDis = Dis2
            end if
      else
            if Dis1 < Dis3 then
                  MisDis = Dis1
            else
                  MisDis = Dis3
            end if
      end if
End Function
```

Script Name: CloseDoor.ebs
Function: To close a station exit door automatically six seconds after its opening. It is used only in center-load station simulations

```
sub task( obj as TriggerDoor )
      dim sglTime as Single
      dim strName as String
      '
      sglTime = Timer
      strName = obj.Name
      strName = "Close" & strName
      '
      if obj.Open = True and sglTime - obj.OpenTime > 6 then
            getPath(strName).Rewind
            getPath(strName).Play
            obj.Open = False
      End if
end sub
```

Script Name: CloseEleDoor.ebs
Function: To close an elevator door automatically six seconds after its open. It is used only in center-load station simulations

```
sub task( obj as SlidingDoor )
      '
      if obj.Open = True then
            dim sigCurrentTime as single
            sigCurrentTime = Timer
            if sigCurrentTime - Obj.OpenTime > 5 then
                  '
                  'get the pathes back to the first points, then play
                  getpath("Path-3").Rewind
                  getpath("Path-5").Rewind
                  getpath("Path-3").Play
```

```
                    getpath("Path-5").Play
                    obj.Open = false
              end if
        end if
end sub
```

Script Name: EleCar-1.ebs
Function: To let user take and control the elevator. It is used only in center-load station simulations

```
sub task( obj as EleCar )
      '
      'determine the position of obj
      dim ECpos as Vect3d
      obj.GetGlobalLocation ECpos
      if ECpos.y = 0 then
            obj.Upper = True
      end if
      if ECpos.y = 46.1449 then
            obj.Upper = False
      end if
      '
      'translate the control to EleDoorA and EleDoorB
      dim SDA as SlidingDoor
      dim SDB as SlidingDoor
      '
      set SDA = getSlidingDoor("EleDoorA")
      set SDB = getSlidingDoor("EleDoorB")
      if obj.Upper = True then
            SDA.Ready = True
            SDB.Ready = False
      else
            SDA.Ready = False
            SDB.Ready = True
      end if
      '
      'if open, close after certain time
      if obj.Open = True then
            dim sigCurrentTime as single
            sigCurrentTime = Timer
            if sigCurrentTime - Obj.OpenTime > 5 then
                  '
                  'get the pathes back to the first points, then play
                  getpath("CloseEleCarDRA").Rewind
                  getpath("CloseEleCarDRB").Rewind
                  getpath("CloseEleCarDRA").Play
                  getpath("CloseEleCarDRB").Play
                  obj.Open = false
            end if
      end if
      Exit Sub
end sub

' Event Handling
Sub OpenChanged ( obj As EleCar )
      '
      if obj.Open = true then
            getpath("OpenEleCarDRA").Rewind
```

```
            getpath("OpenEleCarDRB").Rewind
            getpath("OpenEleCarDRA").Play
            getpath("OpenEleCarDRB").Play
      end if
      Exit Sub
      '
End Sub ' End of subroutine: OpenChanged


Sub InsideChanged ( obj As EleCar )
      dim AV as Avatar
      dim Pos as Vect3d
      set AV = GetAvatar("Avatar-1")
      AV.GetTranslation Pos
      if obj.inside = true then
            'if Pos.Y < - 18 and Pos.Y > -64 then
            '      getmotionlink("motionlink-2").enabled = false
            'elseif getTriggerController("TriggerController-
1").OverTrigger = False then
            '      getmotionlink("motionlink-2").enabled = true
            'end if
      end if

End Sub ' End of subroutine: InsideChanged
```

Script Name: EleDoorA.ebs
Function: To control one of the elevator's doors in different circumstances. It is used only in center-load station simulations

```
sub task( obj as SlidingDoor )
      'open the door when ordered and ready
      if obj.Ordered = True and obj.Ready = True then
            '
            'get the paths back to the first points, then play
            getpath ("OpenEleDoorAA").Rewind
            getpath ("OpenEleDoorAB").Rewind
            getpath ("OpenEleDoorAA").Play
            getpath ("OpenEleDoorAB").Play
            '
            'get the open time
            Obj.OpenTime = Timer
            '
            'set aproppriate property values
            obj.Open = True
            obj.Ordered = False

            'open the car door
            dim EC as EleCar
            set EC = getEleCar("EleCar-1")
            EC.Open = True
            'set open time for the car
            EC.OpenTime = Timer
      end if
      '
      'close the door if opened for a certain time
      if obj.Open = True then
```

```
            dim sigCurrentTime as single
            sigCurrentTime = Timer
            if sigCurrentTime - Obj.OpenTime > 5 then
                  '
                  'get the pathes back to the first points, then play
                  getpath("CloseEleDoorAA").Rewind
                  getpath("CLoseELeDoorAB").Rewind
                  getpath("CloseEleDoorAA").Play
                  getpath("CLoseELeDoorAB").Play
                  obj.Open = false
            end if
      end if
end sub
'
'EventHandling
Sub OrderedChanged (obj as SlidingDoor) 'when ordered changed, get the
car and set ready to true
      '
      if obj.Ordered = True then
            'Get the EleCar info
            dim EC as EleCar
            set EC = GetEleCar("EleCar-1")
            if EC.Upper = False then 'if Car is on the lower floor
                  getpath("GoUpEleCar").Rewind
                  getpath("GoUpEleCar").Play
            end if
      end if
      Exit Sub
End Sub
```

Script Name: EleDoorB.ebs
Function: To control the other one of the elevator's doors in different circumstances. It is used only in center-load station simulations

```
sub task( obj as SlidingDoor )
      '
      'Open the door when ordered and ready
      if obj.Ordered = True and obj.Ready = True then
            'get the paths back to the first points, then play
            getpath ("OpenEleDoorBA").Rewind
            getpath ("OpenEleDoorBB").Rewind
            getpath ("OpenEleDoorBA").Play
            getpath ("OpenEleDoorBB").Play
            '
            'get open time
            Obj.OpenTime = Timer
            '
            'set properties
            obj.Open = True
            obj.Ordered = False
            '
            'open the car door
            dim EC as EleCar
            set EC = getEleCar("EleCar-1")
            EC.Open = True
            'set opentime for the car
            EC.OpenTime = Timer
```

```
        end if

        'Close the door
        if obj.Open = True then
              dim sigCurrentTime as single
              sigCurrentTime = Timer
              if sigCurrentTime - Obj.OpenTime > 5 then
                    '
                    'get the pathes back to the first points, then play
                    getpath("CloseEleDoorBA").Rewind
                    getpath("CloseEleDoorBB").Rewind
                    getpath("CloseEleDoorBA").Play
                    getpath("CloseEleDoorBB").Play
                    obj.Open = false
              end if
        end if
end sub
'
'EventHandling
Sub OrderedChanged (obj as SlidingDoor)
        '
        if obj.Ordered = True then
              'Get the EleCar info
              dim EC as EleCar
              set EC = GetEleCar("EleCar-1")
              if EC.Upper = True then 'if Car is on the upper floor
                    getpath("GoDownEleCar").Rewind
                    getpath("GoDownEleCar").Play
                    getpath("GoDownAvatar").Rewind
                    getpath("GoDownAvatar").Play
              end if
        end if
        Exit Sub
End Sub
```

Script Name: Trigger-1.ebs
Function: To let user invoke triggers, such as pressing a button to order an elevator. It is used only in center-load station simulations

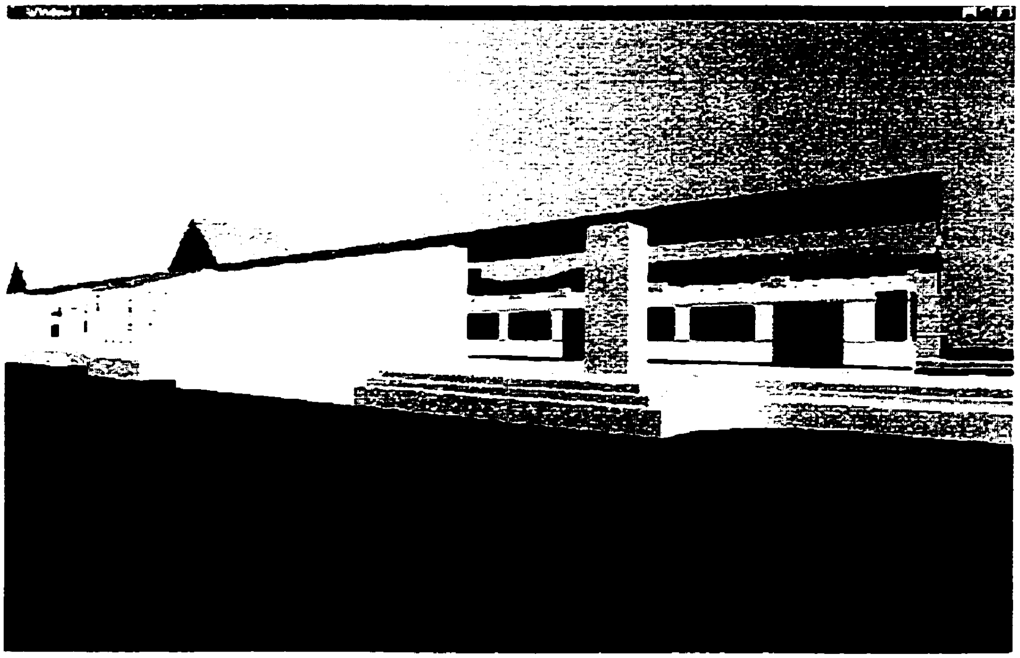
```
Declare Sub RotateDoor (obj as TriggerController)

sub task( obj as TriggerController )
        '
        'set a mouse
        dim m as mouse
        set m = getfirstmouse
        '
        ' set sliding doors
        dim SDa as SlidingDoor
        dim SDb as SlidingDoor
        set SDa = getSlidingDoor("EleDoorA")
        set SDb = getSlidingDoor("EleDoorB")

        '
```

```
	'if mouse is not down, check the mouse position and set
appropriate cursor stype
	dim MouseDown as Boolean
	MouseDown = m.MiscData and LeftHeld
	'
	if not MouseDown then
		'
		'was the mouse over trigger?
		dim WasOverTrigger as Boolean
		WasOverTrigger = obj.OverTrigger
		dim WasOverTriggerDoor as Boolean
		WasOverTriggerDoor = obj.OverTriggerDoor
		'
		'get mouse position
		dim Mposition as Vect2d
		m.getposition Mposition
		'
		'pickup the geometry
		set obj.TriggerObject = PickGeometry(Mposition)
		'
		'if a geometry was picked up
		if obj.TriggerObject is not Nothing then
			dim GeoTrigger as Trigger
			'
			'first test if it is within Trigger class
			set GeoTrigger = CasttoTrigger(obj.TriggerObject)
			if GeoTrigger is Nothing then
				obj.OverTrigger = False
				'
				'if not within Trigger, test TriggerDoor Class
				dim GeoTriggerDoor as TriggerDoor
				set GeoTriggerDoor =
CasttoTriggerDoor(obj.TriggerObject)
				if GeoTriggerDoor is Nothing then
					obj.OverTriggerDoor = False
				else
					obj.OverTriggerDoor = True
				end if
			else
				obj.OverTrigger = True
			end if
		else
			obj.OverTrigger = False
		end if
		'
		if WasOverTrigger and Not obj.OverTrigger then
			if getAvatar("Avatar-1").OnTerrian = True then
				GetMotionLink("MoveAvatar").Enabled = True
			elseif GetEleCar("EleCar-1").Inside = True then
				GetMotionLink("MoveAvatar").Enabled = True

			end if
			SetCursor("ARROW")
		end if
		if Not WasOverTrigger and obj.OverTrigger then
			GetMotionLink("MoveAvatar").Enabled = False
			SetCursor("HAND")
```

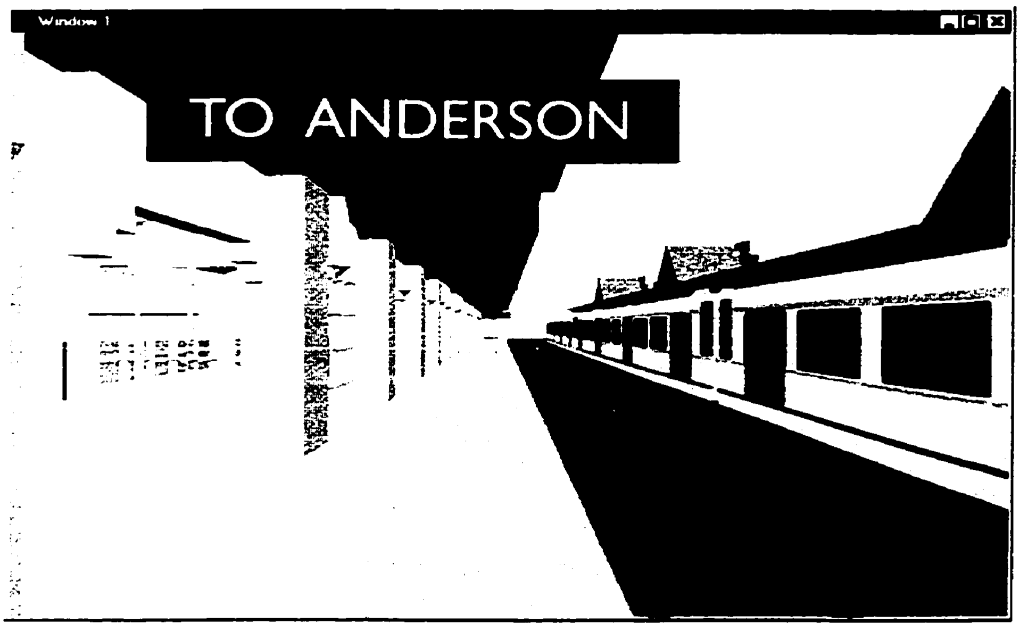
```
        end if
        '
        if WasOverTriggerDoor and Not obj.OverTriggerDoor then
            SetCursor("ARROW")
        end if
        if Not WasOverTriggerDoor and obj.OverTriggerDoor then
            SetCursor("HAND")
        end if
    end if
    '
    'click the trigger
    if m.MiscData and LeftDown then
        '
        if obj.OverTrigger = True then
            'change the open property of appropriate target
            Select Case obj.TriggerObject.Name
            Case "EleTriggerA"
                GetSlidingDoor("EleDoorA").Ordered = True
            Case "EleTriggerB"
                GetSlidingDoor("EleDoorB").Ordered = True
            Case "EleTriInsideUp"
                dim DoorObj as SlidingDoor
                GetSlidingDoor("EleDoorA").Ordered = True
                if SDa.Ready = False then
                    getpath("GoUpAvatar").Rewind
                    getpath("GoUpAvatar").Play
                end if
            Case "EleTriInsideDown"
                GetSlidingDoor("EleDoorB").Ordered = True
                if SDb.Ready = False then
                    getpath("GoDownAvatar").Rewind
                    getpath("GoDownAvatar").Play
                end if
            End Select
        else
            if obj.OverTriggerDoor = True then
            RotateDoor obj
            end if
        end if
    end if
    '

end sub

Sub RotateDoor (obj as TriggerController)
    dim strName as String
    dim D as TriggerDoor
    '
    strName = Right(obj.TriggerObject.Name, 2)
    '
    strName = "D" & strName
    Set D = GetTriggerDoor(strName)
    '
    strName = "Open" & strName
    GetPath(strName).Rewind
    GetPath(strName).Play
    D.OpenTime = Timer
```

```
          D.Open = True
          '
End Sub
```

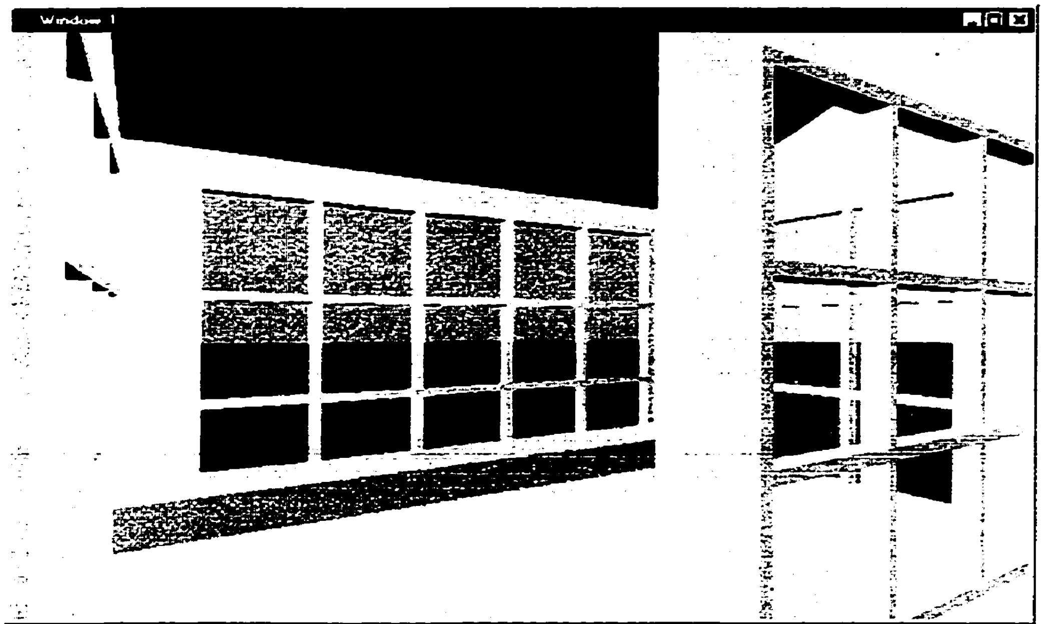
APPENDIX 4 VIRTUAL REALITY SIMULATION IMAGES



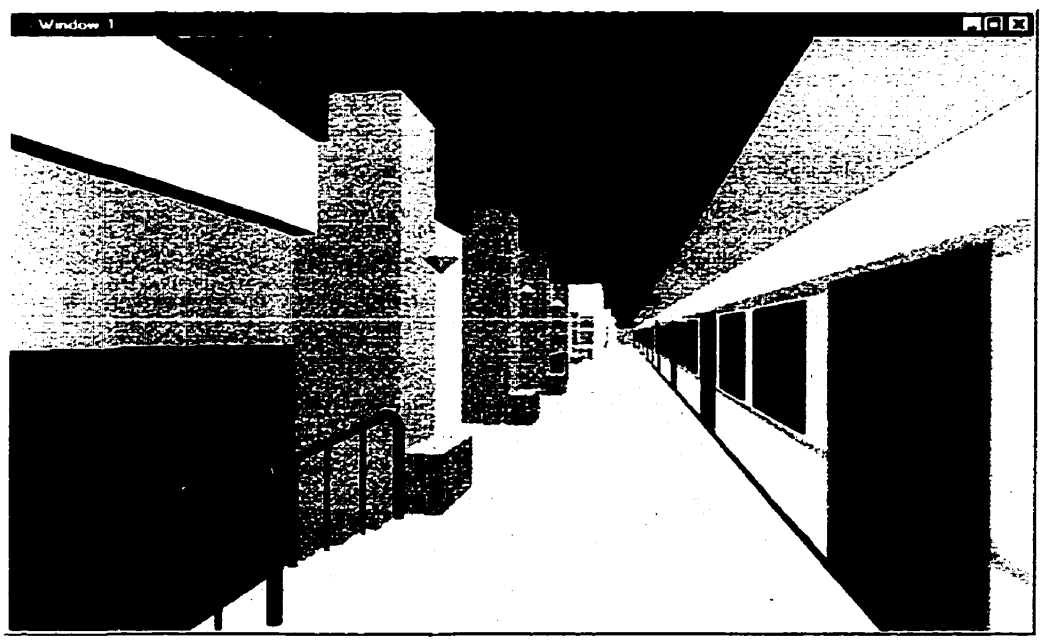
Start a Side-Load Station Simulation



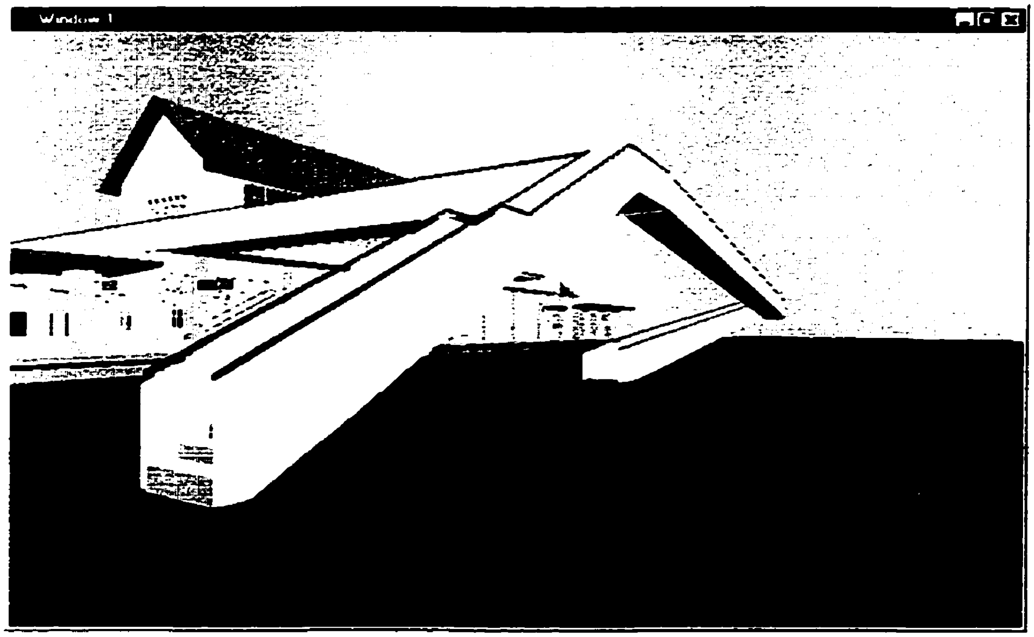
Signage of the Side-Load Station



A Kiosk (Enclosure) in the Side-Load Station

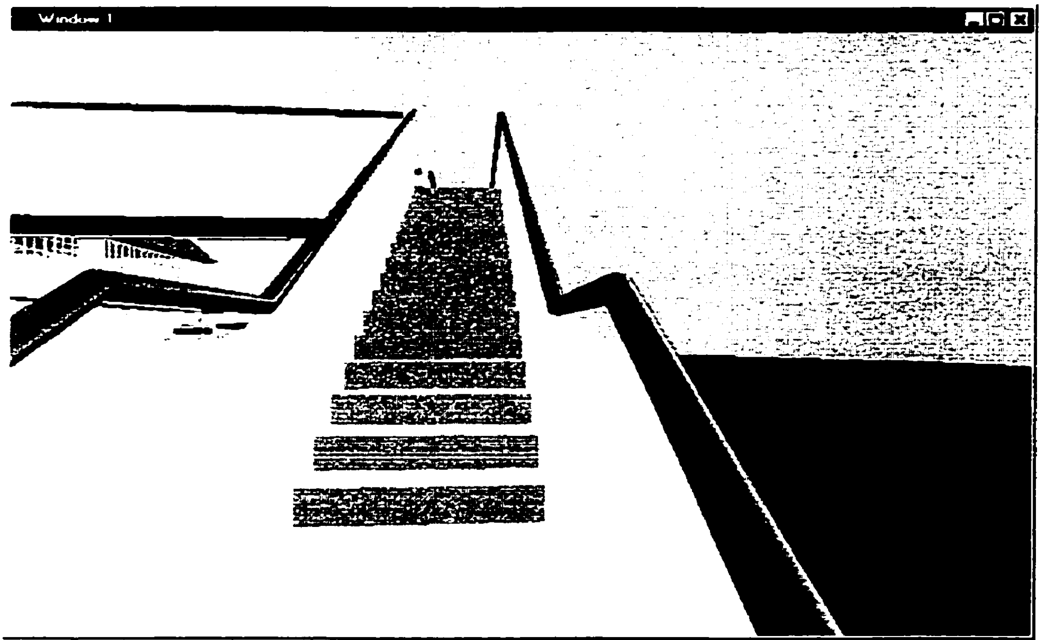


Another Platform of the Side-Load Station

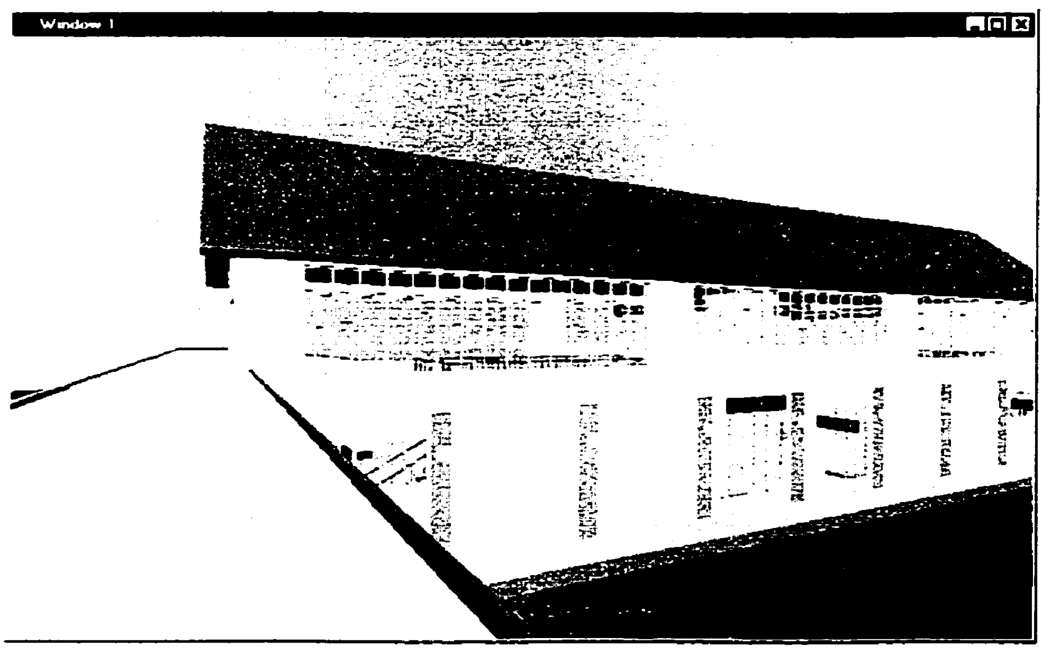


A Center-Load Station's Stairs and Ramp

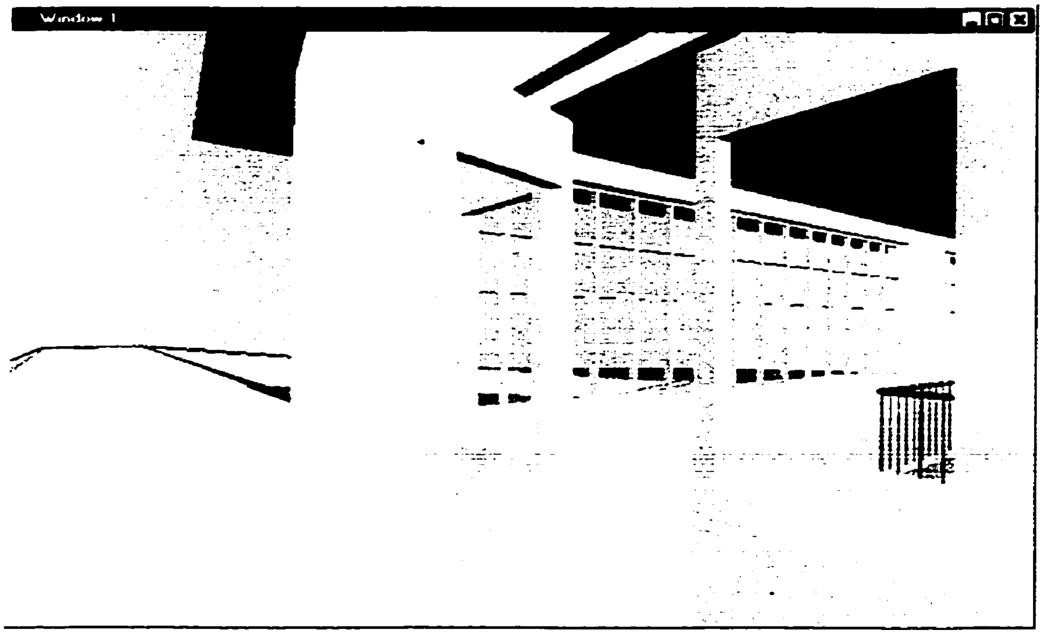
The Footbridge and Station Building



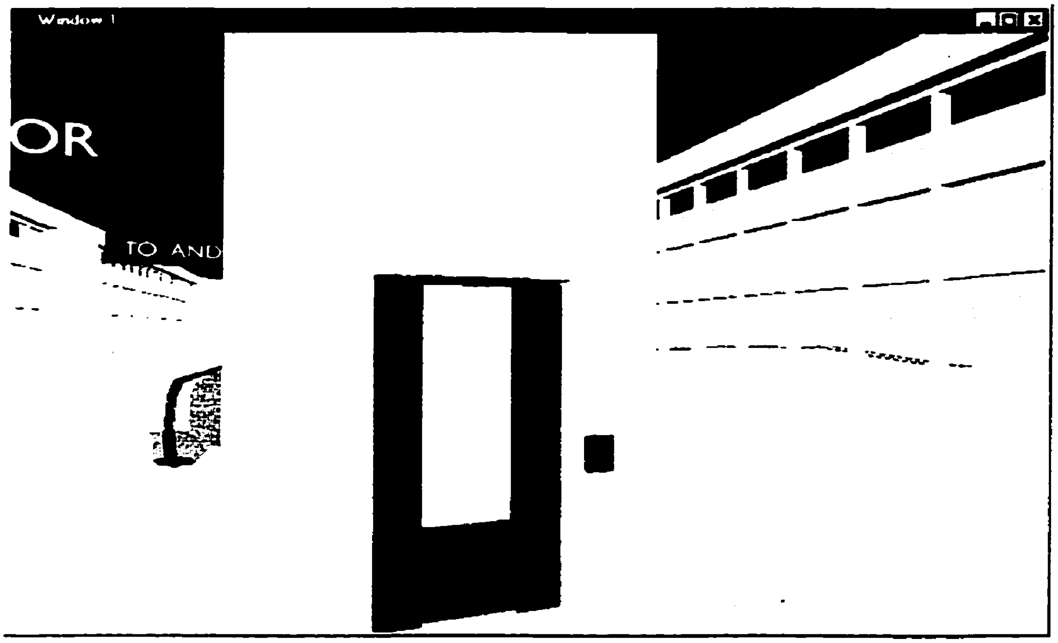
The Center-Load Station's Stairs



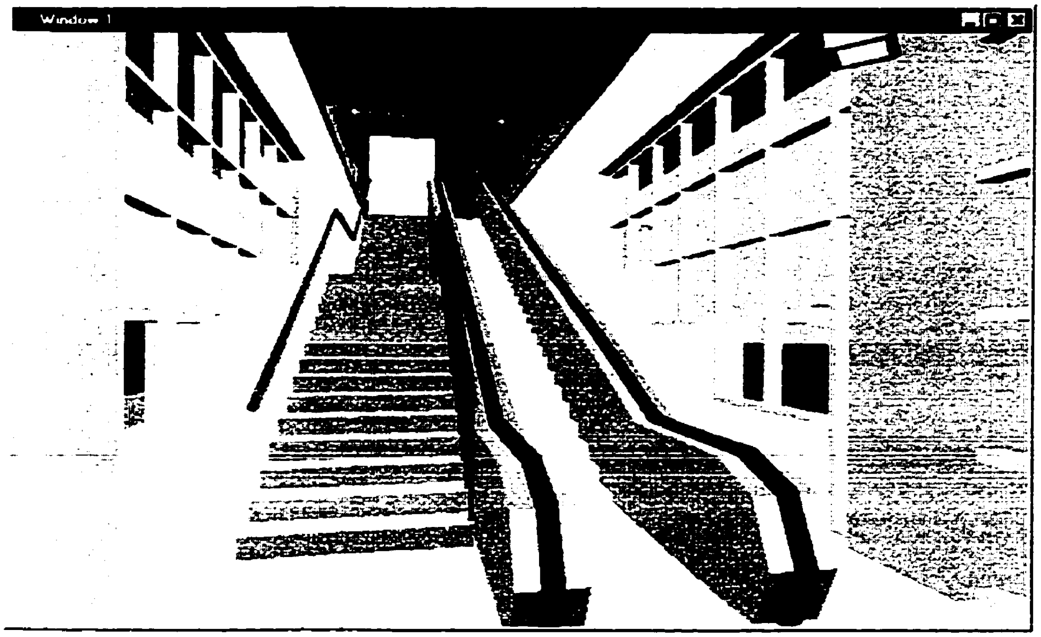
Walking on the Footbridge



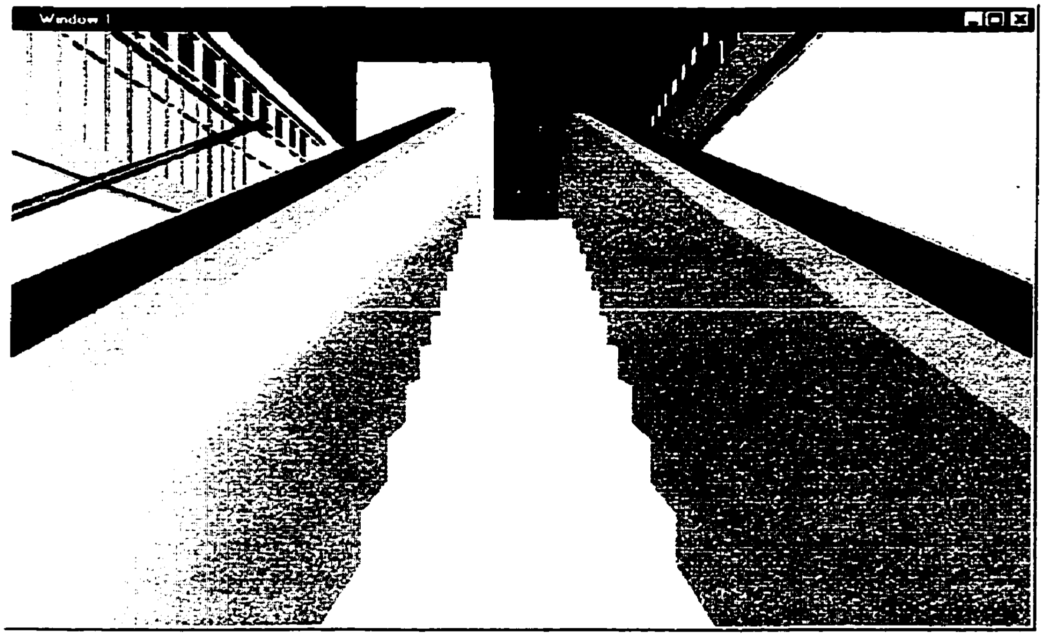
Opening a Door



Taking the Elevator

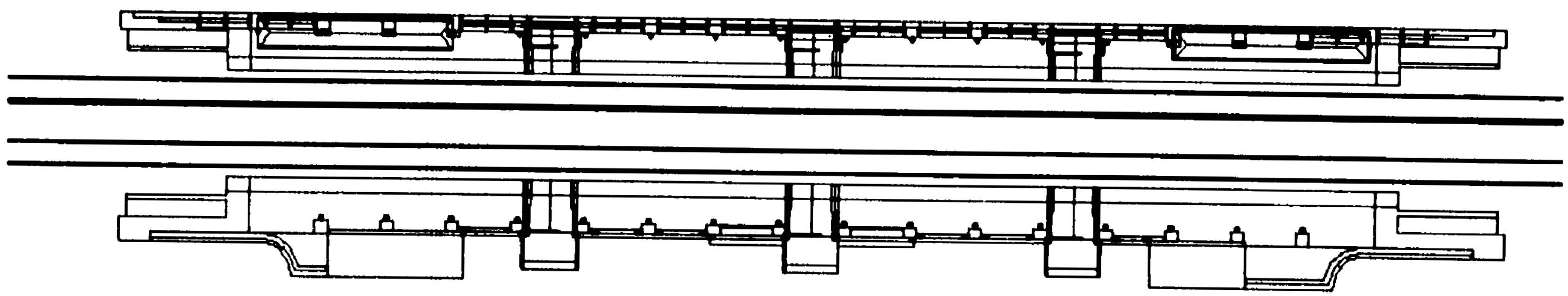


The Center-Load Station's Stairs and Escalator

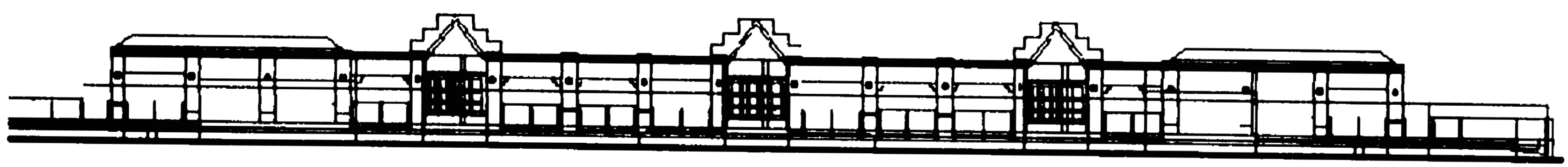


Taking the Escalator

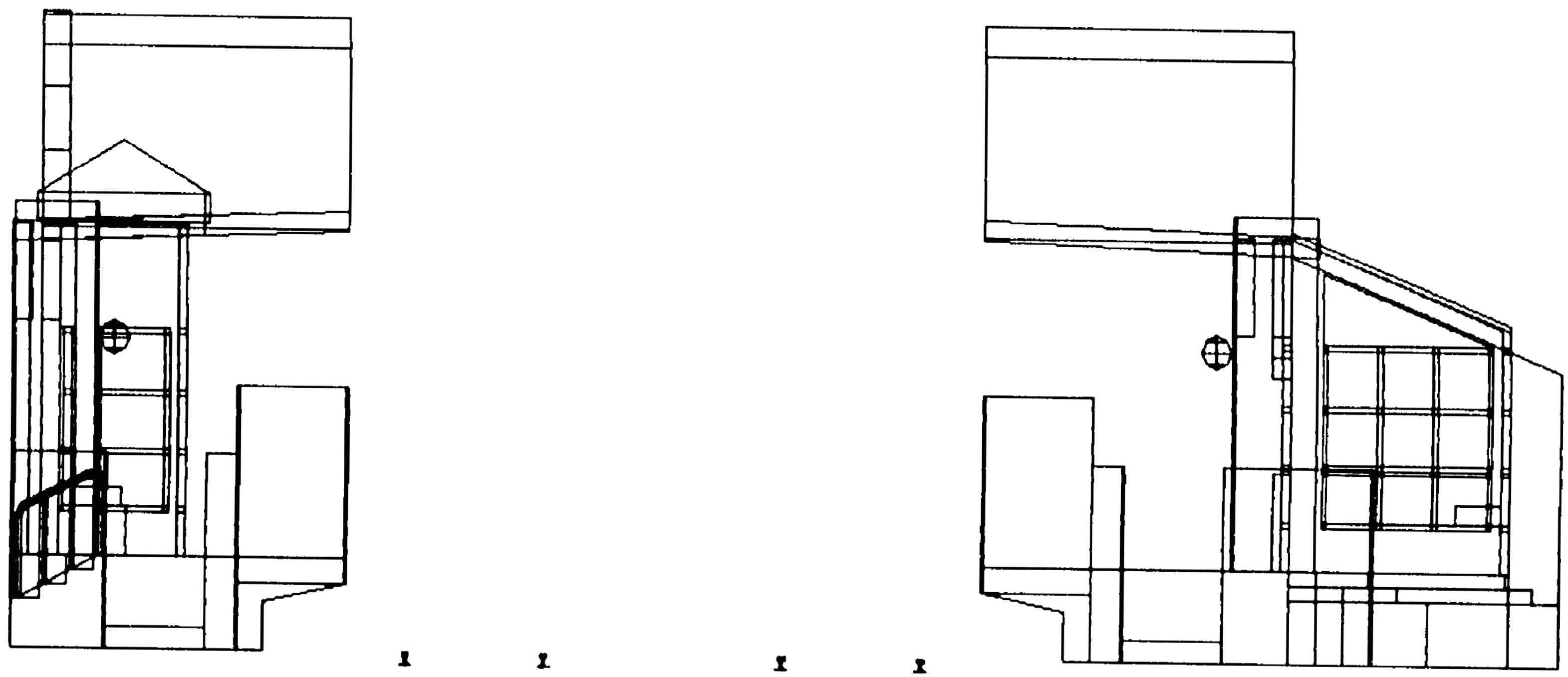
APPENDIX 5 CAD 3D MODELS OF LRT STATIONS



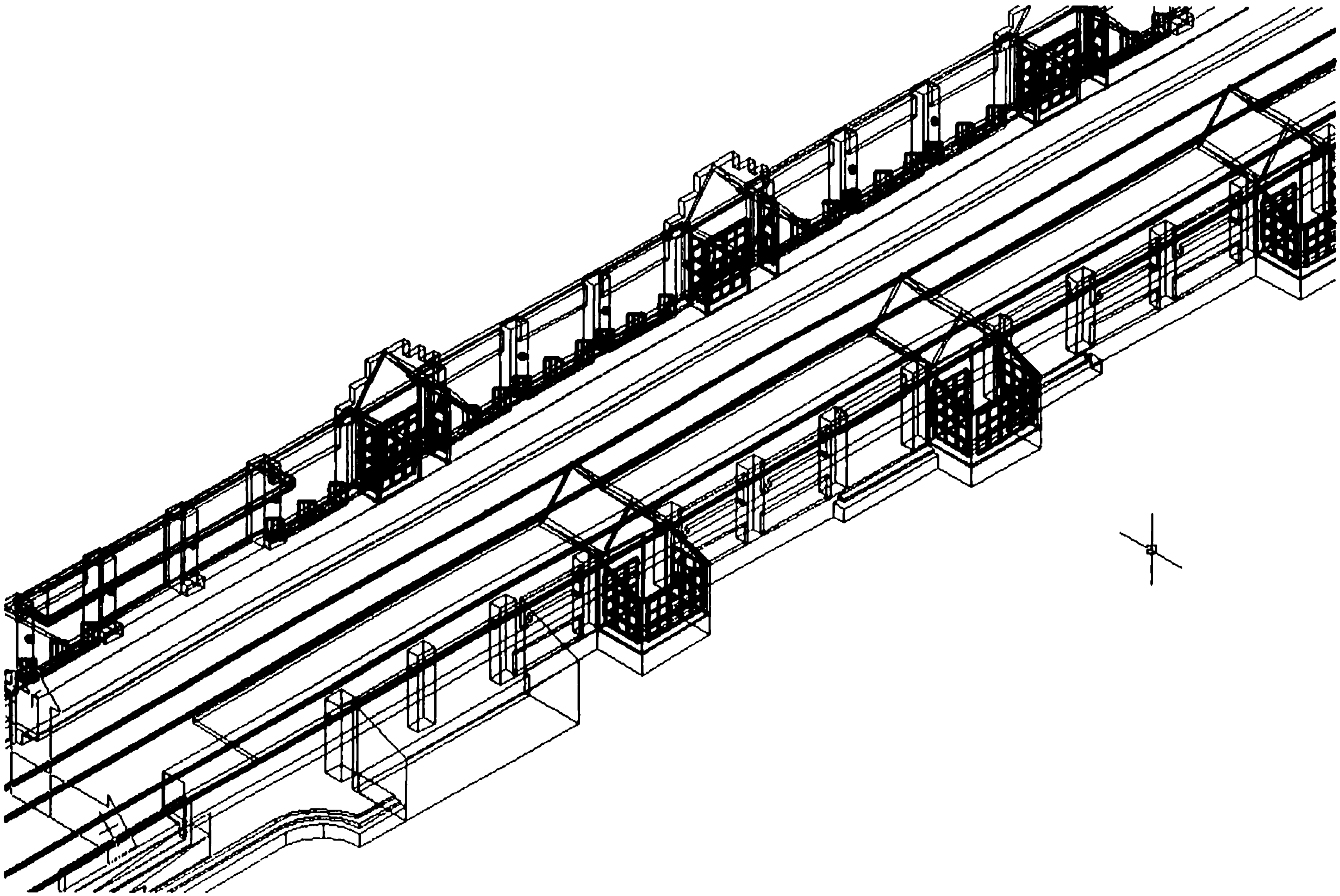
Plan of a Side-Load Station



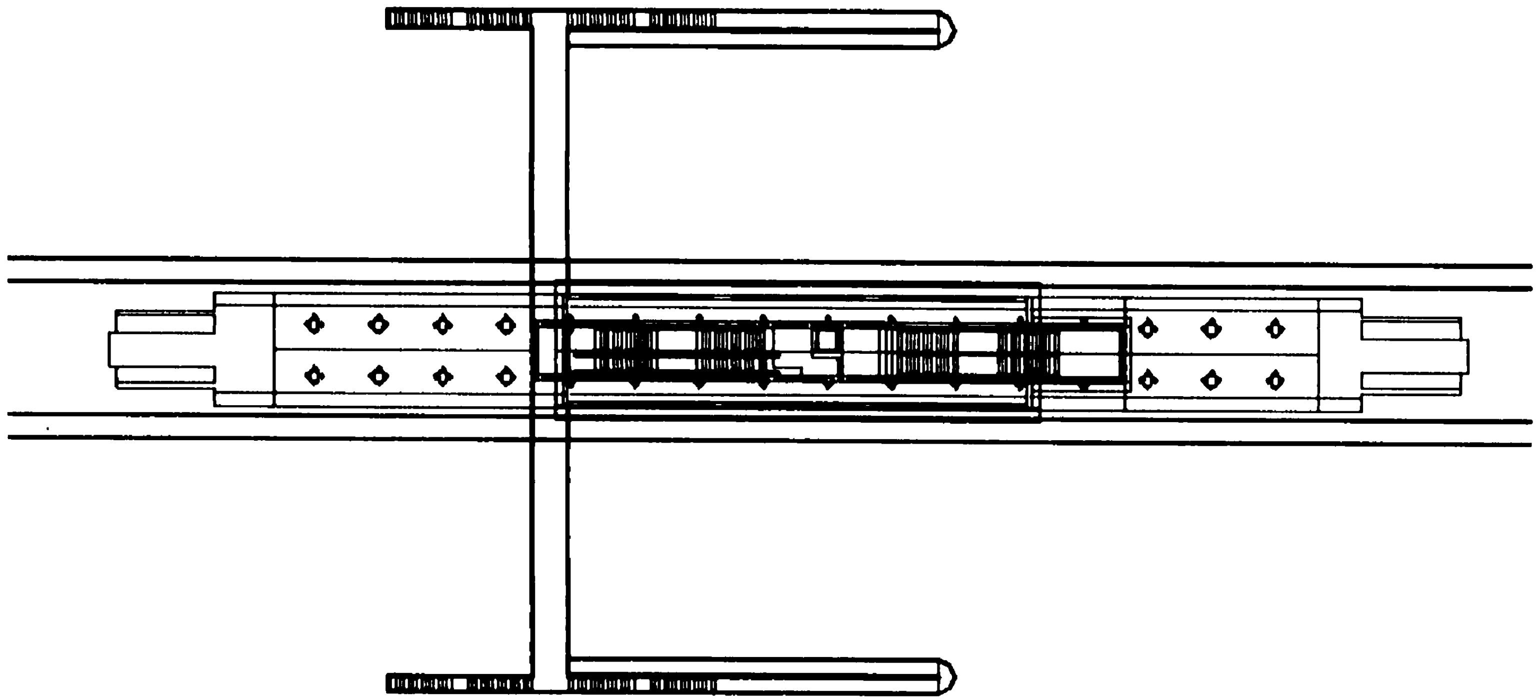
Front Elevation



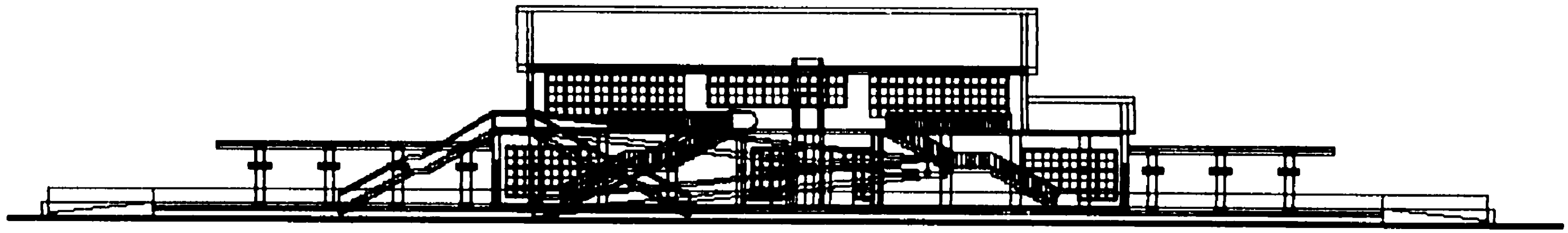
Side Elevation



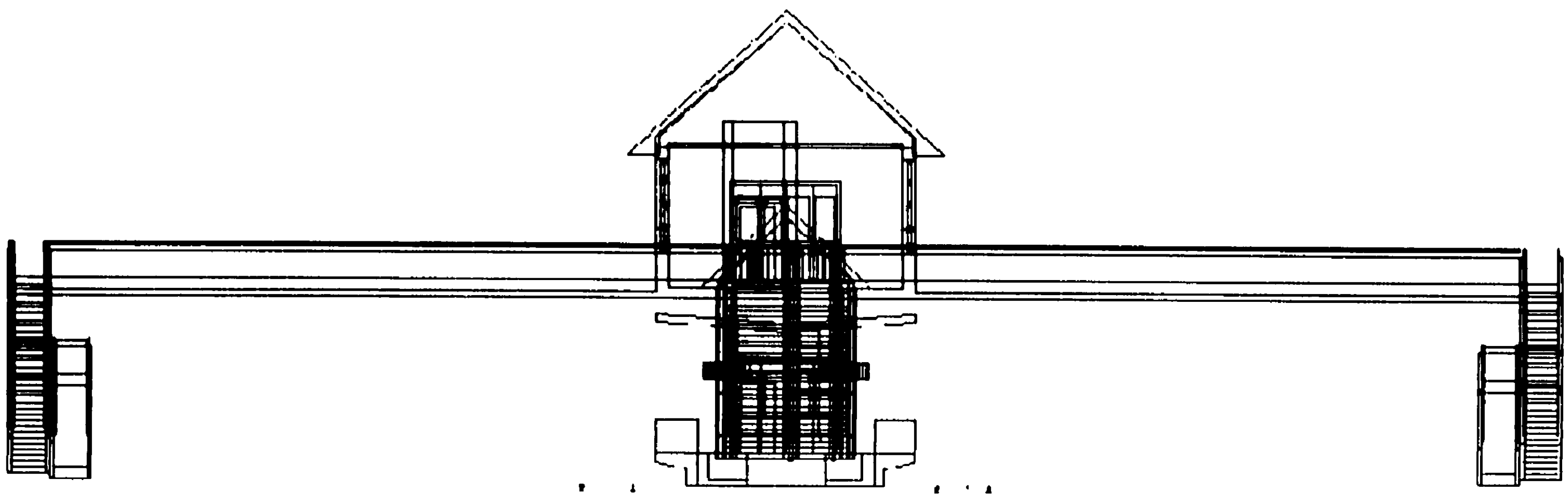
Southwest Isometric View



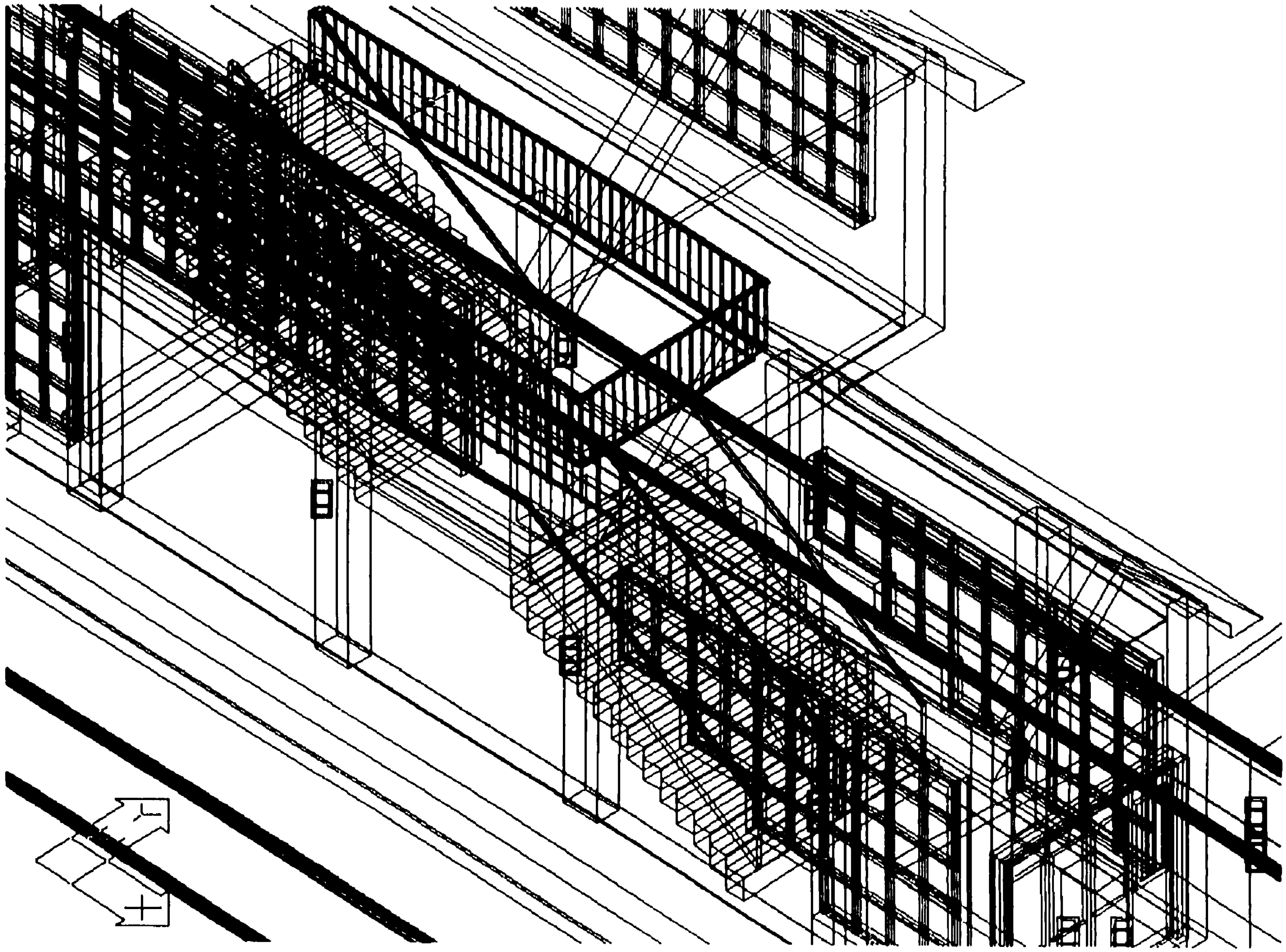
Plan of a Center-Load Station



Front Elevation



Side Elevation



Isometric View (Part)