

IMPLEMENTATION OF A DEMONSTRATION
DUAL-MODE TRANSPORTATION SYSTEM
IN AN URBAN CENTER

by

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ABSTRACT

The urban transportation problem is largely one of congestion-controlled expressways and chronic mass transit ills. The dual-mode vehicle (car or small bus) is an effort to combine the privacy and mobility of the auto, with the compactness and efficiency of transit, without the woes of downtown parking, congested local streets and clogged arterials. Dual-mode vehicles in the manual mode are driven normally on regular streets, while on the automated guideway (grade-separated) steering and speed control is achieved automatically by the vehicle and/or the guideway.

The type of dual-mode vehicle chosen for design study has dual guidance arms, which grip lateral guiderails for guidance, electric power pickup for on-board motors, and control signals for speed, switching and communications. Vehicles operate either entirely electrically or under combined ICE and small electric motor power. No batteries need be carried, and the vehicle modifications cost is about \$400 to \$700, in the range of the luxury options most buyers request or obtain on new cars.

Preliminary design, simulation and testing indicates that the vehicle is stable. A prototype vehicle has been modified, and tested 70-80 times on a 200-ft. straight track. Design concepts have been generated on the more advanced aspects of dual-mode, covering the full range of components from the guideway, vehicle modifications, stations similar in concept to transit stations, automated peripheral parking garages and exit/entrance ramps. An implementation strategy is developed for various demonstration stages and a demonstration route is suggested for Boston.

Thesis Supervisor : Dwight M. Baumann
Professor of Mechanical Engineering

DEDICATED to the Living Memory of....

.....GEORGE MASON, author of the Virginia Declaration of Rights and underdog advocate for the Federal Bill of Rights.

.....ALEXIS DE TOCQUEVILLE, remarkable foreign observer, analyst, and seer of the American scene.

.....FREDERICK LAW OLNSTED, far-sighted and enlightened planner of Boston's early park system and green space.

.....CLARENCE DARROW, blunt and caustic, humorist and pessimist; the non-conformist Ralph Nader of his day.

.....BUBBER MILEY, inventive cornet lead with the Duke Ellington band of the late 20s, expert at merging the subtle tonal phrase into the expressive whole.

.....BESSIE SMITH, Empress of the Blues, interpreting the intricate emotional shadings of life, love and liquor.

.....STAN LAUREL AND OLIVER HARDY, who made the antagonisms and conflicts of everyday life into a ludicrous crescendo of hilarity.

.....RICHARD WRIGHT, expressive Black novelist, realistic even to his own imperfections.

.....GEORGE ROESCH, guiding light of the Roesch-Talbots of the 1930s, who - in 1949 - transmitted his fascination in automobiles to a 5-year-old American boy.

.....CHARLES HILLIS KAISER, a father who with a minimum of words succeeded in teaching a son the value and practice of independent thought.

.....BERNARD FALL, an Expert in the true sense, with his expertise matching his reputation; possessor of an understanding of the past, critical analysis of the present, and predictions of the future of Asia -- landmark techniques for planners and analysts in all fields.

.....MALCOLM X, a fine example of A Man -- unafraid of his own sordid past and fearless of the future, willing to change his views and sacrifice his ego in the search for truth; a contemporary hero in an age of non-heroes.

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NOMENCLATURE

A	=	(a). Point A ; (b). Area
B	=	Point B
a	=	(a). Acceleration ; (b). $l - b$
b	=	Distance from rear axle line to Center of Gravity
d	=	distance
d_s	=	Slot Length
d_ψ	=	Lateral displacement at a switch
F	=	Force ; F_a = Force in arm
h	=	height
I	=	Moment of Inertia
k	=	(a) Spring constant ; (b). Comfort coefficient (c) constant
k_v	=	Fraction of G force from heaves & hollows
k_b	=	fraction of G force from bumps in guideway
l	=	wheelbase
m,M	=	Mass, weight N = normal force
p	=	pressure \bar{p} = power per vehicle
q	=	(a). Lateral measured displacement; (b) distance of seat from car centerline, measured laterally.
Q	=	(a). Vehicle Flow (b) Queuing Capacity
R	=	(a). Radius (b). Resistance
s	=	distance along guideway
t_f	=	Time to negotiate one quadrant (90°) of a curve transitional
V,v	=	(a). Velocity (b). Voltage

\bar{y}	=	$\frac{\text{length of second segment of transitional}}{\text{length of first segment of transitional}}$
α	=	wheel slip angle
β	=	guideway banking angle
$\bar{\beta}$	=	slip angle of car centerline relative to velocity
β_o	=	$\frac{\beta_{\max}}{0.89}$
γ	=	cornering power, \overline{CP}
δ	=	(a). Steered angle of front wheels; (b) Spring deflection
θ	=	Angle of guideway slope
λ	=	overall flow density of guideway
μ	=	coefficient of friction
ρ	=	(a) flow density ; (b) mass density (c) radius
σ	=	ramp length ; also specific density of material
ϕ	=	roll angle
ψ	=	heading angle, direction
ω	=	angular frequency
H	=	Heat
T	=	Temperature
L	=	Slot length (also d_s)

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Over the years, many individuals have contributed advice, work and information which have been used in this thesis. In the Fall of 1963 and Spring of 1964, design classes 2.732 and 2.731 at M.I.T. began the first studies of automated automotive vehicles and their associated guideways. Most of the work was performed by juniors from the class of 1965. In 1966, an interdisciplinary design group of students and faculty at MIT developed an overall transportation system for Boston which focussed on evolutionary automated transportation. In the intervening years, most of the dual-mode work at M.I.T. has been carried out under Prof. Dwight M. Baumann, initially under the general direction of Project Transport, headed by Prof. William Seifert, and later by the Urban Systems Lab of M.I.T., under the direction of Prof. Charles Miller.

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From the beginning, the dual-mode project has been largely

a group effort, and it is difficult to credit individuals with their contributions. William Zimmerman and William Hall took prime responsibility for design, fabrication and installation of the test guiderail at M.I.T. Phil Davis and Robert Tanner designed and worked on the test follower, with help from William Hall. Data on test car specifications (a Ford Mustang) were provided by Wayne Hamonn, Richard Shackson and Foster Weldon of the Ford Motor Company. K. Captain provided the initial analysis and calculations on power conductor sizing and vehicle dynamic effects, and William Zimmerman further refined these efforts in his Masters Thesis on guiderail design. Much of the artwork and sketches are by Scott Danielson, with E. Llevada helping on the final diagrams. Analysis of vehicle power requirements, guidance arm forces and control stability, speed control requirements, stations and guideway/ramp geometry have been the primary responsibility of the author.

A preliminary report was prepared in January 1970 covering most of the technical features of dual-mode systems, and the help of Miss Ann Iverson and Miss Debbie Etsten in typing (and the M.I.T. Graduate Student Council in providing facilities and a typewriter) is appreciated.

ORIGINS OF THE THESIS

This effort had its origins in a somewhat unusual concept : that in early 1968, the Mechanical Engineering Department would support the concept of a joint thesis in Mechanical Engineering

and Political Science. Such a "radical" idea now seems quite appropriate. While I must note the important role of Prof. Alan Altshuler (particularly in being a major activist in relating transportation to the political process) and to a lesser extent, Prof. Robert Wood and John Saloma, it is with some sadness that I cannot find more elements within political science as a discipline that have application to this thesis. Similarly, I cannot acknowledge (with one exception) a breadth of inputs from Civil Engineers, whose established role in transportation issues should make them a storehouse of vital information and incisive analysis. I regret that I find their traffic analyses and predictions somewhat faulty and their knowledge of vehicles minimal, that their views are too close to the highway Establishment and too ignorant of community values. The primary exception has been Prof. John Clarkeson, whose experience and willingness to give time and patience to students are unmatched in today's times of research-professors-too-busy-to-teach. He not only comprehends the practicalities of highway design -- he has come to know the political process well.

Special mention must be made of the Mechanical Engineering Department and its major function in the highly flexible process which made this thesis possible. Although the depth of transportation expertise within the department is not extraordinary, there did exist a design division, with members such as Prof. Dwight Baumann who are receptive to studies in the area of engineering/society

interactions. Within the department, there did exist the flexibility to allow a student to engage in such a rash and pioneering effort of venturing into the domain of political science -- a flexibility which belies the traditional departmental image of stuffiness and provincialism. Most notable was Prof. Warren Rohsenow, who demonstrated openmindedness and the true experimental spirit right from the beginning, offered cooperation from his office and, most important of all, never gave the impression that the Department and its rules were ever getting in my way. This liberating influence was crucial in my early investigations into many areas of political science and urban studies and in becoming more of a generalist rather than more of a specialist as I proceeded through my graduate education. This flexibility and particularly the understanding of Prof. Baumann extended to my considerable involvement as editor of the graduate student newspaper, the *Catalyst*, with its roundabout payoff for this thesis in terms of writing clarity and expressiveness. In sum, I have been given plenty of rope, and I hope that this thesis is evidence that I did not hang myself.

A final word of appreciation must be given to an unusual source vital to my understanding of Boston, its traffic movements, its congestion, its developing plans and construction. Always faithful was my forlorn motorcycle, a 1966 Honda S-90, which provided on- and off-the-road mobility for on-site inspections, extending the range of a walking tour, yet without the surface analysis of a car tour.

INTRODUCTION

"States which analyze only a sample of intrastate payments should multiply each figure in the resultant sample distribution obtained for columns II, III, and IV of section B by a factor equal to the ratio between the total number of intrastate first payments issued during the quarter and the total number of intrastate first payments found in the sample, and should multiply each figure in the sample distribution obtained for columns II, III, and IV of section C by a factor equal to the ratio between the total number of intrastate second and subsequent benefit periods compensated during the quarter and the total number of second and subsequent benefit periods found in the sample, thus deriving and reporting an estimated distribution of the total number of benefit periods covered by intrastate payments issued during the quarter."

-- *the explanation by a statistician to cooperating State agencies on preparing a report of their activities.*¹

"Baroque can be regarded as a countergradient or as a counterthrust or as a return to balance and classical poise after the onset of visual specialism and mannerist fragmentation. If the entire development of perspective is considered as a steadily developing gradient or environmental stress in the Western world, then the virtuoso effects of the mannerist in literature and in painting alike can be seen as a kind of faltering of that gradient."

-- *Marshall McLuhan*²

"REPRESENTING TRANSPORTATION TECHNOLOGY

Transportation can be represented as a production process, in which different combinations of resources can be applied to produce transportation. We characterize transportation as a production function Φ in this way :

$$\Phi (C, L, V, T) = 0$$

where T = specification of transportation system options

V = volume of flows actually moving through system

L = level of service provided....

C = resources consumed ~ "costs" incurred....

In general each of these variables is vector-valued ; it has many components....The function Φ describes a surface in (C,L,V) space,

for given T....the demand $V = D(L,A)$, where A is a description of the socio-economic pattern of activities...."

-- LECTURE NOTES : MODELING TRANSPORTATION TECHNOLOGY,
Marvin Manheim, Department of Civil Engineering, M.I.T.
October 1969.

* * * * *

The above three quotations represent styles of analysis and writing which I shall *not* seek to emulate in this thesis. Occasionally, the verbiage is so baffling one doesn't know whether something significant has been said or not. If I were to write in the above style, I would encourage and warrant a response similar to the memorable comment by Sir Winston Churchill to a young writer : "Thank you for your manuscript. I shall lose no time in reading it."

OBJECTIVES AND GROUND RULES

The main objective of this thesis is the communication of simple concepts in a simple manner and of complex concepts in as simple, clear and straightforward syntax as possible for a dual-mode system. All too frequently in the past, a doctoral dissertation has served as an excuse -- even an obligation -- for exasperating pedantry and confusing obfuscation. Such writing has been aimed at an existing over-specialized group of experts, instead of seeking to extend the significance of one's research and discipline to audiences in different fields.

This thesis is not predicated on any special faith in conventional political science or sociology. Although it probes

familiar issues, it adheres to no formal discipline nor to the guiding declarations of intellectual potentates and associated demigods of varying degrees of intellectual fiber. Value judgments will not be avoided and often will be stated. I am prepared to defend them, although a full defense within this thesis would result in too many diversions and detract from the main purpose : the presentation and analysis of certain positive transportation planning concepts for the coming years. There will be no effort to hide behind sociological statistics, computer programming analyses (either as a crutch or to substantiate weak hypotheses), or quotations from the Masters of the Urban Field.

This is not to say that the effort lacks discipline, rigor and a reasonably structured approach. Variations on past techniques are made not because the old is necessarily bad or stale, but rather in the expectation that some improvement in analysis, planning sensitivity and insight can be gained by appropriate deviations from traditional academic and professional byways. Ideally, the reader should develop an intuitive sense of the operation, size and scope of a dual-mode system and should be impressed by what he understands, rather than by what he does not. Given the complex subject matter and time limitations, this goal may not be realized. Like Pascal, I believe it was, who apologized to a friend for writing such a long letter "because I did not have time to write a short one," I apologize for any sections of this thesis which appear unnecessarily complex or confusing, because I

did not have time to make them clear and concise.

SCOPE OF THE THESIS

This thesis is intended to be a comprehensive introduction to guideway systems involving self-contained dual-mode vehicles. It is not a detailed technical report describing all engineering work to date, nor an account of all the logic of design decisions. It is an attempt to outline major options and decision philosophy, describe an overall system and suggest elements of an implementation strategy.

One might well respond critically : "Another Buck Rogers' scheme?" or "More hardware that people won't accept and won't pay for." Dual-mode will be and has been criticized in these terms. One of the difficulties in presenting new concepts of transportation technology has been the activities of past gadget advocates engaged in mythmaking activities on behalf of exhilarating but unworkable devices. Further complicating the situation are the publicity entrepreneurs who trumpet virtually every new bug-ridden concoction of laboratory hardware as the Second Coming of the Technological Christ and the Ultimate Nirvana for the readers of *Popular Science*. Everyday practical difficulties of implementation and operation are underestimated as inevitable inaction is the byproduct of this Mythmanagement of New Technology.

This cycle of myth piled upon plan, but without implementation, has aggravated Robert Wood, who, in referring to the stalled goals

for housing, noted :

It is as if this country is doomed to aspire to one impossible dream after another, without even taking seriously the effort to make at least one dream attainable. Increasingly the American mood seems now one of a temptation to talk, to pass legislation, to beat the drums for new policies -- but never, never to act. Increasingly, environmental escapism appears one way in which we submerge our present responsibilities and obligation."³

For the above reason, this thesis extends its focus from hardware conception to political implementation, in particular the realities of present Boston. Moreover, it changes and merges "environmental escapism" into environmental design relevance for the city and its future transportation systems.

Implementation itself will not be easy, and the pitfalls are many. Admittedly, dual-mode systems are not without their difficulties and uncertainties. Whether the problems arise in vehicle control, switching reliability, funding, labor relations, or a public and taxpayers' revolt against technology *per se*, the subject matter is riddled with unforeseen stumbling blocks as well as perceived design and political challenges. Similarly, there are likely to be unexpected allies. This thesis may seem too straightforward and implicitly optimistic in what it seeks to do. May others follow on in presenting critiques, analyses and further design.

SUMMARIES OF CHAPTER CONTENTS

Chapters 1, 2, and 9-12 can be read by a general audience. The remainder can be read or skimmed by one of average engineering skills, although the chapter summaries are intended as general reading. Additional technical data and test track descriptive material is included in the appendices.

CHAPTER 1. THE URBAN TRANSPORTATION PROBLEM.....What is it?.....

the decline in rail transit....inadequacy of highway systems
....Example : deficiencies of the Boston Inner Belt Plan....
Environmental factors : air and noise pollution, Chinese Wall
effect, social factors, homes, jobs....anti-highway protest
and the revolt against the car....evaluation factors and
restated priorities....other possible solutions: better
transit....why automation?

CHAPTER 2. INTRODUCTION TO DUAL-MODE CONCEPTS AND OPERATIONS

(broad methods of operation; design analysis in later chapters)
....dual-mode as part-auto, part-transit....types of
automated vehicles....methods of operation -- a typical trip
....general design aspects of self-contained vehicles....
type of motive power and guidance....advanced systems

(Chapters 3-5 discuss the three elements of CONTROL of automated
vehicles : steering/guidance, switching, and speed/headway).

CHAPTER 3. VEHICLE GUIDANCE AND HANDLING....active and passive systems....forces on vehicles....principles and designs for active guidance.

CHAPTER 4. SWITCHING, GUIDERAIL AND GUIDANCE ARMS....guidance during switching....rail shapes....design of follower....arm design and actuation.

CHAPTER 5. VEHICLE/SYSTEM POWER AND SPEED CONTROL....motor drive arrangements....acceleration power requirements.... principles and methods for speed control....braking.... signal pickup and distribution.

CHAPTER 6. GUIDEWAY STRUCTURES.... comfort requirements....maximum guideway curvature and banking....guideway elevations and structural design....parking garages....aesthetic aspects.... overall guideway impacts on local communities.

CHAPTER 7. MANUAL/AUTOMATED TRANSFER AND SAFETY FACTORS
Entrance and exit procedures....takeover and relinquishment of automatic control....emergency situations : mechanical malfunction.... rescue and removal of stranded vehicles.... emergency repair and access by emergency vehicles.... policing, vandalism....insurance and liability aspects.

CHAPTER 8. GUIDEWAY STATION DESIGN AND PEDESTRIAN CIRCULATION
....Vehicle flow through stations....ticket and fare processing....requesting vehicles....pedestrian movements and the intermodal interface....station size & aesthetics.

CHAPTER 9. COST ESTIMATES OF SYSTEM COMPONENTS....R&D time and dollar estimates : dual-mode vs. transit, buses, highways
....possible economies in mass production.

(The final three chapters attempt to deal with the political and strategic questions of implementing a demonstration system).

CHAPTER 10. GENERAL DUAL-MODE IMPLEMENTATION STRATEGY....EXISTING Highway power structure and interests....Highway Trust Fund
....Financing options and lessons of the past....COMSAT.... SST....BART/MBTA....Role of DOT in funding the demonstration developing dual-mode support....likely opposition....

....community design role....advocate planners....policies and techniques of staged demonstrations.

CHAPTER 11. A DEMONSTRATION SYSTEM FOR BOSTON

History of the city & its highway/transit plans....areas needing service....primary guideway demonstration links.... station locations....growth possibilities....relation to future highway/transit plans....phasing of services.... demonstration system costs....services and impacts.... form of proposal.

CHAPTER 12. CONCLUSIONS AND EVALUATION

Tentative conclusions are drawn relating to technical feasibility, chances for political success, additional uses for bus use and airport access and the implications of success or failure. More difficult to predict will be the public response, particularly in today's troubled world and with public ambivalence over technology.

* * * * *

CHAPTER 1 THE URBAN TRANSPORTATION PROBLEM : POSSIBLE SOLUTIONS

In 1800, a stagecoach journey of 800 miles took several weeks and cost the early American traveler as much as \$250. Given the historical developments in transportation technology, how can one complain about the quality of urban mobility? Apparently, people's mobility needs are never satisfied, although the difficult task for the traffic designer/analyst is the determination of how much mobility is wanted, how much is really needed, and what happens when our expectations are not met by the transportation system.

The problem is larger than transportation alone -- it includes national and social goals for the use of leisure time, as Will Rogers slyly noted forty years ago¹ :

Every invention during our lifetime has been just to save time, and time is the only commodity that every American, both rich and poor, has plenty of. Half our time is spent trying to find something to do with the time we have rushed through life trying to save. Two hundred years from now history will record : "America, a nation that flourished from 1900 to 1942, conceived many odd inventions for getting somewhere, but could think of nothing to do when they got there.

We are faced today with the ambivalent nature of the automobile, and its supporting structure of highways. The value of an expressway lies in its ability to furnish mobility for many purposes : goods as well as people, for social, recreational, business and other needs (on a flexible schedule) as well as the

repetitious commuting journey to work. Modern roads serve a wide ranging multitude of vehicles, from motorcycles, sports cars and compacts to limousines, delivery trucks and semi-trailers. On the negative side, highways become congested arteries spewing pollution and floods of vehicles into urban communities, contributing to the parking glut, local street congestion and traffic fatalities -- in general the disease of Urban Autosclerosis. Whatever the sentiments about cars in general, there can be little disagreement that America is heavily dependent on the auto as fundamental transportation and also suffers from some of the consequent side-effects (Table 1-1, 1-2).

* * * * *

TABLE 1-1. AMERICA'S DEPENDENCE ON THE AUTOMOBILE

- * Of the over 125 million persons presently living in metropolitan areas, almost 53% live in the suburbs -- over 65 million.
- * In recent years, transit has decline & greater reliance on highways has developed -- 8 out of 10 employed people use their autos. 94% of person-mile travel is by auto, 4% by bus, 2% by rail (nationwide)
- * 80% of all families (nationally) own at least one car; one in three owns more than one car. 80% of all people old enough to drive have a driver's license. About 60% of all women, 15 yrs. and older are licensed to drive, and about 91% of all men.
- * In 50 years, since 1920, the U.S. population has risen from 110 million to 205 million and the vehicle registrations have grown from 9 million to 110 million (a vehicle increase rate six times that of population); gasoline consumption rose from 4 billion to 90 billion gallons
- * Passenger car sales have risen from 2,787,000 in 1930 to 9 million in 1970.
- * Total vehicle miles traveled rose from 458.2 billion in 1950 to 800 billion in 1963, a 75% increase in 13 years.

* * * * *

TABLE 1-2. PROBLEMS ASSOCIATED WITH AUTO-ORIENTED TRANSPORTATION

- ** AUTOS : peak hour congestion, time delays, dollar risks and operating costs, air and noise pollution, breakdowns, parking difficulties, cost & inconvenience; land use and parking lot consumption; psychological strain and frustration; accidents; insurance; poor service
- ** HIGHWAYS : land consumption and housing/business displacement; Chinese Wallbarrier; favoritism to certain classes, groups and businesses; inaccuracy and uncertainty of highway design; traffic handling and distributional failures on expressways; opposition to new highways and highway improvements; ecological damage; variation in financial and political support & inflation; permanence of many roads after they become obsolete; unsafe roads and too much access for illegal drivers; too much time spent on design, study and review so that Master Plans quickly become outdated.
- ** DRIVERS : variability and unpredictability among different drivers; inconsistencies as a function of mood, drowsiness or drunkenness (out of 1969 highway toll of 56,400, drunken driving was responsible for 28,000)
- ** GENERAL SYSTEMS PROBLEMS : heavy peaking of flows during rush hours -- average expressway designed for peak traffic, or only 20 hours per week, while remaining 148 or 88% inefficiently underutilized; highways largely to blame for decline in transit; multiple political & planning jurisdictions; patchwork of highways, airlines & transit and difficulties of fully utilizing park-and-ride facilities; development of strong bureaucracy and coalition of interest groups that opposes major change in urban transportation thinking and design.

In many cities -- Boston, Chicago, New York -- more vehicles are being moved in and out of the core CBD each day, but fewer people. Between 1948 and 1956, New York City took in 36% more cars per day, but 375,000 fewer people. In Boston, the number of persons crossing into Boston proper declined from a total of 1,767,747 in 1938 to 1,650,246 in 1964.² The average vehicular speed in New York is 13 mph and decreasing and city cars are idling at least 1/3 of the time.

An unnerving Expectation Gap is created by 300 horsepower Detroit Iron crawling erratically in "creep-and-beep" traffic at speeds of 3 to 5 mph. The economic indirect effects become very important in terms of lost manpower, peace-of-mind, productivity and accidents that American cities have inflicted upon themselves through the medium of traffic congestion. One critic has observed that no longer can life be divided among the three areas of work, sleep and leisure; there is now a fourth category -- time spent sitting in vehicles becalmed amidst the bottlenecks. The day may come when businesses and industries not part of the so-called "highway lobby" will demand that services be improved and controlled above their present chaotic state. Through declining business profits due to transportation losses, the effective push may come for improved urban mass transit.

Unfortunately, transit is not without its own problems. Between 1945 and 1970, rail and bus transit riders dropped from 23 billion to 8 billion per year, while equipment grew older, service poorer, fares higher and system deficits unmanageably

out of control. Despite the "subway" image of transit, eight out of ten transit vehicles are buses, and hence highway dependent. A combination of backlash against desegregation, vandalism and poor maintenance has created a public image of the bus which is far from positive, connoting a crowded, lurching, dirty, noisy, uncomfortable rattlebox which shows the evidence of graffiti, seat-slashing and cigarettebutts. In contrast to the red London double-decker bus, the American bus is totally without personality, fun, and that crucial element of charm.

Rail transit continues to operate below expectations. Crowding and frequent station spacing lowers the average speed on the Chicago transit lines to 8.9 mph. Subway stations in America are almost always dirty, dismal and deteriorating and doubly without charm. From entering turnstile to uncomfortable seat (for those lucky enough not to have to stand), the experience is usually unaesthetic and ungracious for all but the most hardened rail fan. The noise, the uncomfortable ride, the stops and changes with long walks, waits and poor connections combine with a notable lack of privacy to create a breed of transit riders who are grimly resigned and unenthusiastic to their mode of travel.

In contrast to the "dynamic" and vigorous industries relating to automobile and highway operations, transit companies -- particularly Boston's MBTA -- propagate agonizing vibrations of bureaucratic senility, backwardness, a public-be-damned-because-we-don't-care

attitude about service, plus a union/management morass which is more ingrown and seemingly immovable than the operations of the U.S. State Department. It is little wonder that more than 250 transit companies have discontinued operations in the past 15 years, but all the more tragic that many small cities and suburbs find themselves isolated without transit or passenger rail service, and large cities must shoulder spiralling deficits by taxing themselves through higher fares and property taxes.

The basic transportation problem is a conflict between the desire to devote space and environment to buildings and parks on the one hand, and on the other, to provide access space from, to, through or around these public facilities. This is truly a question of urban priorities, and not simply a matter of hauling people and goods around more quickly and economically. Because of the heavy economic interest in transportation (20% of the GNP) and the long neglect of our cities, the urban transportation problem has always been defined in transportation terms ("a level of service unsatisfying to the expectations of the transportation user."). The crux of the issue centers on the possibility of deciding that these user expectations will be reduced simply by systematic refusal to promise official response to every "stated need" by transportation users. In other words, total demand will not be met and we will not even try to meet it unless this goal can be achieved without sacrifice of other major urban or social objectives. Highway planners have continually

sought to answer every demand, while transit companies ignore not only demand but also values, other than getting their existing rolling stock to stagger through another day without major breakdown.

WHY EMPHASIZE TRANSPORTATION?

Although transportation is 20% of the GNP, the average family spends only about 7% for transportation, compared to 26% for housing.³ Are we spending too much time worrying about transportation and not enough about people, homes and places? In fact, the problems are all interrelated -- witness the concern for people and structures in the New Boston, where massive new office buildings are erected with little thought for access and parking, with the evening rush hour becoming a purging process of opening the human flood gates and disgorging a skyscraper's capacity of officeworkers onto crowded local streets, sidewalks and transit facilities. .

Transport is a part of the urban fabric -- older stable communities value their streets almost as much as their homes. Mobility channels should connect the component parts of a city and help them to work, while respecting the human capacity of certain spaces and the reasonable needs for privacy and peace of mind. The value of property is nil, if access is inadequate. Access becomes an obvious and critical control variable which must be considered in the overall process; otherwise it will be controlled by those

who value access only.

The central area of a city can be viewed dynamically as adopting the role of a giant switchyard. Three functions -- business/recreation, vehicle storage, and traffic interchange -- all compete for the same space, and the pedestrian is often lost far behind in the shuffle. This concentration is not a matter of "too many people being in one place" and hence leading to the utopian cop-out of decentralized cities and New Towns. People can live densely and compatibly -- they exist very happily in many sections of Cambridge having incredibly high building density (although not high-rise) while many less dense areas from slums to suburbs and small towns are far less satisfactory living areas. The most important factors are not density, but the quality of life and community -- and the positive/negative impacts of transportation are an important contributing factor.

The goal of this thesis is to plan for an appropriate transportation future for a dense city, namely Boston. The challenge will be to find a plan which is responsive to urban goals, rather than the rigidly confining impediments of highly complex, structured and systematized Master Plans, which often lead to the implementation 20 years later of concepts which were probably obsolete when the plan was developed. Boston's Central Artery as an example of this classic process will be discussed later in this chapter.

THE GROWTH OF CONGESTION
AND
THE FAILURE OF PREDICTIONS

Especially in post-war years, autos and highways have defied professional predictions and anticipations, often with a crippling degree of uncontrolled growth. Freeways -- by their very nature of being "free" -- have few controls over their use except access limitations and congestion. A new freeway may act as an accelerated self-fulfilling prophesy, inducing new demands which are stabilized only by future service deficiencies such as congestion, inconvenience or emotional stress (which are the primary ills freeways are designed to ameliorate!).

Despite the efforts of a few capable analysts, there has been a truly remarkable poverty of past projections of traffic flow. In 1962, Anthony Downs described a process which so few of his contemporaries understand⁴ ;

1. Peak-hour traffic congestion on any expressway linking a central business district and outlying areas will almost always rise to surpass the optimal capacity of the expressway.
2. Therefore, in relatively large metropolitan areas, it is impossible to build expressways wide enough to carry rush-hour traffic at the speed and congestion levels normally considered optimal for such roads. The forces of traffic equilibrium will inevitably produce enough overcrowding to drive the actual average speed during peak hours to a level below the optimal speed.
3. Commuters driving on expressways should resign themselves to encountering heavy traffic congestion every day, even though they may spend less time commuting than they did before using expressways.

...6. ...marked improvement of roads without any improvement in segregated track transit may cause automobile traffic congestion to get worse instead of better.... continued failure to undertake an analogous program for other forms of urban commuter transit (other than highways) may result in a generally higher level of rush hour automobile traffic congestion in those cities which now have extensive segregated track transit facilities serving commuters.

Despite the claim of state highway departments that they are in the business of "solving congestion," common experience and traffic counts suggest otherwise :

- * The Congress St. Expressway in Chicago, designed for 96,000 vehicles per day (ADT), was saturated with 115,000 before it was fully completed.
- * The Hollywood Freeway in Los Angeles was built for a design capacity of 100,000 ADT. It opened in 1954 and in one year was carrying 168,000 ADT.
- * The New Jersey Turnpike, which also opened in 1954, soon carried traffic three times that predicted; 1955 traffic exceeded estimates for 1980, and the road has recently been widened from six to twelve lanes.
- * The Verrazano-Narrows Bridge was opened in 1964, incorporating a second deck planned for 1980. Congestion required opening the lower deck in 1969. (Note : the George Washington Bridge required a second level 30 years ahead of time, and today the access lanes to the bridge are badly congested).
- * The Long Island Expressway was designed in 1953 to carry 80,000 cars per day by 1970. In 1966, the Expressway was carrying 170,000 on some days.
- * In Atlanta, Georgia, the northern portion of the expressway already has enough traffic to warrant sixteen lanes, with a rapid need increase rising to 36 lanes in the 1970s.
- * In Boston, the Central Artery and Southeast Expressway showed unexpectedly high usage from the day of opening. In 1966, the Southeast Expressway was carrying more daily traffic than the predictions for both the SE and SW Expressways in 1970, as originally planned as part of the Inner Belt.

Today, somewhat belatedly, the Department of Transportation is beginning to recognize some of these facts of life -- and growth. The phenomenon in traffic terms is known as "induced flow," whereby new roads draw in new industries and commuting workers, with the highways saturating long before their time. Edmond L. Kanwit, Director of the Social Impacts section of DOT, describes this flow process :

As the periferal suburban area expands, traffic continues to grow, and gains in speed are often offset by longer trips and traffic tie-ups at ramps and interchanges. Improvements to highways attract new residential and commercial building and often generate enough traffic within a few years to equal or exceed twenty-year forecasts.(5)

Nevertheless, the claim is often made that expressways will relieve local street congestion, but in many downtown areas, this situation is not the case. Within cities such as Boston, Chicago and Los Angeles, the relief is only temporary, and thereafter traffic builds up and expressway exit ramps present new congestion locations. In 1963, S. S. Taylor, General Manager of the Los Angeles Traffic Department, predicted that traffic conditions in Los Angeles might well be worse in 1980 than they were in 1963, despite increased freeway construction. By 1980, he said, LA would have as much traffic on its city streets as it had in 1960 on freeways and streets combined.⁶ The freeway exits place severe distributional constraints on the city, because maintaining high capacity requires that exits be spaced several thousand feet apart. However, in a built-up area, the low density of exit ramps means that each exit carries a heavy flow, with

the potential for traffic back-ups at two places :

- a. local streets, where capacity is insufficient to handle heavy exit flows;
- b. on the expressway, at the beginning of the exit ramp -- where ramp capacities are 800 to 1000 vph without special lanes and local street/arterial distributional is available.

The expressway becomes limited by the fact that it becomes impossible to get the cars off the multi-lane facility, given the requirements for weaving and exit spacing. The radial expressway tends to get wider and wider as it approaches the core and then choke on its own exits. To seek improved exit capacity and distribution may tend to make streets into local arterials and local arterials into mini-expressways -- which may still be limited by bottleneck constrictions. Improvements in local street capacity to handle expressway flows seem counterproductive at best and infeasible at worst, with severe impacts to city form and non-transportation urban goals.

Some urban highways are advisable, where right-of-way already exists and local streets desperately need a bypass for heavy through traffic. Numerous crosstown links are needed to avoid the concentration of vehicles at the core, but care must always be taken to respect the complexity of impacts on traffic and land use caused by new highway construction. The analyses and proposals for Boston (Chapter 11) are developed with respect for these difficulties.

Downtown parking constitutes another limiting factor

on vehicular mobility. The parking disarray is familiar in many cities, with illegal parking and lot/garage operations with rates which favor all-day commuter parking. Out-of-pocket costs and threat of fines is a limited control on the process, since the New York experience with combined \$50 towing fee and \$25 illegal parking ticket yielded only 5% fewer cars towed.⁷ Boston's towing program has had more elementary differences, as motorists either choose to take the risk of fine, count on police laxity or engage in the widespread process of paying off police and meter maids. This latter expedient is so extensive that police have been openly witnessed to go along streets with their little black books, indicating which cars should be or should not be towed. Boston's AAA has complained that "nothing important has been done" on the towing program that began in November 1970 on 12 downtown streets. Illegal parking is still tolerated and the traffic department asserts that only about 30 cars are towed daily.⁸ In Tokyo, regular parking spaces cost three times as much as the rent of the average Japanese family, and a Japanese cannot legally buy a car until he can prove that he has a place to park it. Despite these stringent rules and other efforts -- such as a daytime ban on heavy trucks -- traffic flow in Tokyo is still congested and not improving.

The pressure for parking and its lucrative business

opportunities result in a city cut up by small parkinglots, extensive streetside parking, and large parking garages. The concentration of large parking facilities (especially in expressway airspace) can present a serious pedestrian transportation problem. Finally, the recirculation through local streets of slow-moving vehicles looking for parking spaces (and often ending up doubleparking) severely impairs the effective mobility function of local streets.

TRAFFIC CONTROL vs. FREEDOM OF MOBILITY

The glory of the "Freeway" concept has yielded to the somewhat suffocating image of the "Chaosway," an uncontrolled anarchy of vehicle flows, turns, weaves, crossover movements and stop-and-go interactions, all sprinkled with breakdowns, accidents and the impediments of weather. The oppressive bonds of congestion are the fruits of excessive utilization of individual motoring freedom. The limited controls of the past (traffic lights, low speed limits, no-passing lanes) have been relaxed by expressway construction to the extent that the only controls over flow volumes and direction are possible at entrance ramps through ramp metering. Once a vehicle enters the main traffic flow, he is lost to any form of rational system control. Because of the basic randomness of vehicular traffic, there can be no control of merges or exits.

The image and the promise to the contrary, modern expressways have as their primary equilibrium control variable the well-evident factors of congestion and parking scarcity. In terms of the demand factor, the matter is one of the degree of frustration which the traveler can take. Other factors of lesser importance are :

- a. tolls and parking costs
- b. operating costs or reliability; wear and tear on vehicle
- c. Inconvenience factors beyond congestion, such as psychological stress & strain of driving; threat to safety, availability of car; insurance costs and cancelation; repair costs and inefficiencies; vandalism
- d. transit services and costs
- e. Possible pollution standards or tax
- f. Special personal or professional problems of being delayed by traffic.

The use of toll roads to stabilize flow is of limited usefulness because of the strict access problems, extensive tollgate land and personnel usage, and the regressive social inequities associated with a flat toll that is not graduated according to income or horsepower. The traffic light is a far better controller because it is automatic, can deter certain types of undesirable traffic movements, and are not unfair or regressive in their impact : time is the element that is sacrificed, rather than simple cash. Unfortunately, the auto owner and highway engineer have combined to seek enactment of their ultimate millenium -- to drive cross-

country without encountering a single traffic light! This obsession to rid our highways of traffic lights has led to the current chaotic flow nature of urban expressways, and has virtually nullified the chances of traffic lights in the future serving to control arterial flows at other than congestion breakdown levels.

In sum, a freeway/expressway system is inherently without controlled impedance to flow demand. There is neither direct expense or enforced regulation to act as an impedance, so that flow equilibrium is generally determined by congestion and the construction of more highways offers "only temporary relief from congestion."

A CLASSIC CASE OF CONGESTION OVERLOAD : BOSTON'S NORTH TERMINAL AREA

The so-called North Terminal Area of Boston is usually defined to include Charlestown and the Northwest corner of downtown Boston. Although much highway construction is currently suspended pending review, two expressway projects are still on-line for 1972-1973 completion within this limited area (Fig. 1-1), and the traffic impacts can reasonably be predicted as leading to traffic congestion of most serious proportions, leading to exaggerated examples of conditions mentioned heretofore, such as merge, weave and capacity constraints; exit ramp

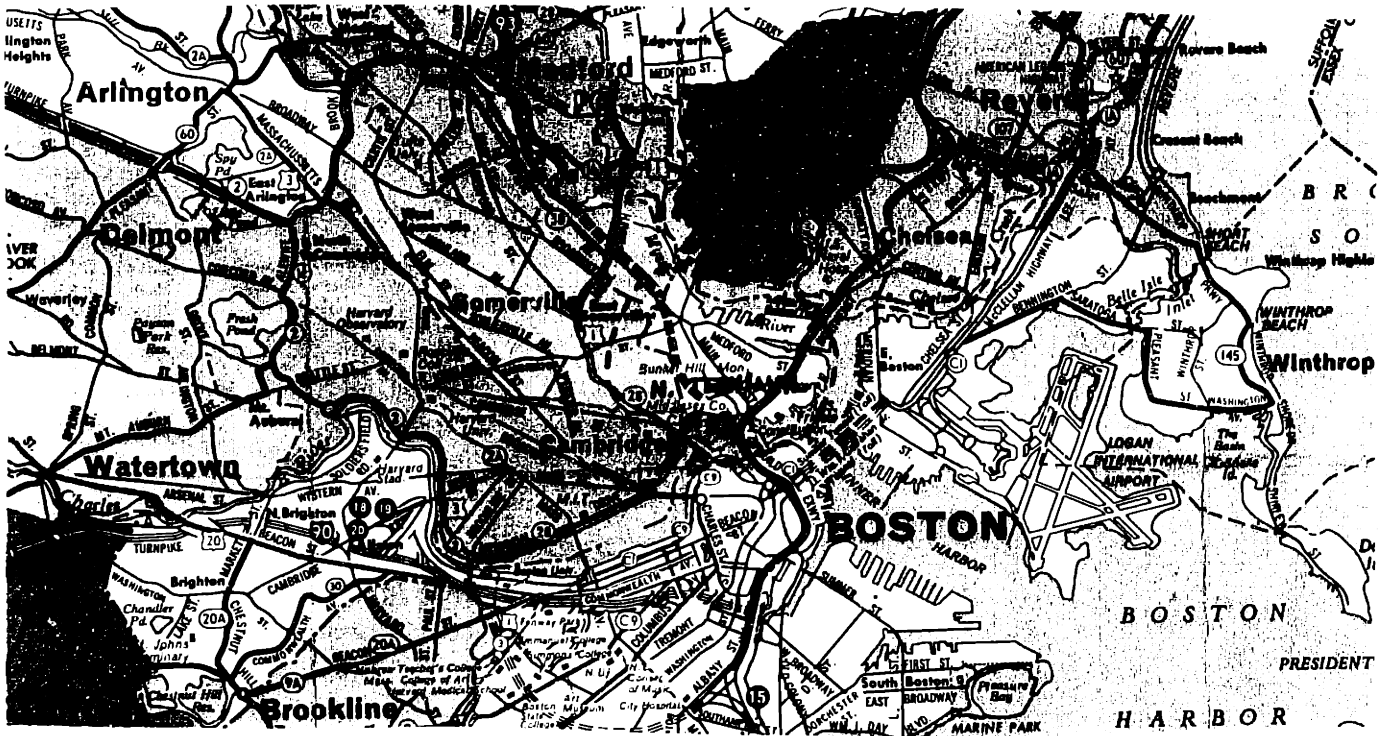
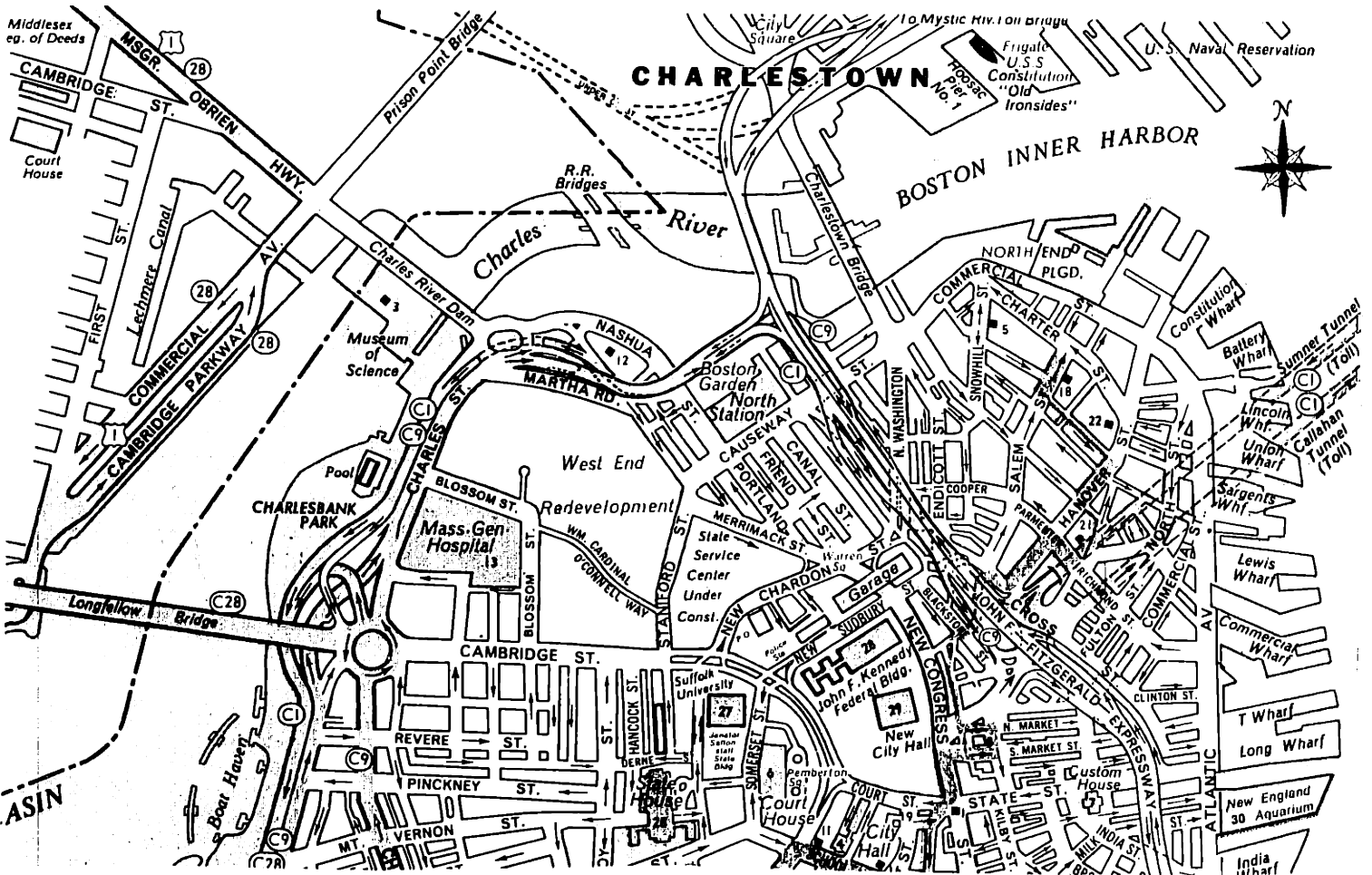


Fig. 1-1. North Terminal Area of Boston .



congestion; local street saturation; induced flow; downtown parking limitations; and finally a new impact -- deteriorated service on existing and antiquated expressways connected to the new facilities.

The history of roadway development in Boston is rich and fascinating...and so far unwritten. It involves plans, personalities, brilliant design, clumsy shortsightedness, inane arrogance, agency conflicts, citizen protests and constantly evolving highway plans -- the details of which are beyond the scope of this thesis and warrant only the briefest summary. A 1930 thoroughfare plan for Boston included a main North-South arterial through the city core, composed of the Northern Artery (McGrath-O'Brien Highway), the downtown elevated Central Artery, and the Southern Artery. The 1948 highway Master Plan recommended the 1930 arterial spine plus an overlay of an Inner Belt and connecting radial highways. By the 1950s and early 60s, the plan had been coalesced into a fully interconnected Inner Belt with seven radial spines, thus conforming to the classic radial-circumferential network concept. Unfortunately, the Inner Belt is highly eccentric to the Boston CBD and is composed partly of the Central Artery, which is not a beltway -- instead it is a traffic dumping device for the downtown and was designed that way.

Today, it is a very unlikely possibility that the section of the Inner Belt through East Cambridge will ever be built. When

the state Department of Public Works ~~was~~ forced to withdraw their Cambridge alignment, they chose to proceed with part of the Inner Belt in Charlestown and its connection to the stub end of I-93 at the Somerville-Medford line. The DPW in its infinite wisdom is now in the unfortunate situation of connecting an 8-lane expressway into the existing congested and obsolete Central Artery. Moreover, through its TOPICS funding program, the DPW will be building Boston's "hidden expressway" : the widened Rutherford Avenue project of the Boston Redevelopment Authority. Where today, the basic I-93 corridor carries the equivalent of two lanes of traffic, the construction of both I-93 and Rutherford Ave. yields eight plus eight or sixteen lanes in the same corridor, aimed primarily at the Boston waterfront, its limited bridge crossings and the constrained distributional network of local Boston streets. The possibilities for overloading and a major traffic catastrophe seem apparent to all except the structures-bound DPW.

To handle the waterfront traffic impact and shunt the traffic over the river, the DPW, BRA and Port Authority have been pressing for the construction of an interchange and bridge complex which, in its entanglement of ramps and turns, will make it Boston's answer to the Spaghetti Bowl in Chicago, the Mixmaster in Los Angeles, and the Whirlpool in Chicago. Both new and old

bridges involved are the Prison Point Bridge, a proposed Leverett Circle Bridge, the Central Artery Bridge, and the Warren Ave. Dam/Charlestown Bridge pair.

A standard flow model for the North Terminal "control volume" can be used to estimate the impacts of morning commuter inflow to Boston. The general rule is that when the outflow from the control volume into the Boston CBD is exceeded by the inflow of traffic from the north, then expressway and local street congestion occurs, unless there are massive parking facilities to absorb and store the flow. Ideally, the flows from I-93, Rutherford Avenue and the Mystic River Bridge should not exceed the CBD distributive and arterial capacity, which can be calculated as follows, using existing capacity traffic counts and estimates of expressway lane capacity = 1500 veh. per hr. design (DHV) and signalized arterials at 800 DHV :

<u>FACILITY</u>	<u>DHV</u>
* Central Artery Southbound	4600
* Charles St. Westbound (Leverett Circle Bridge)	3500
* Prison Point Bridge Westbound	1600
* Warren Ave. Dam (Rutherford Ave) Southbound	2500
	<hr/>
total arterial & distributive capacity	12000 DHV

However, from this total must be subtracted flow components which come from directions other than the North Terminal expressways :

<u>FACILITY</u>	<u>DHV</u>
* Downramp to Charles St. Westbound from Central Artery Northbound	2400
* Upramp from Leverett Circle/Charles St. to Central Artery Southbound (BRA estimate; currently 30,000 ADT and 2500+ DHV)	1800
* Prison Point Bridge Eastbound via Warren Ave. dam short-cut to CBD (subjective estimate of induced flow)	300
	<hr/>
	(-) 4500 DHV

Thus the net distributive/arterial "absorptive capacity" of the Northern end of Boston is 7500 DHV.

In effect, the Mystic Bridge, Rutherford Ave. and I-93 must compete with each other for this 7500 DHV availability. Today, the Mystic Bridge carries up to 4600 DHV on a three-lane inbound scheme, and its recent operation of a reversable fourth lane will result in higher counts. If we assume that in the future, the Mystic Bridge will carry 4500 DHV, this leaves only 3000 DHV for I-93 and Rutherford Ave, combined. However, the lane capacity of these two facilities exceeds 10,000 DHV, which is a measure of the overload capability of the expressways in this area.

The controlling bottlenecks are (1) the at-grade intersection of Prison Point Bridge & McGrath/O'Brien Highway; (2) Charles St. & Charles Circle; (3) Warren Ave. Dam & at-grade intersection with Causeway, with additional back-up from Government Center on Staniford, New Chardon, New Sudbury & New Congress Sts.; (4) the obsolete Central Artery between the Central Artery Bridge and the Haymarket/Dock Sq. exits. Because of a badly designed structure originally, the Central Artery will need to have two ramps closed in 1972, nevertheless leaving a resulting traffic condition of sequential Merge-Worse Merge-Weave blockbuster which hit the driver in rapid-fire succession of a few hundred yards and give him insufficient time to recover from each constriction & prepare for the next.

The DPW is continuing on with construction of I-93 and plans for widened Rutherford Avenue, and the likely catastrophic effects will reverberate through politics, engineering and business in 1972-73 and could mean the end of the urban interstate system in Massachusetts and in other states as well. It is difficult to imagine a more magnificent disaster with which to write the ringing finale to the urban expressway concept.

What went wrong? How could such a seemingly robust and dynamic agency such as Public Works find itself in the

awkward position of championing a highway structure which :

- (a) Will not itself function adequately except for low-travel periods of the day;
- (b) Will effectively kill off the Central Artery through overload and thus reduce the functional efficiency of the Mystic Bridge to that of a stop-and-go parking lot;
- (c) Will be a boxy, unimaginative elevated steel structure, 90 ft. in the air through Charlestown, etching itself on the Boston skyline for all to see its aesthetic and function failings?

Operations experts at the DPW admit privately that the I-93/Inner Belt connection will be "a big parking lot," that "we've got far more cars than we can ever handle up there," and "you could build everything on the map and plans, and it still wouldn't work." The unfortunate realities indicate that the DPW planning and decisionmaking structure are somewhat inverted, as one consultant noted : "the structures are designed first and then kicked upstairs to have the (traffic) numbers put on them." The agency is dominated first by structures engineers, then by computer analysts, and minimally by operations experts and traffic planners, largely because the money is stacked in this direction. The construction budget of the DPW is \$100 million a year, 30X that of Administration and Engineering. While numerous multi-million dollar computer study designs are done of highways, the task is mainly one of justifying the location of an 8-lane facility within a pre-selected corridor. Consultants doing

business with the DPW are not likely to reach conclusions contrary to the DPW desires and still stay in business, so there is a natural tendency to "modify" computer analyses and routines so that the traffic is elegantly detoured around congestion points via techniques which lead some very honest DPW engineers to admit in conclusion that "you can prove anything you want to on a computer." In the hands of the DPW/contractor combination, the computer has ceased being a vital element in the complex truth-seeking process, and instead has become an obfuscator and confusion-device which blocks the layman from realizing that basically a structures decision has been made.

The history of highway development in Massachusetts has been characterized by weak traffic analysis and a disconcern for prediction accuracy. The Inner Belt concept for Boston was generated on the basis of traffic demand studies performed in 1945, when gas rationing was still in effect and car production had ceased for four years, when the GNP had hovered around the \$100 billion mark for 15 years. There is minimal concern for checking the accuracy of past predictions, understanding the concept of induced flow, and appreciation of merge, weave, exit ramp congestion and parking limitations. For any new developments in transportation, from a State Department of Transportation & reorganized DPW and MBTA to a new Dual-Mode system, operations people must be elevated above structures men

in the planning and decisionmaking heirarchy.

THE SOCIAL IMPACTS OF HIGHWAYS

There are four basic types of consequences or impacts from major highway improvements, three to the roadway user and a general category of community impacts :

- (a) Commodity savings or costs.....affecting the direct consumption of commodities, vehicle running costs & other direct road user costs (cash savings or outlays)
- (b) Travel time aspects.....vehicle running time (higher av. speeds vs. traffic jams), opportunity to productively use time saved or consumed in travel
- (c) Personal preferences.....benefits of comfort, convenience, feelings of safety, uniform speed, landscaping, aesthetics, privacy, freedom of scheduling, frustration & tension -- generally non-economic factors and thus inappropriate analysis results from the application of cost/benefit techniques.
- (d) Community consequences.....aesthetics, visual effects; business & trade, tax loss or gain; land values & land uses; social effects of business & housing displacement, rent escalation, fractured neighborhood community; social interchange barrier effects; air and noise pollution; access and mobility to local autos; fewer trucks or effects on local street congeston; community pride; recreation; national defense.

Usually analyses of highway pros and cons are greatly oversimplified in the homes-vs.-highways controversies. A

diagram illustrating some of the elements of the sequential direct and indirect impact process is shown in Fig. 1-2, including some of the planning and construction impacts as well as operational aspects.

Ideally, there should be some form of complete costing of highways, including indirect effects and at least in checklist form taking into account the qualitative social factors. Unfortunately, the cost/benefit analyses of the past have too frequently been a restricted quantitative crutch to highway departments and have been restricted to overemphasized user benefits. The justification for any new or improved transportation system or plan must be a dramatic improvement over the traditional cost/benefit analyses, which have not changed in their basic approach since formulation in the 1930s. We must develop plans for operational facilities which emphasize net services to users and non-users rather than monumental structures which for the sake of expediency tend to follow the line of least resistance -- usually through parks, low-income neighborhoods, or along potentially invaluable railroad right-of-way.

New transportation facilities must be conceived with a strong concern for all forms of pollution -- visual, as well as air and noise. Even Sect. of Transportation John Volpe has laid down the law to highway designers⁹ :

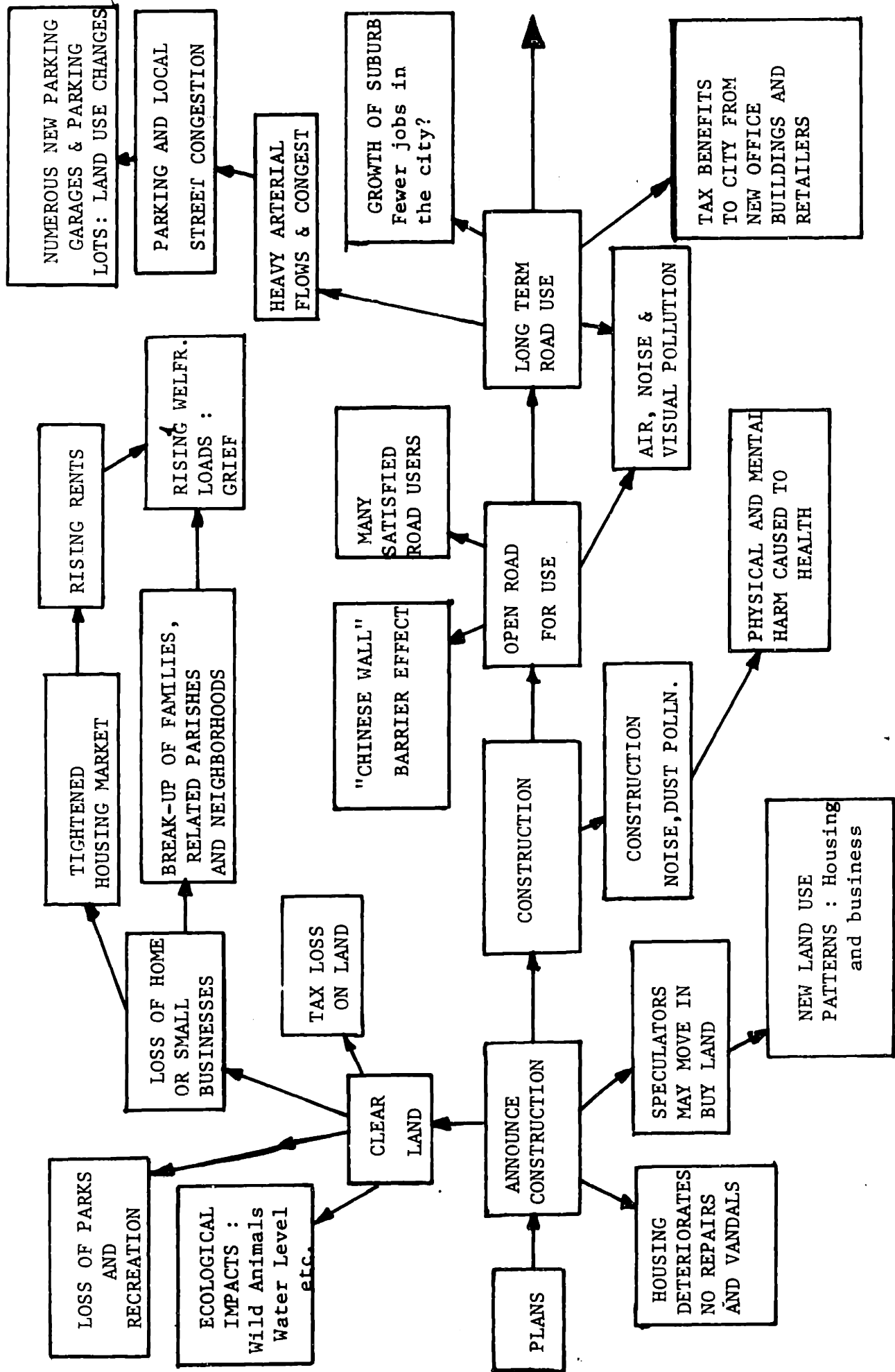


Fig. 1-2. The Social Impacts of Highways.

Two weeks ago the Wall Street Journal...headlines read : "Volpe stiffens stand on roads that disrupt housing, scenic sites." And in about the fifth paragraph they quoted me directly I said then -- and I say again now -- "Freeways that adversely affect our environment cannot be built."

Additional factors of social inequities, new requirements are being set to better serve the very poor, sick, old and young, or handicapped, since half of all Negro households and half of the elderly households have no car. Minority job recruiting is severely limited by the auto-orientation of many Boston area firms.

Land use and land value changes are often dramatic and quite unpredictable. Few analysts anticipated the 4 to 30x rise in land values along Route 128, nor have they appreciated either the loss of taxable land to highways or the incidents of declining urban land values. Wilfred Owen noted in a study for the Brookings Institution,¹⁰ that

One of the most significant factors in the declining tax base of the city is the liquidation of properties being absorbed by major highway projects.

The vast freeway network in Los Angeles has not led to an increased downtown tax base, since the assessed value of land downtown dropped 63 per cent between 1931 and 1962, and downtown department stores, which in transit-oriented 1929 accounted for 75% of such sales in the metropolitan area, accounted for only 19% thirty years later.¹¹

In some cities, there has been dramatic development in

certain areas, and business declines in others, with no net gain to the city. Often shopping centers are prime visible means of development, but the side effects are less visible. The economic impact of America's 3,000 shopping centers, at which Americans spend \$54 billion a year is quite pervasive, especially if one considers the side effects of the 50 billion miles per year housewives use to reach shopping centers and the 10 million phone calls they make to garagemen to rescue their faltering vehicles. Thus on the average, each shopping center does \$7 million per year in business, and such incredible magnetism will tend to influence business for miles around. Business failures may result, as small grocery stores cannot compete, but in cities placing the blame is very difficult. In the rural areas of the South and West, the situation is simpler and clearer, with shopping centers developed at major highway intersections causing people to drive 50 to 100 miles to them from all directions every week or two for a major shopping effort. As a result, the intervening local stores and towns are bypassed in favor of the wider selection and lower prices of the high volume shopping centers, which are efficiently supplied by truck traffic from the highways. The smaller stores, businesses, farms and even churches go under as their former customers "leapfrog" past them to the shopping centers.

So it is that a new ghost town effect is generated,

and the results are visible across the country on existing smaller, roadways....the Berlin Turnpike, Route 66 in the Southwest, and areas of the Carolinas and Dakotas. While thirty years ago, garish strip development occurred on many highways, today many older roads suffering from expressway competition have become a strip slum. New proposals for linear cities and air rights construction are simply a new form of strip development, often of a visual and functional distorting nature to the original community, and are expensive and pollution-plagued.

The inverse of overdevelopment by highways is the underdeveloped barrier, the Chinese Wall barricade which at best serves to "delineate" functional areas of the city or "screen off" industrial sections from residential neighborhoods and at worst leaves a nasty scar through a community which previously had been heavily dependent on road, street and walkway crossing. Many multi-lane expressways have presented a quality of wall-to-wall concrete which separates and boxes in many areas and severely hampers the local street distributional system by creating detours, dead-end streets and bridge/underpass congestion. Lewis Mumford notes the sad historical continuity of planning :¹²

We've repeated with the auto all the mistakes we made with the railroad. The railroads plowed right through the city to dump their loads in the freight yards in the center. Now the same kind of thing is being done on an even greater scale by the motor car.

The Great Wall of China, built in 230 to 210 BC, included a highway along its top. Because it was intended to stop the invading Mongols from the north, it could probably be called a national defense highway, although priorities were skewed towards providing an efficient barrier. Today the emphasis is on the transportation aspects, while the barrier is a secondary consideration. The visual aspect of the Chinese Wall effect of transportation arteries is clearly shown in Figs. 1-3 and 1-4.

THE TARNISHED IMAGE OF THE CAR

The concern for the impacts of highway construction has been complemented by growing disaffection among the ranks of the auto-enamoured American public. For years a love triangle has existed between the motorist, his auto and the politician who appreciated the value of "the 10¢ highway dollar," as funds for Interstate Highways are commonly known. For decades, post-frontier America turned its crude pioneering spirit to the automobile, constantly developing the device until it became an everyday necessity.

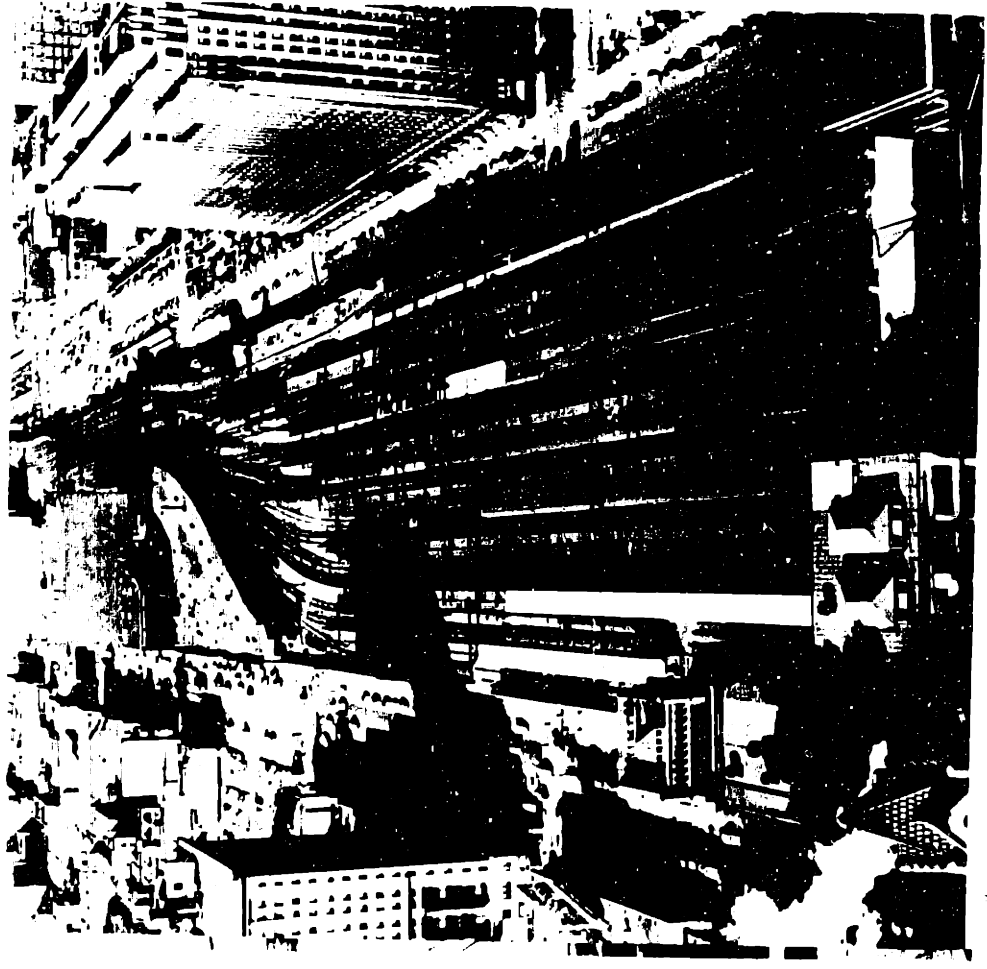
In seventy years the auto has gone through the life cycle of a personal relationship, more than a marriage and akin to the auto as a mistress. From early years of erratic infancy, of bumps and bruises, the auto blossomed into the glamorous splendor of the 20s and 30s, although the 40s and 50s aged into a pudgy utilitarianism shielded by the cosmetic splendor of chrome. But now the mistress has become



97 This view of the Dan Ryan Expressway and the Robert Taylor Homes shows what happens when 16 lanes of moving traffic are confronted with no attempt at architectonic control, the result, certainly nobody "designed" this design of highway. One could say the same for the public housing developments in the background. The Robert Taylor Homes are a good indication of what is wrong with public housing. It takes 100,000 square feet of housing in America to house one person, whereas in most other countries it takes only 20,000.

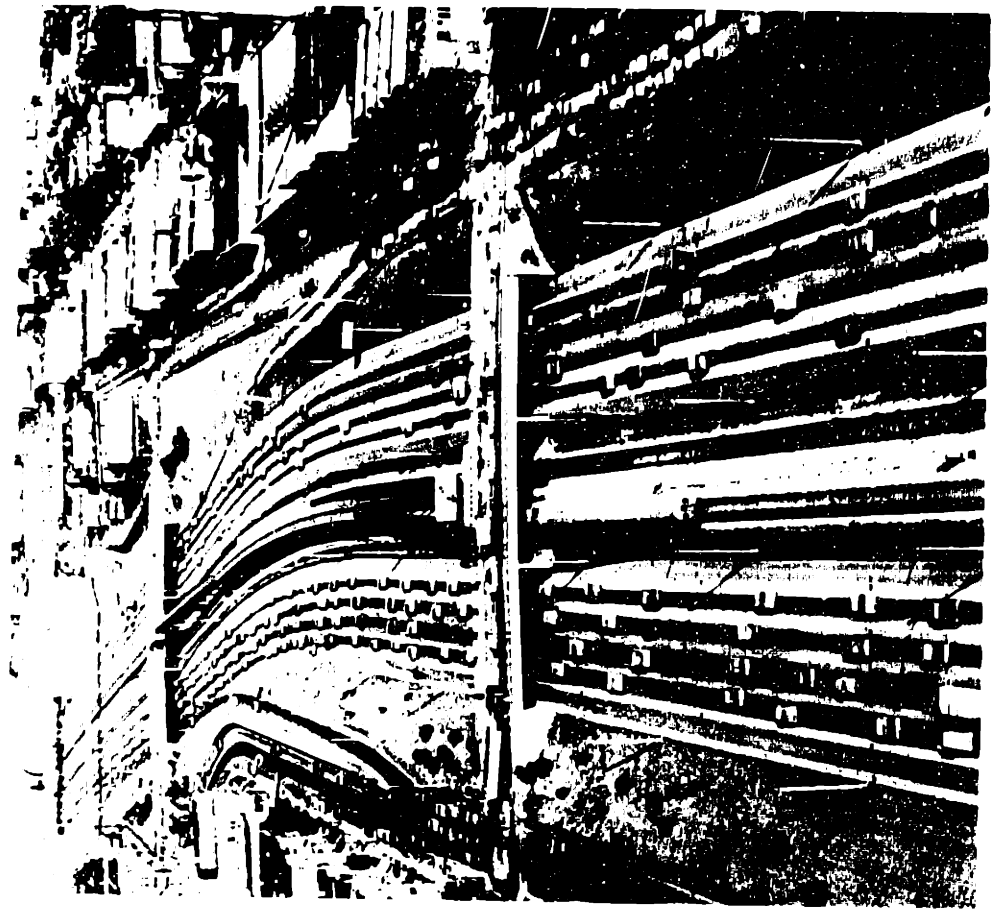
(From Lawrence Halprin
Freeways, Reinhold
 New York, 1966)
 Evaluation of Freeway Types 67

Fig. 1-3 The Wall-to-wall Concrete Effect of Expressways



(From Lawrence Halprin, Freeways, Reinhold New York, 1966.)

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The railroad train and the automobile penetrating into the core of the city—lessons in parallelism. (189) The famous Chinese Wall complex of railroad tracks in the center of Philadelphia. When this was finally removed in 1953, it made possible the rebirth of downtown Philadelphia, now the site of Penn Center. (190) The recently completed Dwight D Eisenhower Expressway in Chicago

Figure 1-4. The Chinese Wall Effect of Railroads and Highways.

so popular and accepted that almost every family had one. Then something went wrong.... the mistress was asked to serve beyond her capabilities, to be available day in and day out for mundane household functions and everyday tedium. The auto became a domicile, despite the desperate efforts of Detroit to project a supersex and individualistic image in recent years. In earlier days the auto had superceded the house as a prestige item, a portable symbol of property and ownership. Today, as the auto becomes a septugenarian, the old image is badly sagging. The auto's "medial bills" are rising, in terms of pollution, safety, congestion and highway costs, high insurance and repair costs, high first cost and rapid depreciation and the depressing sameness of all the brands.

In George Gershwin's "An American in Paris," the sounds of traffic are portrayed as bouncy, rollicking and exhilarating. Now urban traffic has a monotonous drone, punctuated by harshness, squeals and roars and shrouded in choking smog. New Yorkers dance in the streets when Fifth Ave. auto traffic is temporarily banned, and exult in the open streets caused by the recent taxi strike. Except for a few foreign sports cars, the modern automobile is utterly without fascination.

The revolt against the automobile is a most unusual phenomenon, the disappointment of the sports car buffs, the hot-rod fans in constant search of the rapidly disappearing open road,

THE SHATTERED DREAM OF THE AUTOMOBILE

"We entered the Sixties on the billowing rhetoric of Jack Kennedy and there was no reason to believe that any part of the American experience, including its automobiles, would falter. But then... came a cruel and widespread shattering of icons -- including our wonderful cars. Yesterday, they were symbols of freedom, of mobility, of self-expression, of honest ego-drive, of mechanical ingenuity and innocent sport. Overnight they became suspect as killers, as polluters, as mechanical Visigoths defiling our nation and its people.... Somewhere, as a lost clock-tick in the years 1965-67, the car, as symbolically related to men, reached terminal velocity, spun off a curve and destroyed itself."

Brock Yates, columnist and auto enthusiast for
CAR AND DRIVER August 1970 p. 12.

the harried housewife, the frustrated and antagonized commuter, the family travelers who years ago saw a long trip as a voyage and excursion rather than a tedium of listless driving, car sickness and hamburger stands. From California to Boston, a coalition of blue-collar communities, city planners, the so-called "environment lobby" and others have become quite solidly arrayed against the auto, in the short space of a few years, as the claim is made that the exalted "victory march of

the automobile" is devastating our cities and our natural resources, land, air and watershed. A measure of this revolt can be seen in the special section of the April 5, 1970 *New York Times* on the International Automobile Show, which is normally a device to stimulate Spring auto sales. In a major front page article, "The Car : Devil With a Halo," Jerry Flint observes :

The Car stands before the bar of Society convicted :

- * Of polluting the air with fumes and noise.
- * Of filling the streets with traffic jams and junked cars.
- * Of destroying the beauty of neighborhoods with gasoline stations and garages.
- * Of taking billions of dollars from consumers' pockets to correct shoddy engineering or workmanship.
- * Of killing nearly 60,000 persons a year.

And some feel its greatest guilt is that it has helped create urban sprawl and the destruction of cities, allowing the more affluent members of society to escape the problems, leaving the blacks the the poor helpless in decaying cities.

In this era of declining faith, the auto becomes a vehicle of guilt, but a necessary vice. It is not something worthy of exuberant pride and utmost confidence; instead its drivers are uneasy about its faults, harsh in their criticism of other drivers, and awkwardly addicted to the auto's excruciating necessity as a chain smoker is to his cigarettes.

Combined with the increasing guilt of operating an auto in the city is the frustration of commuter driving. A *New York Times* commentator has asked : ¹³

Why do they do it? Why do they undergo the daily torture of battling inch by inch across a no-man's land of overstuffed tunnels, overcrowded highways, and overage pavement, especially when the "fearless forecaster in the helicopter is radioing down to them the implausibility of it all?

conditioning and its steady reinforcement makes it possible to struggle along the Southeast Expressway at 5:30 p.m., suffering the fumes and frustrations of stop-go driving." ¹⁴ Is it possible that we are creating severe psychological and social problems (or aggravating existing ones) by subjecting people to such alienating traffic conditions? The strain of driving and delays will tend to take its toll in both office and the home. A few years ago, then Governor John A. Volpe asked, "What is it that makes a courteous human being turn into a maniac when he gets behind the wheel of an automobile?" ¹⁵ Margaret Mead has labeled the automobile as "easily the most dangerous thing loose in our society today."¹⁶ In this century, we have fully accepted the automobile, without asking what it has really done to us as human beings.

The last decade has seen a concentration of discontent on certain parties and scapegoats, from highway engineers and government planners to auto companies and oil firms. The safety crusades of Ralph Nader and the consumer revolt have focused discontent on the car and its manufacturers, rather than the drivers. The auto industry and the engineering profession have been especially challenged and stimulated into defensiveness. The effort of General Motors to restyle its 1971 cars and advertise them in the form and tradition of the 1930-1950 period is unlikely to prove successful in recreating the

"good old days" when the auto was truly king.

Despite the dissatisfaction, the auto remains very much a component part of modern American life, and ingrown element which cannot be banished overnight. A measure of this inherent determined allegiance to the auto has been demonstrated in nationwide surveys. In 1967, the question was asked : "The auto pollutes the air, creates traffic, demolishes property and kills people. Is the contribution the auto makes to our way of life worth this?" 80% responded yes, even in dense urban areas.¹⁷

Car sales continue at high rates and transit ridership declines, even worldwide. It appears that family income is more important in the decline of transit than deteriorating service, since Sweden's new Stockholm transit system has not increased ridership significantly. England is experiencing the spread of cars, as London Transport has hundreds of venerable old double decker buses gathering dust in storage yards. John Dickman¹⁸ makes a good point in observing that "although the automobile is not a technically elegant solution to the urban transportation problem, it is a socially engaging one because of its adaptability, social prestige and acceptability." More explicitly the car offers privacy and freedom of scheduling, which appear to be more important to the driver than raw speed or travel time saved. Any effort at new transportation developments must respond to these entrenched sentiments in favor of the auto.

With these values in support and opposition to the car kept in mind, the goal/evaluation factors of any new transportation system can be arranged in a list, without necessarily indicating priority :

I. USER-ORIENTED OBJECTIVES

- a. high capacity....both line haul and distributors
- b. low door-to-door travel time
- c. flexibility or frequency of scheduling
- d. high predictability of arrival time; reliability
- e. high comfort, convenience and privacy factors
- f. average performance close to optimal; no major drop in service with breakdowns
- g. fail-safe or fail-soft systems for safety
- h. good access to all; equitable transportation opportunities
- i. good aesthetics for traveler, view from the road.

II. Engineering and System OBJECTIVES

- a. Sensible flow control (other than congestion & tolls)
- b. Minimum right-of-way and parking, periferal impacts
- c. Good aesthetic design; minimum damage
- d. political and financial feasibility
- e. maintainability
- f. good off-peak service & usage
- g. system flexibility and adaptability (evolutionary
growth capability)

III. Local and Regional Social/Economic OBJECTIVES

- a. national, regional and local economic growth
- b. prevent decline of existing neighborhoods and businesses
- c. appropriate concern for environmental factors
social impacts

NEW SYSTEMS

Any discussion of transportation improvements must compare the advantages of developing new technology vs. the new application or control of old technology. Possible strategies range from an all-out ban on the downtown auto, to all-out accommodation of it, with numerous mixed strategies in between. Improved or automated traffic control, like lane widening, offers only a temporary solution. Steam or electric cars would affect the pollution problem, but not congestion or parking problems. Better transit or variations such as dial-a-bus are a partial and difficult solutions which sidestep the basic problem of massive auto dependency, and traffic flows determined by congestion. Many people who ride transit do not really do so out of preference : they are either too poor or weren't licensed to drive or are driven to straphanging by auto congestion and parking scarcity. The typical MBTA rider in the peak hour earns \$10,000 or more a year, owns one car and is a professional,¹⁹

while in the off-peak, blue-collar and elderly persons predominate.

A major issue in seeking an alternative to additional urban highways is choosing between improved transit or new forms of technology. The argument is made that transit technology and R&D funding for the past 60 years has been virtually static, and transportation problems will be largely resolved by massive Federal investment in facilities and research. In 1970, the first major transit bill was passed in Washington, comprising a total \$15 billion program, of which \$10 billion is the Federal component via a 66/33 matching ratio. Spread over a number of years, the program heavily favors construction of conventional rail systems and buses:

- * \$5.5 Billion for major new rapid transit systems
- * \$2.5 Billion for improvements in existing systems
- * \$1.5 Billion for medium and small-scale systems
- * \$0.5 Billion for R&D, demonstrations (3% of total)

Much of the success of future transit systems depends upon the fortunes of BART in San Francisco. BART is the first new rapid transit complex to be introduced in any U.S. city since Philadelphia in 1907^{*}, and is seeking average speeds of

40 - 50 mph with 80 mph peaks. In effect, BART is an automated
* * * * *

* Boston introduced the first system in 1897, and after only a decade of subway introductions in New York, Chicago, Cleveland and Philadelphia, success stopped. Other cities have tried, like Cincinnati in 1919 but only 1/3 of the system was completed before financial problems caused abandonment.

commuter railroad with good downtown access and widely spaced suburban stations. Yet BART is also very much like a transit highway -- paralleling numerous freeways and having an average station spacing of 2 miles (a well designed 8-lane freeway has exit ramps spaced 2 or more miles apart).

Unfortunately, too much transit design has been oriented towards use of highway right-of-way, particularly rail transit in the median strip of highways. The result is severe distributional problems at both ends of the trip :

- (a). There is too concentrated a people-flow in one corridor, although downtown passenger distribution via transit is quite efficient.
- (b). Because of the highway, few people will be living close to the transit line and walking access will be difficult. Park and ride makes minimal sense for drivers approaching the station on any road, since the tendency will be to drive the rest of the way or as far into the city as possible before bad congestion; the orientation of the parking lots to auto ramps and transit station becomes difficult and important.

Rail transit also makes little sense in the circumferential direction, at least as long as transit continues to serve the high peak commuter and shopping flows in a radial direction. Moreover, travel circumferentially via an in-bound radial/ outbound radial pair is possible and is often faster than the bus, which does perform circumferential feeder service, usually at a loss.

In sum, transit fails to resolve the highway congestion problem, either in immediate impact or long-term effect. BART by 1975 is expected to carry about 5% of all daily trips in the three principle counties, about 2.5% in the larger 9 county area. Virtually all the remainder -- 95% and 97.5% -- would be carried by autos and buses. Although BART capacity is rated at 30,000 seated passengers in the peak hour, 1975 volumes on the four BART gateways in 1975 are estimated as 16,700, 5,900, 5,200 and 3,700.²⁰ Moreover, BART will require an annual subsidy about double its fare box revenues and will provide minimal service to the city core area's citizens who are poor and carless and will still be dependent upon buses and cabs. Worst of all, transit does not deal with the reduction of auto congestion by control mechanisms other than congestion.

The limitations of conventional transit might be avoided by proper utilization of new technology or revitalized old technology in various coordinated combinations. There has been a fairly limited choice among options which have seen practical implementation beyond localized world fairs and special applications : auto, bus, rail transit & commuter train, taxi, with minor variations such as car pool and chartered bus and special enthusiast devices such as bicycles and motorcycles which appeal to a small but energetic minority. Over the years monorails and moving sidewalks have been tried, but without established success.

PERSONAL RAPID TRANSIT

Some of the personal transit systems advocated in recent years have sought to combine the personal service aspects of the auto and the compact efficiency of transit.

- (a) "Dial-a-Bus" is a combination of bus and taxi, activated on demand by potential passengers (via telephone) and consequent computer scheduling and routing of buses. For smaller systems, manual scheduling is possible and is currently undergoing UMTA demonstration.
- (b) Continuously Moving Belts, "moving sidewalk"
- (c) Personal Transit Capsules, traveling over exclusive rights-of-way, automatically routed from origin to destination over a network guideway system; for low- and medium-population density areas.
- (d) Dual-Mode Vehicle systems involve small vehicles which can be individually and manually driven on conventional streets and then converted from street travel to movement on automatic guideway networks, similar to the personal transit capsule.

Dial-a-bus has to date not lived up to performance expectations, with development and fare costs too high and in general a tendency to combine the lesser characteristics of bus and taxi, rather than personal service and area coverage at low cost.

The first known moving platform was proposed for New York City in 1876, using an elevated system of articulated 15 mph platforms capable of turning corners. Parallel six-seat trolleys would move along the periphery of the platforms and by triggering a friction brake could stop or start to pick up

passengers at stationary boarding platforms. In 1888 the first three-speed system was proposed, running in a subway with three parallel platforms moving at 3, 6, and 9 mph, with seats on the fastest one. Nothing was built until the 1893 Columbian Exhibition in Chicago, when a two-speed system was run on a mile-long ellipse at 3 and 6 mph. In Paris, after successful tests in 1896, a two-speed system was developed for the 1900 Paris Exhibition using an elevated structure for 2 1/2 miles with stations at 1/4 mile intervals. It ran for 8 months and was used by 6 1/2 million people running for 12 hours a day carrying 120,000 people and with a total of 40 minor accidents.²¹ In 1923, proposals were made for a continuously moving platform to run below 42nd St. between Times Square and Grand Central Station. A test track was built with three speeds of 3, 6, and 9 mph driven by a linear induction motor below the platforms. Eyewitness accounts were quite favorable and capacity was estimated at 32,000 seated passengers per hour in each direction. It was to run on either side of a shopping arcade, but authorities finally rejected it on grounds that a shallow subway across Manhattan would make future subway construction impossible.

The history of moving belts is interesting because of its early innovation, advanced technology and many demonstrations, yet today there is no extensive application of belt systems as extensive urban transportation. Some short moving belts are used

today, but costs run up to \$1000 per foot for 4-foot widths. The belts cannot negotiate sharp curves, nor can they merge, and for distances greater than 1000 ft. monotony of standing on the belt becomes disagreeable. Belts with seats on them must be arranged in loops, and for safety reasons the National Safety Code permits only 1.6 mph on rises of 15 degrees and 2 mph on the horizontal. Overall, moving platform systems are classic examples of good technology and demonstration failing to yield continuously functioning systems.

New York City in 1905 was also the proposed site for a variable speed, continuous flow personal transit concept, as advocated by two British engineers, Adkins and Lewis. Four-seater cars would run on a track and be powered by a variable-pitch Archimidean screw. At minimum pitch in the screw, the cars slowed down to 2 mph at stations, to let people on and off; at maximum pitch for cruise, the cars traveled at 15 mph. In 1923 a track was built in England, an elevated track carrying 8,000 people per hour. In 1924 the system, called the Never-Stop Railway, operated at the Wembley exhibition in London, with a capacity of 12,500 seats in each direction, running for 1.5 miles in a shallow cut. The next year the system was so inexpensive to operate that it ran free of charge for 12 hours a day, carrying close to 2 million people without accident, until the exhibition

closed. In 1924, Paris planners awarded Lewis first prize for his system but never built it; thirty years later the remarkable and indefatigable Mr. Lewis again tried to interest London Transport in the concept, without success. He claimed advantages of low operating cost (550 kw per route mile), self-operating and minimum staff, no waiting time at any station (because each 50-foot-long station would be presenting a continuously moving wall of open cars) and a high degree of safety. Defects included the inability to turn corners or even gentle curves and the cruising speed limitation. ²²

In 1953, Stephens-Adamson and the Goodyear Tire and Rubber Company constructed a test unit for their Carveyor system, intended to replace the 42nd Street Shuttle service in New York. A series of cabins (4 to 10 passengers) traveled at 15 mph on the moving belt between stations, and then dropped down to roller drive at stations for deceleration, constant 1.1/2 mph through the station and then acceleration. Seated capacity ranged from 5,000 to 11,000 pass. per hr. or from 10,000 to 22,000 seated and standing. Construction cost was \$4 million per mile and the capsule cabins were very simple. However, this system also had trouble turning corners and merging, and -- being completely automated -- one of the difficulties in obtaining approval was union resistance from the Transit Workers Union. Another factor given for not implementing Carveyor was the high total cost of the whole system.

The moving capsule system is attractive because of its conceptual neatness, small size and apparent flexibility, and in many ways is a form of horizontal elevator. Because autos, buses and trains do not travel vertically, the elevator industry has prospered and is an example of a universally accepted, highly reliable form of automated transportation, complete with pushbutton control of destination and automatic door control. Some elevators travel as much as 20,000 miles per year and the safety record is excellent. The elevator is so commonplace that people are less aware of its automation than they are of telephone automation when making a call. Labor problems have been minimal, because elevator operators were only gradually put out of work and do not constitute a rigid, strong force like a railroad brotherhood. Moreover, many elevators have been located in new buildings, so there are no existing people to be put out of work.

The first passenger elevator was installed in a store on Broadway in 1857, but was too slow and costly. Hydraulic elevators were imported from England in 1866 and proved more serviceable. The idea caught on and within a decade began spreading to inland cities. Thus the key development period of elevators predated by only a few years the efforts to develop moving platforms, yet one succeeded, the other did not.

The elevator has always been a free service to the user, paid for by the building occupants and serves the young, old, and handicapped (esp. wheelchairs) better than stairs. Only those afflicted with claustrophobia are discriminated against, although in some buildings, such as high-rise public housing, the elevator can become a frightening crime trap, which it never was in the days of elevator operators.

Far too much advocacy of automation has been made over the labor savings attributed to fewer operating personnel. Usually the saving is only in the cost of motormen, but overall labor includes guards, maintenance men, change makers, car cleaners, Administration, planning, and -- under automation -- additional computer and console operators, as well as legal personnel. As soon as "labor-saving automation" is mentioned, most union officials quite naturally will be strongly antagonistic and the concept may never get out of the planning stage. In the larger sense, the poverty crisis in society has emphasized the need to create more jobs for low skilled persons, not fewer. Thus the goal of automated transportation is to maintain or increase the number of workers, ~~and~~ to phase them into more interesting and productive work than driving a train up and down a tunnel for the better part of one's life. Under these ground rules, unions should be more favorably responsive, and the overall social impact of the system is more positive.

The main advantages of automation are the possibilities for reasonable traffic control, improved safety of components and reduction of human error or inefficiency. Under automated control, there is a standardization of vehicular response and hence predictable behavior and the potential to work out coordinated routines in the event of malfunctions. However, in every automated system, there is an interface between manual and automatic control which must be intently studied. For elevators, the doors open and close on people if inadequately designed. Moving belts have problems as people step on and off. Essential to the development of any automated system is a capable "human engineer," who appreciated the importance of the manual/automated interface.

The human engineer starts with the limitations and variabilities of human performance, the physiological and psychological limitations. He knows that even the most skilled and attentive person can at times of fatigue, stress or distraction become "careless", "Inattentive," "over-reactive" or generally "unresponsive." He cannot plan for the skilled athletic qualities of the astronaut; instead he must worry about a timid little soul called "Aunt Minnie" who may trigger a system slowdown. Human response time in driving varies and depends on many factors, including individual sensing time, decision time and response time. It is the human lag time of

about 0.10 to 0.50 seconds for simple tasks and up to 1.0 seconds for complex tasks. Manual control of vehicles is sensitive to external factors such as fog, drizzle and darkness which limit visibility (on October 9, 1970 along the Eastern seacoast, bad fog contributed to slow-moving traffic and accidents). In addition, inclement weather often has the psychological effect of decreasing driver patience, courtesy, caution and helpfulness.

The effect that complex technology has on simplifying the traffic control task can be seen in the following comparison:

(a). EFFECTS ON CAPACITY OF MANUAL HIGHWAYS : extent of driver skills and familiarity with roadways; weaving merging, diverging; visibility, grades, shoulders & lane widths/markings; cross traffic & pedestrians; traffic controls; speed differentials; distractions; accidents; overloading of exits.....

(b) EFFECTS ON CAPACITY OF AUTOMATED GUIDEWAYS : controlled merging and diverging, weather effects (?), accidents....

There are further aspects of automating the driving task. such as the importance of reducing the commuting routine, the wearing and worrisome agony of congestion; the waste of energy and concentration; the irritation and punchiness which leads to highway aggression and safety problems.

This thesis is based on the assumption that the automobile will continue to be a major part of American life, that certain manual uses are appropriate to less dense urban areas, but that the dual-mode option of automated control should be pursued to simulate transit-like characteristics in the central

city, and that a coordinated pattern of traffic controlled freeways should be implemented (highly limited access to on-ramps to inbound expressway radials) as well as improved people-movers in the CBD to reduce reliance on vehicles.

The process is simple neither as design nor implementation. Engineers have to become enthusiastic. Agencies must be persuaded. Aging and obsolete Master Plans will have to be modified or abandoned. The public, taxpayer and potential user must be interested and willing to support the effort. Community groups will have to be approached for their support, and not left to become the automatic opposition. The foes are apathy, no-sayers, doubting Thomases, vehement defenders of old plans, fiscal bankruptcy, inadequate or sloppy design and inept or unfortunate planning of system demonstrations.

We must remain aware that time and opportunity are scarce, because of the increasing public disaffection with technology, from extravagant space missions to inoperative washing machines to industrial and vehicular pollution. The decline of the sanctity of "Progress" must be taken into account and evidence must be presented that we are not advocating another form of uncontrolled technology, such as autos-on-superhighways and urban airports appear to have become. No longer can we afford to implement complicated systems, while developing methods for understanding and control as a sidelight.

SUMMARY

A new response is needed to provide adequate urban transportation service at a time when expressways and rapid transit seem to be getting worse rather than better. The highways suffer from a flow equilibrium set by congestion and frustration limits, not by more rational means such as tolls or signals. The rail or bus transit option appears to be a solution of the past, and the moribund transit agencies probably will not be able to provide many of the amenities of the auto without the excesses.

Some expressways are being constructed today, such as the Complex in the North Terminal Area of Boston, which will probably choke on its merges and ramps because of excessive arterial overload, so that the roadbuilding agencies may have similar public relations problems to transit. However, the American public is highly dependent upon the auto and tends to support mass transit in the hope that it will be used by others.

Efforts to combine the privacy of the auto with the controlled flow of transit have led some designers to favor special moving capsules or horizontal elevators; however, the plans have never got beyond the World's Fair stage, because the proposed system did not have the flexibility or amenities of the car. Automation should be investigated as the best answer to driving inefficiencies, tensions, and poorly controlled flow.

CHAPTER 2 DUAL-MODE VEHICLE SYSTEMS

An effort to combine the best features of automobiles and transit leads to a consideration of dual-mode vehicles, which are defined as vehicles having two separate modes of operation, namely :

- (a). AUTOMATIC CONTROL of vehicle guidance and speed, usually on a grade separated right-of-way.
- (b). MANUAL (DRIVER) CONTROL of vehicle along regular local streets and arterials (the present mode of automobiles).

There is a clear need to seek an alternative to the plans for doubling or quadrupling the number of conventional urban expressway lanes and to set design objectives which combine the flexibility and individual privacy of autos with the high channel capacity of mass transit, and permit an overlapping of transit and auto functions so that the same right-of-way might include a modal mix rather than a modal segregation, encompassing autos, rail transit, taxicabs,

A dual-mode system integrates public and private transportation on a single network of arterial routes, complementing existing transit and highway facilities and avoiding the expensive duplication of separate new facilities for public and private sectors. The automated travel segment would result in reduced pollution, accidents, delays, and the strain of driving, while offering an increase in transit speed and area coverage and allow transportation facilities for public use to be identified with those for private use every-

where. In terms of social equity, the half of the populace without cars could use public transit and have almost equal access to wide areas of the city. Physically, a guideway system can be defined in terms of its facilities and vehicles : it incorporates a *guideway* for line-haul cruising, a set of *vehicles* which can be controlled manually off-the-guideway and automatically on-the guideway (or automated On-guideway only, the rapid transit version), *entrances* and *exits* (where automatic-to-manual control changeovers occur) and *stations*, which are similar to transit stations except that they are off-line on spur tracks rather than on-line.

The "guideway" is defined as an automated channel that provides speed control, steering control and perhaps power to the vehicle. An urban guideway could be designed so that at larger distances from the CBD, the routes and entrance/exits would resemble freeways and busways in operation and would tie in with existing highway arterials and beltways. Moreover, certain transit advantages could be extended to suburban areas as an optional choice to pure sprawl. Because guideway vehicles would usually be electrically powered and subjected to more manageable noise controls, the full length of the guideway could be used for apartment, office and community center development. Elderly housing adjacent to or in the right-of-way permits easy access to public vehicles both for normal mobility and for easy access to guideway-adjacent hospital and health facilities. The elderly would be able to live in normal apartments, rather than being relegated

to nursing homes or extended care hospitals. Children would have better access to community facilities, ball fields, etc. located adjacent to guideway stations.

Closer to the central city, the guideway would be similar to transit; it could follow railroad right-of-way and emphasize guideway stations (where the passenger leaves his car) and compact automatic parking garages (where private vehicles would be stored). In the downtown area, the guideway would have few entrance/exit ramps and these would have bus-preference during peak hours. The stations become a method of "absorbing" the vehicles of CBD commuters and shoppers without causing wholesale clogging of streets and parking lots.

Two of the more desirable features of transit are those of grade separation and controlled headway.* The grade-separated dual-mode system is primarily a response to the central city and metropolitan area distribution problem and permits uninterrupted flow without friction with local manual traffic, just as current rapid transit tracks are usually grade separated to allow for

* Automated highway systems conceived in the early 1960s by General Motors were conceived to solve the problem of driver drudgery and fatigue on *intercity* and interstate trips. These "buried cable" systems improved channel capacity by only about 100% and -- not being grade separated -- encountered serious practical problems of friction and safety with manual expressway traffic.

controlled flow. Automatic control improves safety and speed by eliminating the factor of driver reaction time and driver error, torpidity, and drunkenness, as well as smoothing traffic flow through merges and avoiding stop/start speed variations. The removal of driver reaction time from the traffic flow process can result in safely reduced headways, higher vehicle flow density and improved channel capacity. Alternatively, the same number of expressway vehicles can be carried more smoothly in an automated channel of reduced lane width, number of lanes, and right-of-way width.

In the express transit function, guideways combine the high channel capacity of rail with the optional stop and off-line station of bus transit. A guideway can also be imagined as the horizontal equivalent of a bank of elevators which serve a range of floors. A guideway bus or transit vehicle is like an express elevator which does not have to stop at each floor. The automation of present-day elevators is entirely accepted by most people : safety is assumed, destination selection is simply button-pushing, and service is usually quite reliable. Elevators become objectionable when they take on the worst attributes of transit....the 100-yard dash before the doors close, the gasping struggle as the last man in is caught in the vise-like grip of the guillotine doors, the awkward sardine-can trip up, the proverbial "slow boat to China" as the elevator aggravatingly stops at each and every floor.

The flexibility of the manually operated auto would be

maintained for local trips and for traveling from home to the guideway entrance -- which is a critically important movement since over 85% of all trips in urban areas have either their origin or destination at home. A dual-mode guideway becomes highly compatible with concepts of car rental, since the guideway can act as a distribution channel for empty vehicles, moving them about the system and delivering them to customers for either automated or manual use.

Realistically, dual-mode developments must avoid the criticism leveled at some hybrid systems that they actually combine the worst characteristics of the systems they are trying to combine. Ill-conceived or poorly executed dual-mode systems could result in the worst aspects of autos (the congestion, delays, lack of equity and excessive capsulization, together with urban sprawl and distorted land use) being combined with the erratic service, poor maintenance, unaesthetic qualities and herdlike atmosphere of much modern transit. Moreover, the better political approaches must be sought in adapting or deviating from existing methods of government support or regulation of rail and highway systems. From the financing and advertising point of view, we should be selling Guideway as an automobile system with transit uses, rather than a transit system with automobile uses. This argument applies because the commuter -- despite the current revolt against the car and the push for mass transit -- still sees "the other guy's car" as the enemy and tends to support

transit as a way of getting "the other guy" off the road. Efforts in Chicago in the past, and one would predict from opinion polls in San Francisco, suggest that urging this mythical breed known as the "other guy" to take transit will be less than overwhelmingly successful.

In summary, we can list the more desirable characteristics of autos and of transit that dual-mode should combine :

(a) AUTOMOBILE : single family vehicle, privacy and cleanliness, individual ownership, individual routing and scheduling, good area coverage and door-to-door service, use for business and pleasure trips; potential for high-speed suburban bus service and coordinated car-pool.

(b) RAIL TRANSIT : automatic control and scheduling, minimal concentration during trip, high channel capacity, grade-separated right-of-way, stations for getting on & off vehicles, avoidance of downtown parking glut, use of abandoned or underutilized railroad R.O.W. good service of high density urban areas.

To insure adequate performance, a Guideway system should conform to certain system performance standards. Qualitatively, the emphasis should be on providing for good average performance and adequate (rather than paralytic) performance in emergencies.

Reliability and assured performance often become more important values to society and the individual when unacceptably high congestion, delays, and weather sensitivity hamper the performance of our land and air transportation systems. Ideally, guideways should offer point-to-point service times guaranteed within a range of $\pm t$ minutes, with the rider compensated for excessive delays by a fare rebate. These performance standards could be maintained by high system reliability, vehicle safety checks at guideway entrances, high mobility of emergency repair & rescue vehicles, and rapid rerouting of traffic around any blocked guideway segment. The goal is the avoidance of the dual-mode equivalent of the massive traffic jam, the saturated air-space above constricted airports, or the transportation paralysis caused by fog, rain, sleet and snow.

Reliability can also be enhanced by emphasizing the grade-separated right-of-way of the guideway, which avoids the dangers of manual intersections, pedestrian crossings, speed differentials between vehicles and other commonplace factors such as doubleparking and traffic conflicts at rotaries. This goal is in sympathy with efforts to restrict the use of the auto in the city, particularly on city streets. The electrically powered and peripheral parked dual-mode vehicle is one method of segregating auto (capsule) movements from the local street network, while maintaining many aspects of transit service. Access to local streets could be permitted for buses or car-pools or for all vehicles except during the morning rush hour. However, the

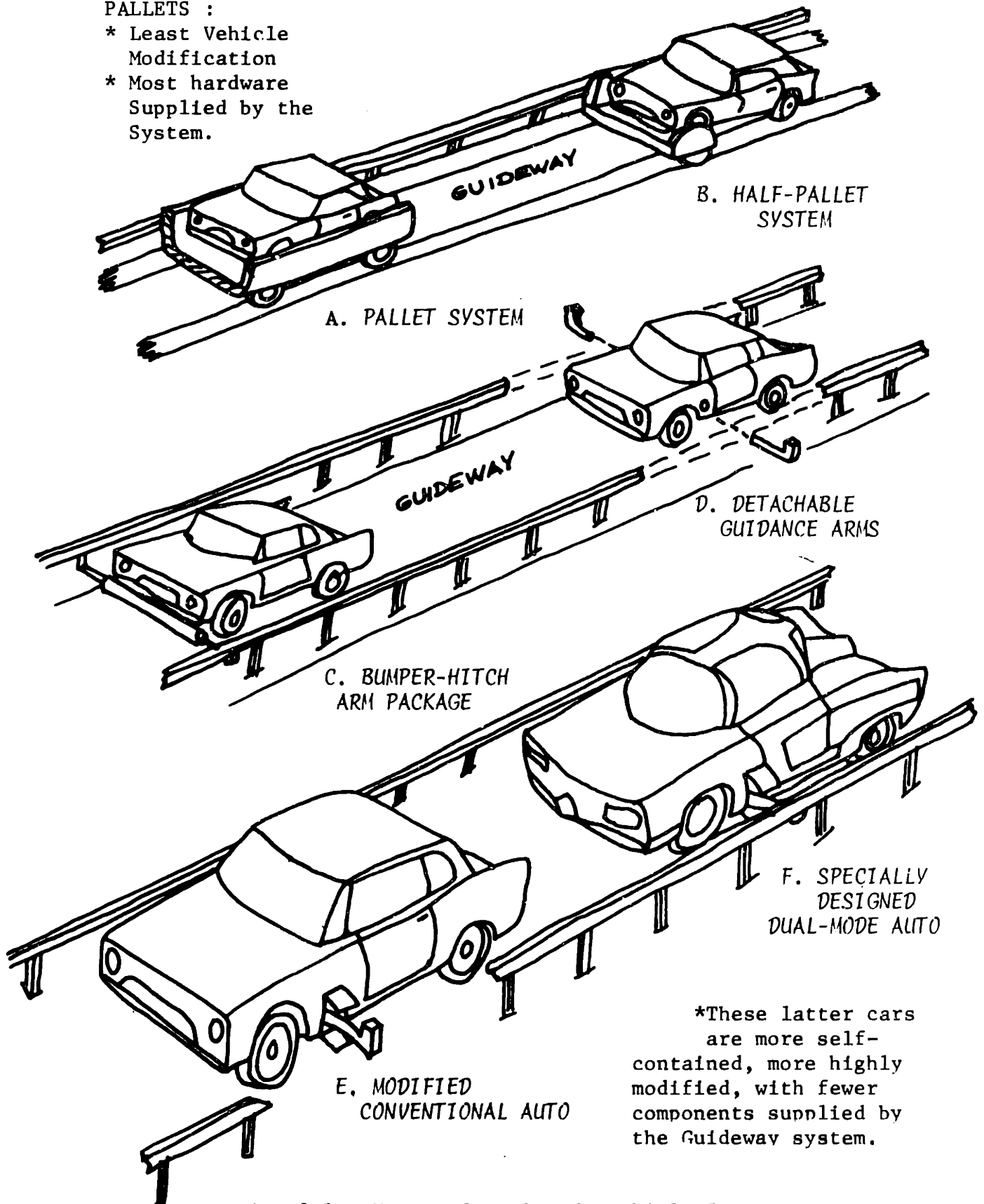
primary objective should be the relief of downtown street congestion while providing adequate people movements -- an objective which should be integral to related highway and transit policies. The current policy (whether intended or not) of solving periferal and outlying congestion problems and thereby transferring the bottleneck or choke point closer to the CBD must be reversed, with downtown bottlenecks being solved first, with the streets opened for truck, bus and shopper traffic, as well as better crosstown service for communities near the core city.

BASIC TYPES OF AUTOMATED VEHICLES

Various types of DM vehicles have been proposed, and their differences can be summarized by the *extent* of vehicle modification necessary for dual-mode operation. The inverse measure is the amount of *system hardware* which must be supplied to each entering vehicle, so that the more a vehicle is modified, the less system hardware is usually required. As shown in Fig. 2-1, design concepts range from pallet systems to self-contained autos. PALLET SYSTEMS require the least modification to vehicles and appear simple to phase-in with present-day autos. However, the pallet is a very significant sub-vehicle (Fig. 2.2) which must be supplied from storage for every entering car. Large numbers of pallets must be stockpiled at entrances, particularly at peak hours, to handle large influxes of entering vehicles, and the considerable movement of empty pallets around the system (from exits back to entrances) would

PALLETS :

- * Least Vehicle Modification
- * Most hardware Supplied by the System.



*These latter cars are more self-contained, more highly modified, with fewer components supplied by the Guideway system.

Fig. 2-1. Types of Dual-Mode Vehicle Systems

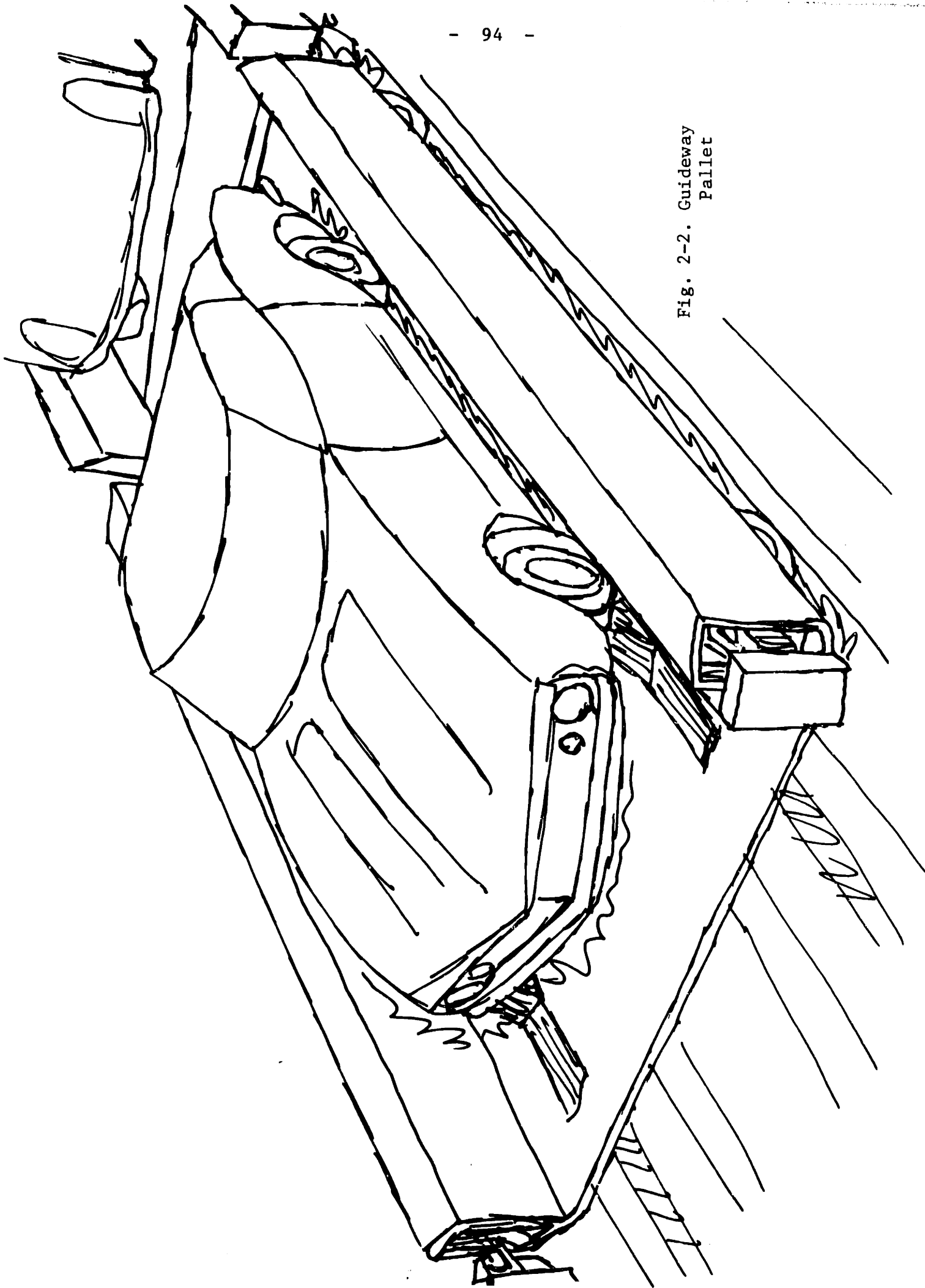


Fig. 2-2. Guideway Pallet

result in lower people-moving efficiency.

Because vehicles may differ in wheelbase and track, pallets will require cleverly designed wheel clamps and stops. Destination indication by passengers may require internal consoles, hence vehicle modification -- and thereby the primary advantage of pallet systems ("no car modification") would be lost. At a pallet station, problems of passengers entering vehicles safely while maintaining station simplicity and compactness become very serious.

At the other end of the dual-mode spectrum is the SELF-CONTAINED auto, which carries all necessary attachments for automatic control and requires important vehicle modifications or even a specially designed vehicle such as the Commucar, Alden StaRRcar or Urbmobile.^{1,2,3} The extent of vehicle modifications will partly be a function of the division of control responsibility between the guideway and the vehicle. Dual-mode cars could range from those 100% passive (like a rudderless dingy drifting down a river) to 100% active control -- with steering, power and velocity controlled by the vehicle itself, subject to guideway monitoring. A railroad train is a very passive pallet, because it is steered by the rails and by switches in the track and may be directly controlled by speed and spacing signals from the track. A trolley car can steer itself through switches, as well as having more driver responsibility and control of speed and spacing -- yet it still takes electric power from the system and must follow a guideway (the tracks). The conventional car is at the extreme

of internal control : its own steering and switching (and destination selection), its own on-board fuel and propulsion systems. The dual-mode auto must maintain all of these regular features of the auto for manual driving plus speed and guidance control for automated travel.

Conceptually, each guideway vehicle could carry its own computer (the human equivalent) which would sense the position of other vehicles, "read" guideway signs to make the proper turns, and stop at exits and stations, while the guideway was little more than a passive channel. Alternatively, the guideway could adopt more responsibilities : supplying switching information, speed and merging data, electric power, and safety monitoring. The more that automatic control is delegated to the guideway, the greater should be the system reliability, the lower the vehicle purchase and modification costs, the more capital investment in the system and the greater safety liability for the system operator. These control decisions must remain consistent with the overall dual-mode objectives of low headways, easy entrance and exit, and the feasibility of guideway stations.

LOW HEADWAYS require an accurate motor control system, and the slow response of conventional ICE engines plus the social objectives of low direct air and noise pollution make electric motor propulsion advisable, particularly since the guideway can supply power similar to an electrified trolley system (no on-board batteries required). Low headways also require that

switches be able to function rapidly, with quick routings of each vehicle Right or Left. A switching mechanism in the track must change to a new position before the next vehicle gets there, but after the previous vehicle has gone through. For 10-foot headways at 60 mph, a switch would have 0.11 sec. to shift position -- a stiff requirement for any load-bearing mechanical mechanism. If the switching is performed by pre-setting a mechanism on the vehicle to follow to the left or to the right, the guideway switch stays fixed and without any functional time-lag.

The requirements of simple ENTRANCE AND EXIT and feasible GUIDEWAY STATIONS demand a non-palletized vehicle that permits access to both sides of the vehicle at stations and a protected power pickup system. To varying degrees, Commucar, StaRRcar, and Urbmobile meet these criteria and in other ways do not. The dual-mode designs developed in this thesis do fulfil most of the important requirements.

THE SPECIAL PURPOSE VEHICLES : COMMUCAR, STARRCAR AND URBMOBILE

The Commucar design (Fig. 2-3) was developed by a group of undergraduate students at MIT as part of course 2.731 in the Spring of 1964. The car was battery/electric powered and had two lateral guidance arms for guidance and switching. This design was a direct precursor to this thesis project effort, which includes experimental hardware. The Alden StaRRcar (Fig. 2-4) was similar in concept, but had peculiar styling and a complex guiderail

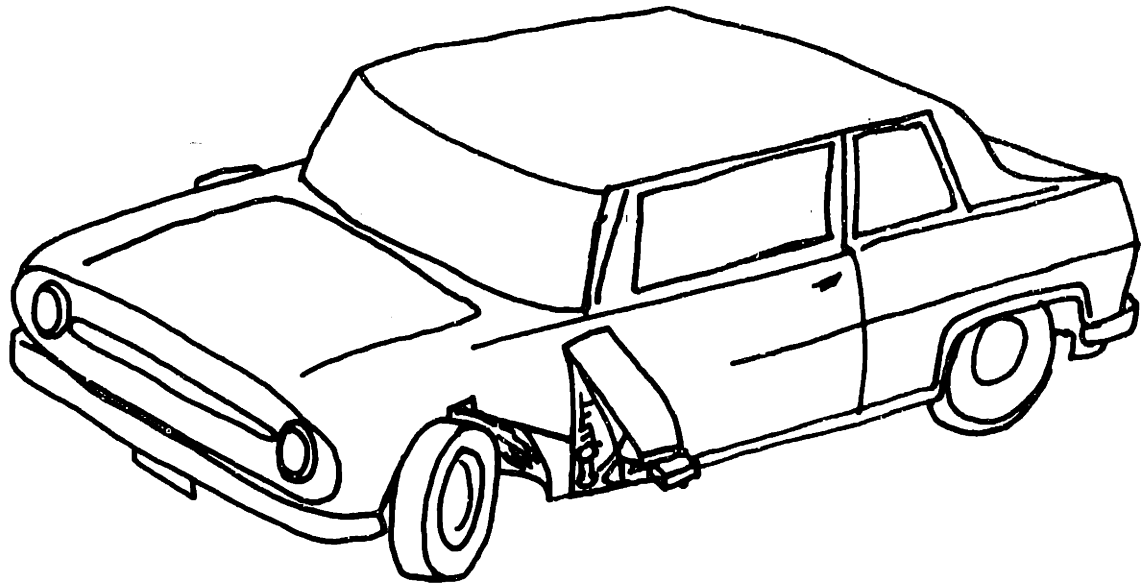
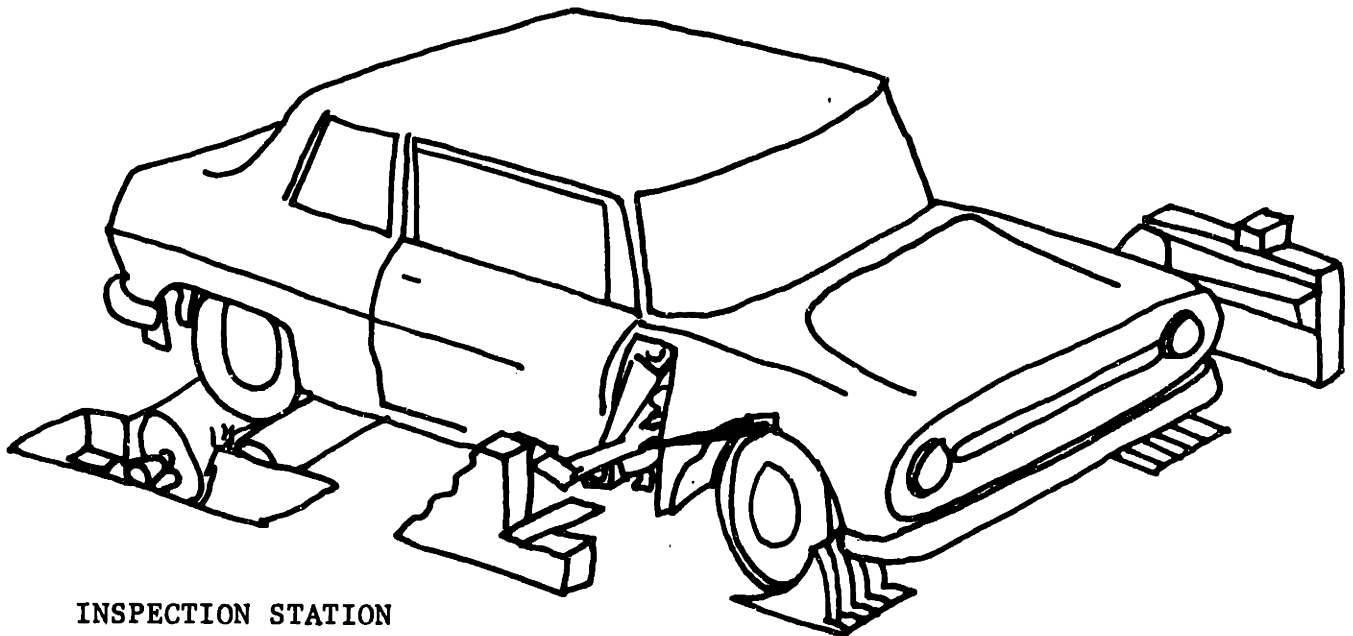


Fig. 2-3 COMMUCAR VEHICLES



INSPECTION STATION

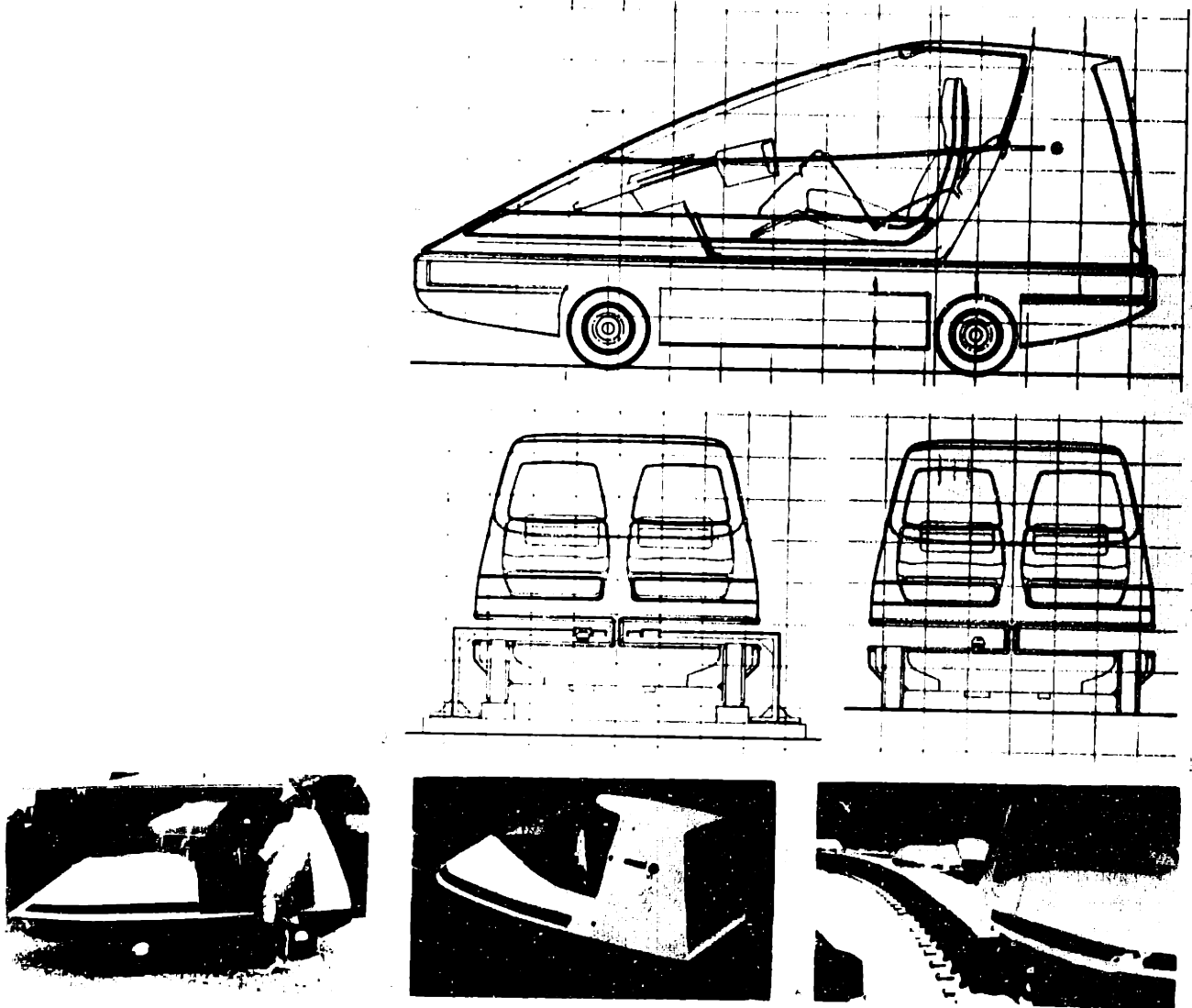


Fig. 2-4. Dual-Mode StaRRcar and Guideway

structure. A test track and vehicle were developed from 1962 to 1966, but initial response was disappointing and Alden has done only limited dual-mode development since this time. The Urbmobile is a dual-mode concept (without hardware) originating from the Cornell Aeronautical Laboratories in the late 1960s. Although a \$100,000 R&D grant from HUD was awarded for Urbmobile, the concept now appears very much in limbo.

All three of these vehicles are essentially commuting vehicles, having limited off-guideway performance and handling. There would be much uncertainty of public acceptability and sales potential, even as a second car. System start-up would consequently be very difficult.

StaRRcar suffered from a combination of the lesser characteristics of a buckboard and a golf cart, and the guideway shape forced the use of small wheels, stiff springs and an odd-looking body.

The Urbmobile is a somewhat more conventionally designed and styled vehicle, using inset steel wheels and a synchronous electric motor for automatic mode operation. Although intended for reliable guidance, the steel wheels are not connected by solid axles (as are railroad wheel trucks) so that the self-centering stability of the railroad wheel is sharply reduced. Noise through the suspension and driveline through the body could be very uncomfortable, and the ride would be worsened by higher unsprung weight and severe lateral motions associated

with warped and uneven railroad tracks. Valuable passenger space would be lost to the large wheel wells necessitated by the steel-and-rubber double wheel combination on all four wheels.

A synchronous electric motor, despite its conceptual simplicity, does not permit safe and efficient speed and merging control. Although the Urbmobile's steel driving wheels would be rotating at the same rate from vehicle to vehicle, slight differences in wheel *diameter* will cause vehicles to possess different cruising speeds and to creep forward or backward relative to each other. Vehicles might even bump up against each other, causing no immediate damage but eventually affecting the drive systems of each vehicle. For example, either there would have to be wheel slippage against the track or the motors would have to slip out of synchronization. A slip-clutch would be needed somewhere in the drive line.

This uncertainty of vehicle location due to minute speed variations poses special problems for traffic merging, where two vehicles might be competing for the same slot space in the merged traffic flow. Synchronous motor control does not permit for vehicles to accelerate or decelerate prior to the merge in order to provide properly meshing flow.

The Urbmobile suffers from design without detail and overpublicity without adequate restraints. By its label of identification, "Urbmobile" is one of the most unfortunate names for any vehicle or system since the Edsel, both of which sound

like a minor form of gastric disturbance.

THE DUAL-MODE FAMILY CAR

The best form of dual-mode car appears to be the self-contained vehicle having standard appearance and off-guideway performance. For acceptability purposes, it is crucial that conventional styling of cars be maintained, never so that so important a system could fail -- even though operationally practical -- simply because the "vehicles looked funny." Such a car would continue to serve families as a multi-passenger conveyance, for carrying packages and luggage for trips, as well as serving as personalized transit on the guideway.

During the phase-in period, conventional autos would be modified by special shops and dealers, while new production models are designed for factory installation of dual-mode components, or for simplified later addition by dealers. In the manual operating mode, the cars are familiar to regular drivers and hence evolutionary in concept. Hardware changes are internal, with minor sheet metal modifications to cover guidance arms.

The guideway will accept a reasonably wide range of vehicles, from modified standard cars to van-buses, mini-trains, and goods-carrying pallets. These pallets might be little more than automated flat-bed vans.

The general appearance and practicality of a modified auto concept is shown in Fig. 2-5 to 2-8. This vehicle is a 1967 Mustang hardtop which was converted to guidance arm steering and optional electric drive, and it will be discussed later in the various chapters dealing with guidance and control.

For guideway travel, *headway reduction* offers the most significant increase in channel capacity. The optimum headway length under automatic control would be determined by the electronic reaction time and the accuracy of the vehicular deceleration control. Currently, good drivers operating conventional gasoline-powered cars on a Los Angeles freeway can maintain high speed headways of 15 to 20 feet (even less in stock car racing), and it appears implicitly feasible to devise automatic controllers which would allow a standard headway of approximately 10 feet, particularly if sufficient "look-ahead" capability is programmed into the controller. Therefore, we can conceptualize a guideway traffic stream as a flow of 30-foot long "moving slots", each slot being vacant or filled by one car of approx. 17 feet in length, with ± 2 feet allowable in guidance accuracy before headways become less than 10 feet between any two cars. Guideway lane capacity is Q/L or 10,560 vehicles per hour at 60 mph, which compares with 1500 to 2000 vph per lane for better freeways. Therefore single lane guideways are adequate for most corridors

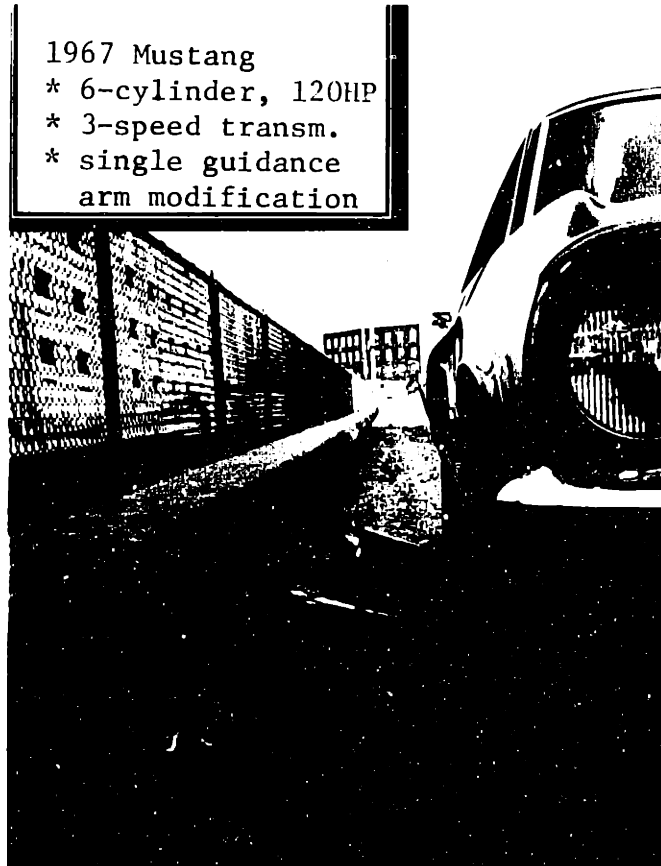


Fig. 2-5. Prototype Dual-Mode System.

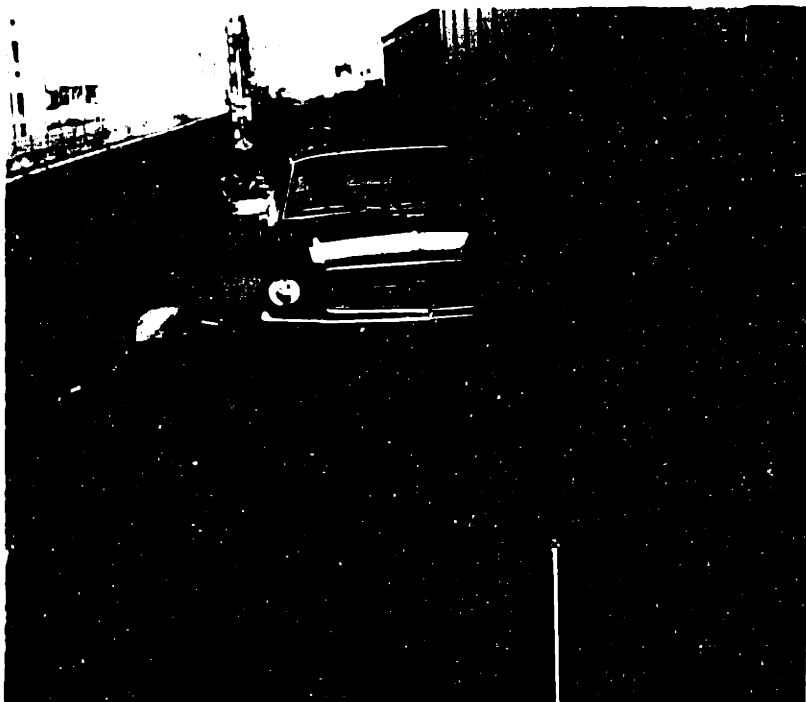


Fig. 2-6. Prototype Dual-Mode Vehicle.



Fig. 2-7. Prototype Follower.



Fig. 2-8. Prototype Motor Assembly.

and reduce the requirements for right-of-way width and land takings. In addition, guideway lanes would be 9 to 10 ft. wide, compared to 12 to 14 for modern expressway lanes.

A TYPICAL TRIP ON THE GUIDEWAY

The owner of a private or rented car would begin his trip by driving from his residence to the Guideway System entrance ramp (Fig. 2-9). He drives into the entrance booth and inserts his credit card into the car's control console. The car is identified for billing, is given a quick safety checkout of the guidance and power system, and is either rejected or given the automatic signal to proceed. Meanwhile the driver dials in his desired destination, and full automatic control is assumed. The car accelerates up the entrance ramp to cruising speed, merges automatically with the traffic stream and proceeds to the desired station or exit.

At a station, the car switches off the main traffic lane and slows to a stop at the platform. The driver steps out, quickly locks his car, and walks to the escalator leading to the sidewalk/subway/bus interchange, while the car is whisked away to a periferal automated parking garage, which is located on low-priority land within a mile or two of the station. For the return trip, the driver summons the car to the station by a telephone call; his car pulls into the station, he gets in and

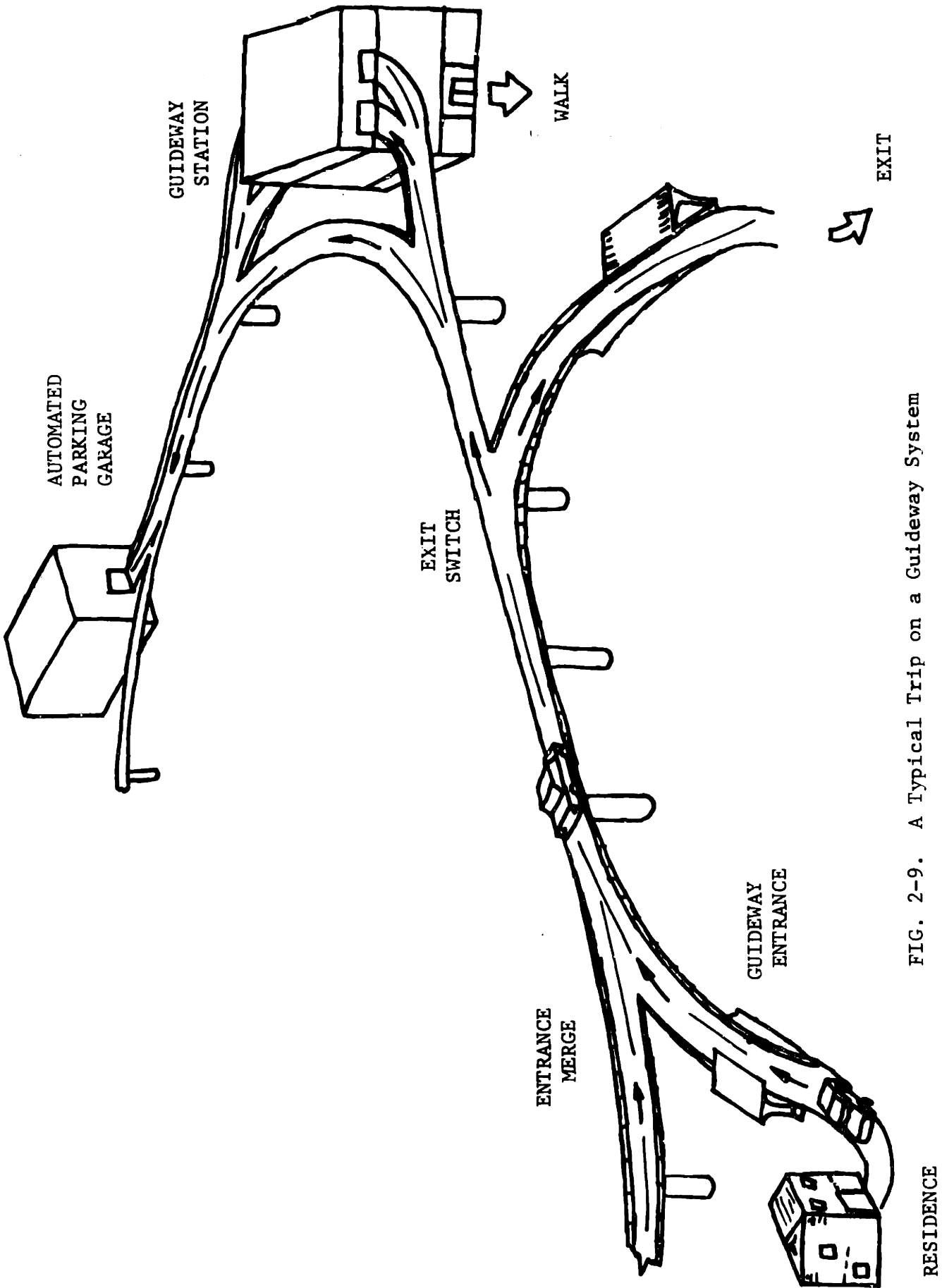


FIG. 2-9. A Typical Trip on a Guideway System

dials his destination, while the car accelerates out of the station, joins the traffic stream and is routed to the desired exit. After final slowdown and identification of the car for billing purposes, the driver reassumes automatic-to-manual control, and either from a full stop or at 3-5 mph drives the car manually back home. The bill would be included later in the monthly gas or electric bill.

Other personal and public vehicles can also be used for the trip, particularly regular minibus or dial-a-bus service. Other buses on the system could operate solely in the automated mode, serving simply as individualized transit, with the possibility of using them in off-peak hours as off-guideway dial-a-buses for non-commuter uses. Some of these automated buses could actually be automated rented limousines, providing personal transit at a first class fare. At stations, all rented vehicles could be immediately returned to the system for reuse.

In simplest form, a guideway trip is like using a telephone. After the desired destination has been dialed in, all other processing of switching and direction is handled automatically until the destination is reached. Guidance, speed control, switching and routing are all systems functions requiring no special demand inputs from the driver or passenger.

The guideway would basically be composed of one-way or paired two-way links of constant speed, but it is also possible to identify certain zones which would have 30, 40 or 60 mph speeds, depending upon density. The zones would be connected by speed transitional lanes where each passing vehicle would be controllably accelerated or decelerated. In built up areas, lower speeds are advisable, not only for alignment flexibility and shortness of ramps, but also for reduced visual impact caused by excessive information input of urban images and blurred images of buildings and bridges.

OFF-PEAK USAGE : THE NON-TYPICAL TRIP

Almost every transportation system has a usage peak, from which demand drops to lower levels of underutilization. Commuter railroads are the prime example at 50% ADT in the peak hour; transit is roughly 20% and autos 10%. For efficient and profitable utilization of guideway facilities, the goal should be to flatten the commuter peak and encourage off-peak usage. Interestingly, this goal largely coincides with the need to provide services to reverse commuters, to elderly and the handicapped, and to the young and the shoppers. The flexibility of dual-mode vehicles which are publicly owned to switch from a predominantly automated mode usage to off-guideway use during non-commuter hours becomes an important planning factor.

Goods movement of small and medium sized shipments becomes a feasible operation, particularly if guideway stations can serve an off-peak dual function as a small goods distribution and pick-up center, just as Greyhound bus terminals perform simultaneous and efficient passenger and express goods handling. After peak hours, the flow of commuter buses could be replaced by delivery vehicles (at guideway and street levels); in fact, the guideway buses would basically be passenger vans -- removal of the seats opens up goods movement possibilities, with the Guideway Company leasing out seat-less buses in off-peak hours to downtown stores and companies for shipping purposes, and as income for guideway operations.

A modified dial-a-bus system might be implemented which would resolve some of the difficulties encountered by present system proposals. Small buses (completely manual or dual-mode) could have the option of stopping at select neighborhood stops along a generally scheduled route. These stops would consist of small stores and community facilities which tend to serve as a thoroughfare/meeting place today. Storeowners might be willing to locate a few waiting chairs in the front area of the store, in exchange for the increased business induced and simplified grocery/goods delivery. The cash register operator would signal Central Dial-a-bus Control that a passenger was waiting and would indicate the desired destination. There would be less waiting on open streets,

more personable service, fewer mixups, and missed rides and less horn-honking for tardy customers. All buses would be painted a cheerful bright red, instead of the dreary MBTA colors. Similarly, cabs could be ordered the same way and offer the option of first-class (express) individual travel or second-class (multiple occupancy) trips at lower rates.

A scheme of using drivers on a work-study program would effectively mean a government subsidy to a union job, which should be acceptable to all sides and reduce seat-mile expenses.

Vehicles to be considered are the snub-nosed vans produced by Ford, Chevrolet, Dodge and Volkswagen. The new Dodge Maxivan is 212 in. long, with a 127 in. wheelbase, and is capable of carrying 12-13 passengers or a payload of 3930 lbs.

The automatic control and controlled access aspects of the guideway offer new opportunities for computerized car pools, which would be available for regular patrons, others who missed their ride or drivers/passengers whose regular car broke down and who needed emergency transportation. The routing and scheduling process would be similar in part to dial-a-bus. The Car Pool Company will provide subscription and special service, with the receipts split among driver payments & incentives, additional insurance coverage, operating costs, and -- hopefully -- profits. The rate might be \$5 per month per passenger, with drivers getting a higher payment with each passenger carried. Finally, parking

costs for Car Pool vehicles could be subject to special rebate, and parking lot operators would be given a special tax break or subsidy if they gave cut rates to Car Pool cars.

Numerous embellishments of the system for specialized uses abound : different classes of bus and limousine travel could be offered and -- similar to British Railways -- minibuses could be reserved for ladies-only, no smoking, etc. Special tourist buses could run off-peak on the guideway and fire-fighting & ambulance services offered.

The types of existing trips for general uses compared to work trips occur as follows : ⁴ home 39.6%, work 20.2%, business 6.7%, shopping 9.7%, social recreation 11.7%, school 3.1% and "other" 7%. This 1961 data will shift with time and location, but the proportions will not vary substantially. Thus we note that business, shopping and recreation (28.1%) exceed trips to work, suggesting that the typical commuting trip may be overemphasized among the various transportation needs. It is conceivable that the commuting vehicle (normally stored in parking facilities 9 to 5) could be returned "home" or to a periferal guideway exit lot for use during the day by other members of the family for shopping, school and recreational trips, then returned to the system for use on the home commute. It is also not impossible that guideway cars could serve as mobile day-care centers for kids to travel around while parents perform shopping chores, etc.

Some new concepts of goods distribution and interface are quite promising but beyond the scope of this thesis. For example, Interstate semi-trailers could be compartmentalized and loaded by simple forklift; at suburban depots, other forklifts would selectively unload and distribute the smaller loads to the flatbed pallets (Fig. 2-10) for automatic guideway routing through the city. At a traffic-controlled exit, the vans would be manually driven off to make deliveries. For small shipments out, the process would be reversed. A possibility for instant delivery stores is opened up, with many stores now able to operate with lower inventories on-hand, hence relieving the pressure for floor and storage space in the core area. Smaller, more decentralized stores would now be possible, thereby reducing the transportation access problem to the stores themselves. Finally, lower inventories would mean less lossage and pilferage. Downtown stores can now "expand" to other urban or suburban locations via guideway without requiring a complete move of all operations. Office personnel might be able to shuttle quickly back and forth as easily as they might use an elevator in a skyscraper office building.

No transportation system is without its disadvantages and difficulties. Dual-mode systems would require vehicle modification and thus a start-up problem which would require many buses on the system initially. Reliability and breakdown factors could lead to deteriorated service. Manual/automated

process, as would vandalism, liability, investment risks, public antipathy to new technology, and general unpredictability of new systems. With these matters in mind, we can set the following design requirements :

- (a). Conventional cars should be subjected to modifications which are relatively simple and not overly expensive and which do not noticeably detract from off guideway performance and appearance
- (b). Land area consumed by the guideway, its interchanges, ramps stations and parking facilities should be of lower acreage and land use priority than that of comparable roadway systems.
- (c). Driver training for use of the guideway should be minimal.
- (d). The guideway should conform as highly as possible with community standards or preferences towards noise, fumes aesthetics and the like.
- (e). The system should be fully tested and checked out for reliability; it should remain reliable as a whole, even in the event of localized malfunction or accident. Weather should not be a critical impediment.
- (f). The system should have good off-peak characteristics and services to minority groups, goods movers and shippers.
- (g). The demonstration system must be well-supported and financed, by many different parties. Efforts must be made to find design errors and induce any latent breakdown capability in the testing phase without undue negative publicity or reaction.
- (h). The range of allowable vehicles should include full-sized cars, compacts, cabs and rent-a-cars, minibuses and vans, delivery vans, emergency vehicles and goods-carrying flat-beds.

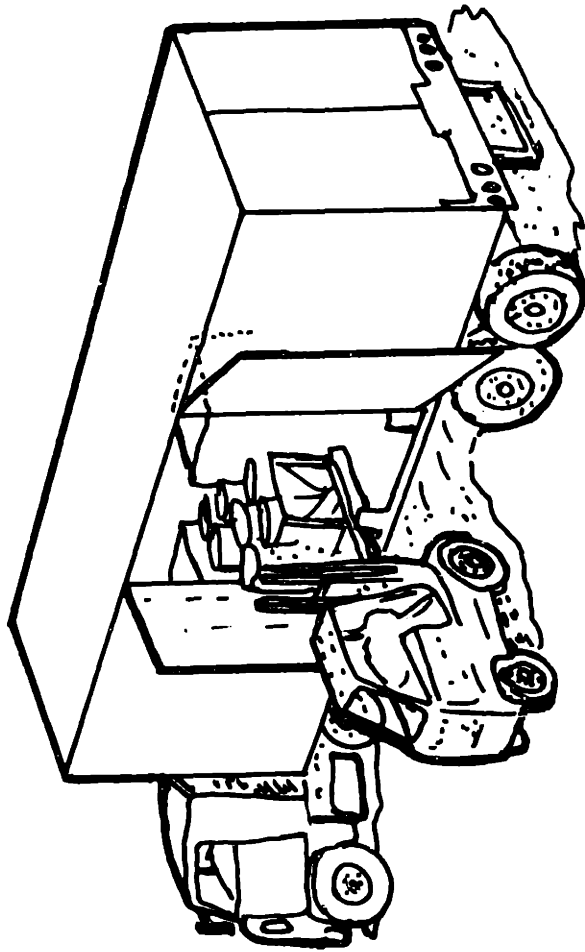


Fig. 2-10. Pallet Truck.

GUIDEWAY SPEEDS AND BANKED CURVES

The constant speed characteristic of the guideway allows a greater degree of superelevation on curves, so that curves can be banked optimally and effectively producing no side thrust on the vehicle or its passengers. The passenger sensation would be similar to that of rising in an airplane during a banked turn. The banking potential permits much tighter and more compact curves. Banking of 18° at 30 mph and 60 mph creates curves of 180 and 720 ft. radius respectively. A more extreme banking of 30° reduces these radii to 110 and 450 ft, and the visual/psychological limits of banked curved maneuvers will be discussed further in Chapter 6.

Land savings will be saved generally because of more compact interchanges and ramps, as well as the removal of current highway limitations of weaves and sign-reading distance, and selectively because the geometrical flexibility of the guideway allows the structure to bypass highly valuable land and existing structures to a great degree. Again, lower speeds in dense, high-land-value areas is not only a passenger comfort requirement but has payoffs in terms of sharply reduced curve radius. Because the vehicle is under automatic speed control even during deceleration, the exit ramps will likely have a number of new and more compact configurations, since expressway exits are often high accident points due to speeding and speed variations, in spite of generously large curve radii.

VEHICLE GUIDANCE

All vehicles would ride on conventional rubber-tired wheels and suspension, rather than using auxiliary wheels. The ride and unsprung weight should be equivalent to that of present vehicles and could indeed be superior, if the guidance arms incorporated damping factors for roll and yaw oscillations and thus simulated the ride of a much heavier and more stable vehicle.

Conceivably, all switching logic could be maintained on the guideway (the common practice among railroads) so that the vehicle serves a passive function in switching. However, the guiderail response time to process a flow of densely packed individual cars having less than 1/3 second separation will be some small fraction of 1/3 second, and a reliable mechanical device appears unlikely, since a rather large inertial section of the guiderail would have to be displaced, rotated, opened, etc. Monorail switches pose similar problems on a larger scale.

For reasons of lateral guidance, switching, guideway safety, and all-weather reliability, guidance arms should be located on each side of the vehicle, rather than underneath or overhead. At switches, the maneuvers are a matter of releasing the regripping the opposite guiderail from the direction of turning. Fig. 2-11 illustrates the case of a car turning left by releasing

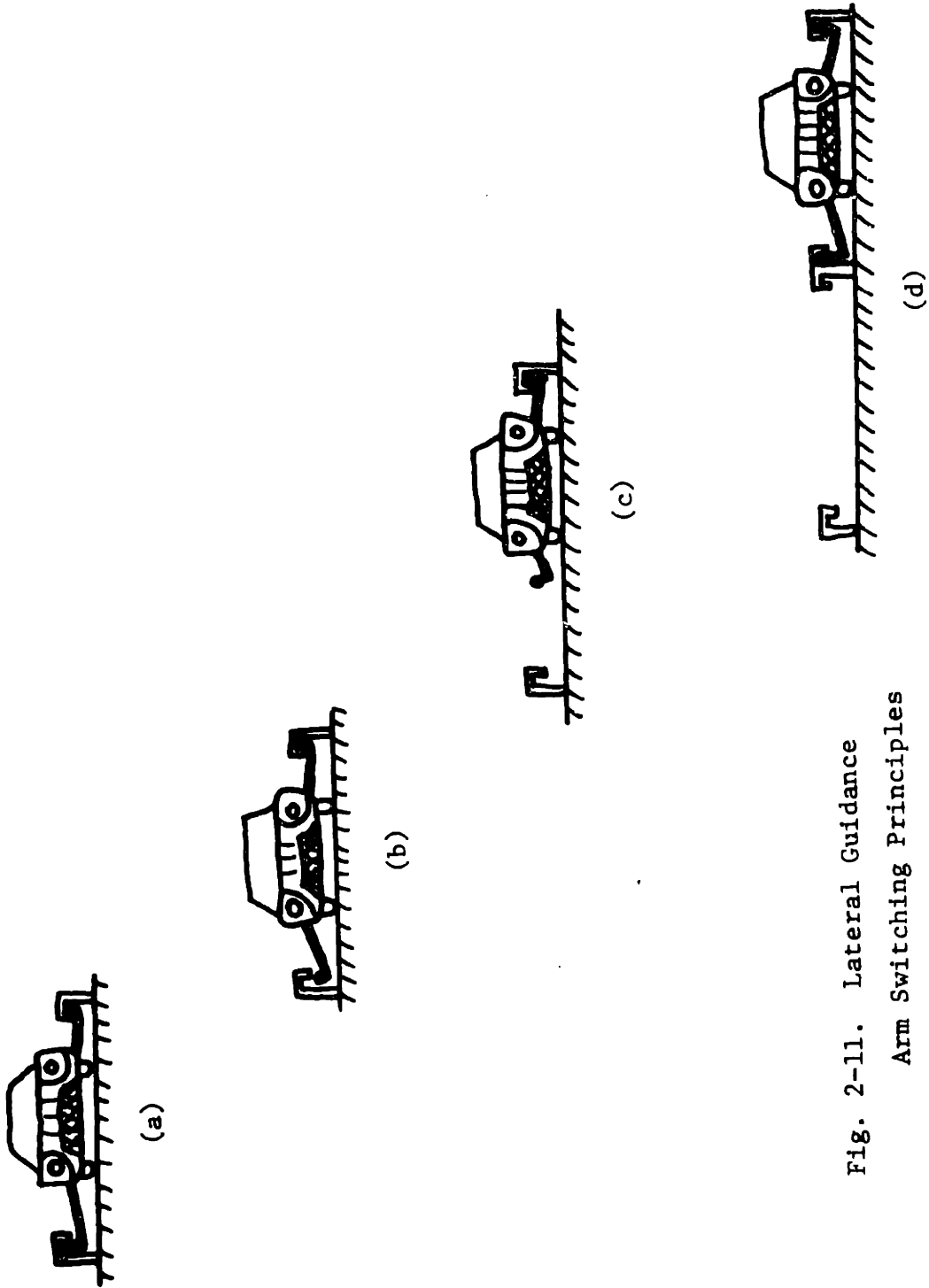


Fig. 2-11. Lateral Guidance
Arm Switching Principles

the right-hand guidance arm.

The width of the guiderails will determine the range of vehicles capable of traveling on the guideway. A reasonable maximum width of allowable vehicles is 81 to 82 inches, the breadth of the widest auto and small van.

The most important design question is probably the operation and appearance of the guidance arms and guiderail. The issue is important to the engineer, the stylist and the marketing manager and entails many unfamiliarities. In Tables 2-1 and 2-2, the numerous functions of the arms and guiderails are outlined. For reasons of safety and reliability, the arms should have load-bearing capability in the lateral direction. Failures of vehicle steering or traction are compensated for by this emergency lateral support, particularly if cars are stopped on a banked curve. For lateral load-carrying, horizontal arms located on the side of the vehicles are superior to arms underneath the car, since lateral arms take these loads in tension rather than bending. Moreover, a guard rail and general grade separation fence must be supplied in any case, so that the lateral guiderail can combine the functions of fence, guiderail and emergency support rail.

Ideally, the more the arms are mounted forward on the car towards the front bumper, the greater is the "lead" term in the controller and the more quickly information is available to the

TABLE 2-1 FUNCTIONS OF THE GUIDANCE ARMS

1. Grip the guiderail during automatic operation and be freely articulated to permit vehicle roll, yaw and pitch.
2. Provide steering guidance inputs to the vehicle.
3. Pick up signals for speed and switch control; communications
4. Pick up electric power for the auxiliary electric motor.
5. Drop the opposite arm for switching and regripping the rail after merges and switches.
6. Drop to curb level or below at stations to allow access to all doors on both sides of the vehicle.
7. Absorb certain levels of static and dynamic lateral loads in the event of an accident, skid, vehicle malfunction, etc.
8. Should not touch the ground during switches except during gross vehicle sway or bounce (then a skid plate must protect the arm).
9. Be provision for emergency shearing of the arm or extremity of the arm in the even of jamming in the rail; any disabled or jammed arm component must have an emergency collapse device to permit detaching from the rail and falling to the ground.
10. During manual driving, the arm should be folded up or absorbed into the car sheet metal and be shielded from sight; it must be aesthetically and stylistically unobtrusive as possible.

TABLE 2-2 GUIDERAIL FUNCTIONS

1. Provide a smooth surface for the gripping slider of the arm.
2. Geometrically and structurally allow for gripping, ungripping, and withdrawal of the follower at switches and merges.
3. Provide funneling & positioning function for follower regripping.
4. Carry signal wire and provide a slider surface for pick-up.
5. Carry power cables, with provisions for sliding power pick-up.
6. Provide lateral restraint for emergency loads on the arm.
7. Serve as a barrier or fence to emphasize the grade-separated nature of the guideway and reduce the chance of pedestrians, animals or other vehicles straying onto the guideway.
8. Serve as an emergency crash and restraining barrier.

control system that the car needs a guidance correction. However, the arms must be retractable, unobtrusive and fairly well protected from collision damage -- and thus cannot be located too close to the front bumper. Given the above concerns, the following arm locations were considered for feasibility (Fig. 2-12):

- (a). Behind the front bumper, in the sheet metal preceding the front wheel
- (b). In the front wheel hub
- (c). In the front fender well
- (d). In the front door
- (e). In the rocker panel
- (f). Under the hood

The front fender well location appears, in balance, to be the best choice, for reasons of good space availability within current vehicles, good accident protection, and ease of vehicle modification, as well as strength, aesthetics and articulation, with fair guidance stability. The front bumper location has problems of accident vulnerability, strength, lack of available space and sheet metal/bumper modifications. The wheel hub option suffers from space constraints and difficulties in designing for strength, articulation and hubcap aesthetics. The door location also has problems of space and strength, as does the rocker panel area. The under-hood arrangement would be cumbersome and heavy, being quite unsatisfactory from the aesthetic point of view.

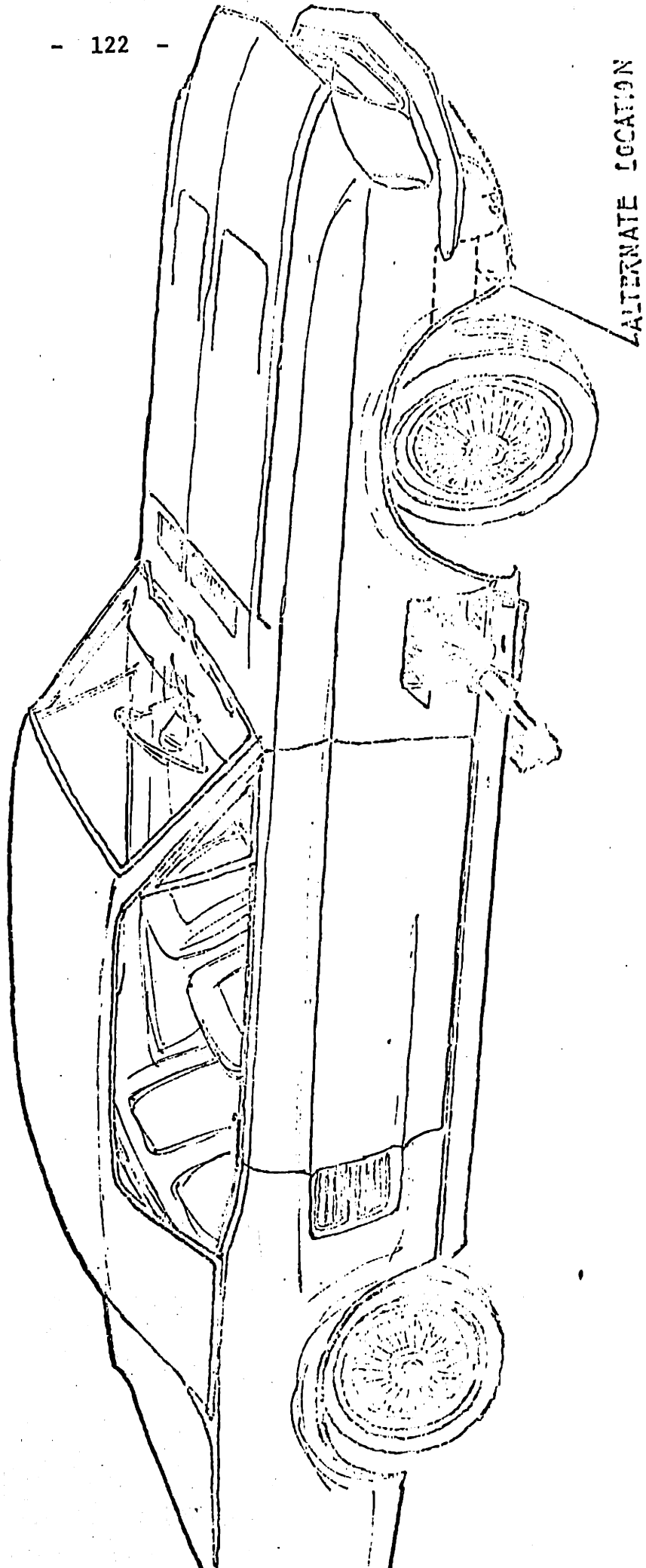


Fig. 2-12 Typical Dual-Mode Vehicle : Mustang

Guiderail width and height have been determined as outlined in Tables 2-3 and 2-4 to be 2.4 meters (94.56 in.) and 0.4 meters (15.75 in.) respectively. The primary selection of metric standards is based on the need to appreciate international metric standards and the possibility that the United States and Canada, the only two remaining non-metric nations of appreciable size, may have to develop metric systems in the future. Because vehicles are not as long-lived as structures, most vehicle specifications will be expressed in English units, in deference to familiarity.

GUIDANCE ARMS FOR THE DUAL-MODE MINIBUS

The van-type bus is compatible with guideway width and performance requirements and offers good express service and multi-door access and egress for quick loading. In fact, most of the lateral sheet metal of the minibus is often composed of doors, which makes location of guidance arms more difficult. Arm functions are similar to those of autos, except that for single-mode automated buses the arms need not be retractable. Generally, aesthetic considerations would be less important than those for private autos, and the bus arms would be reinforced for added strength and reliability.

Many vans, such as the Dodge Maxivan, have considerable space between the front door and side doors, so that guidance arms

TABLE 2-3 DETERMINATION OF GUIDERAIL WIDTH

* Maximum vehicle width	=	81 in.
* Crabbing allowance	=	\pm 1 in.
* Steering control limits	=	\pm 2 in.
* Guiderail deviation (lateral)	=	\pm 1 in.
* Oversteer/understeer allowance	=	\pm 1 in.
* Minimum Clearance allowance	=	1-2 in. each side

Minimum width : 93 - 95 in.

(Thus, a reasonable guiderail standard to set is 2.4 meters inside width between rails or 94.56 in.)

TABLE 2-4 DETERMINATION OF GUIDERAIL HEIGHT

Minimum height :

* Curb height	=	4-5 in.
* Clearance height to allow follower to drop	=	7 in.
* Min. ground clearance allowance	=	1-2 in.

Minimum height 12-14 in.
(to bottom of rail)

Minimum height 14.5 to 16.5 in.
(to centerline of rail)

(Thus, a reasonable standard to set is 0.4 meters to the guiderail centerline or 15.74 in.)

NOTE : The rail height for high speed sections should be fairly near the center of gravity height (20-25 in.) of the vehicles, yet low enough to swing down at stations and be aesthetically acceptable. At different locations along the guideway rail height could vary, being higher on banked curves where lateral guidance support is vital.

could be located in the fixed sheet metal. Others, such as the Ford Econoline and VW Microbus, have closefitting doors, so that the guidance arm package would now be arranged to fit under the floor and behind the rocker panel (a space now occupied on some vans by a swing-out step for passengers). The higher ground clearance of the van-buses would permit under-floor location of guidance components without causing major operational problems. However, with proper prior planning, all buses could be designed to have arm packages located between side doors.

Because of the testing and start-up problems associated with any new system, the first years of guideway operation will emphasize mass transit services (both dual-mode bus and automated capsule). The phasing sequence begins with captive van-buses carrying test personnel and then initial passengers to acquire maintenance and reliability experience. As confidence in system reliability improves, dual-mode buses and dial-a-bus will be introduced, then dual-mode taxis, limousines and rented-cars. The next stage becomes the introduction of private dual-mode vehicles onto a system which has been fairly well use-tested and is operating at reasonable capacity. Proper early planning in the current design stages of the 1973 to 1975 cars would greatly facilitate the phase-in procedure and lead to more adequate traffic relief and control.

THE PURPOSE OF AN ACTIVE DEMONSTRATION

A demonstration can serve a similar function to market research and market testing, but for transportation purposes the test goes beyond profitability to include service and side-effects & impacts. Guideway demonstration goals are :

- * To check hardware reliability during extended use and under varying weather conditions.
- * To determine public response sufficient to predict the degree of success of the guideway under full-fledged system operations.

Some of the relevant criteria by which to judge the demonstration include :

- (a). Minimal ROW and land acquisition, disruption of land uses.
- (b). Service equity and area coverage
- (c). Time and delay aspects, service reliability, graciousness of trips, "satisfactory" service to patrons.
- (d). User costs and fare processing; system costs.
- (e). Maintainability and hardware reliability; passenger safety.
- (f). Social acceptability & accepted willingness to use system; crime control & latent resistance to new technology.
- (g). Breakdown modes, emergency vehicles & repairs & quick return to service.
- (h). Appropriate and efficient interface with MBTA, highways, pedestrian movements and parking.
- (i). Route flexibility and aesthetics

ROUTE DESIGN AND FLEXIBILITY

The narrow and geometrically agile guideway structure can be run along railroad ROW either at grade or elevated 20 feet, and in most cases should require the taking of only one railroad track width, and often this width has been abandoned already.

Land takings will be important only in the vicinity of entrances,

exits and stations. The elevated guideway sections could span industrial areas, while at-grade versions could use the left-most lane each direction of expressways. Representative configurations for elevated, at-grade and below-grade options are shown in Figs. 2-13, 2-14, and 2-15.

Because of the available right-of-way in railroad corridors and the possibility of using semi-permanent structures for the dual-mode demonstration in Boston, probably the initial loop or spine should be laid out almost exclusively along this right-of-way. After practicality has been shown, then consideration should be given to locating sections of guideway in expressway corridors, both to provide dual-mode transit service radially and to reduce the corridor flow of uncontrolled freeway traffic aimed at the city core. These issues and their tradeoffs will be discussed in more detail for Boston in Chapter 11.

Fig. 2-13. Elevated Guideway.

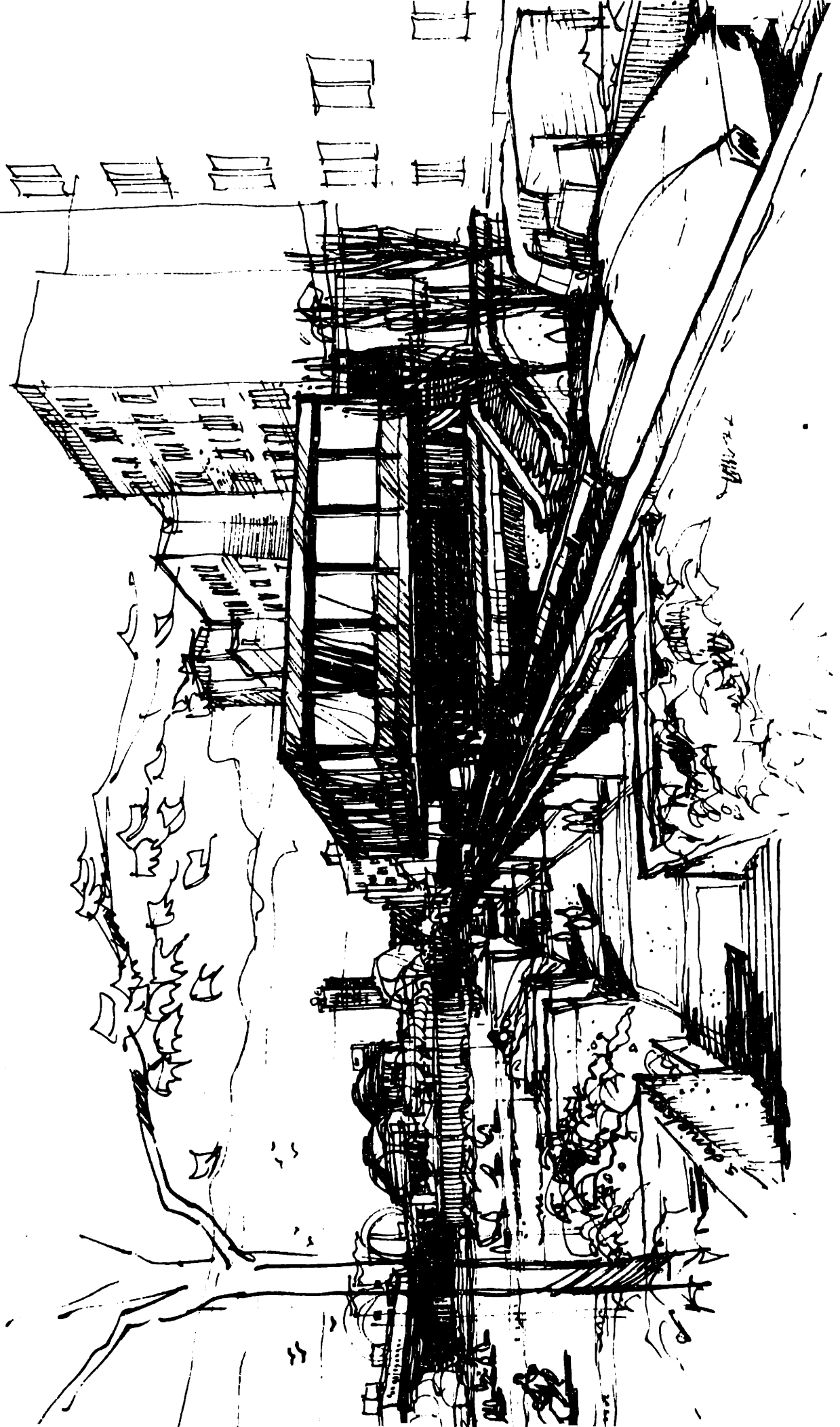
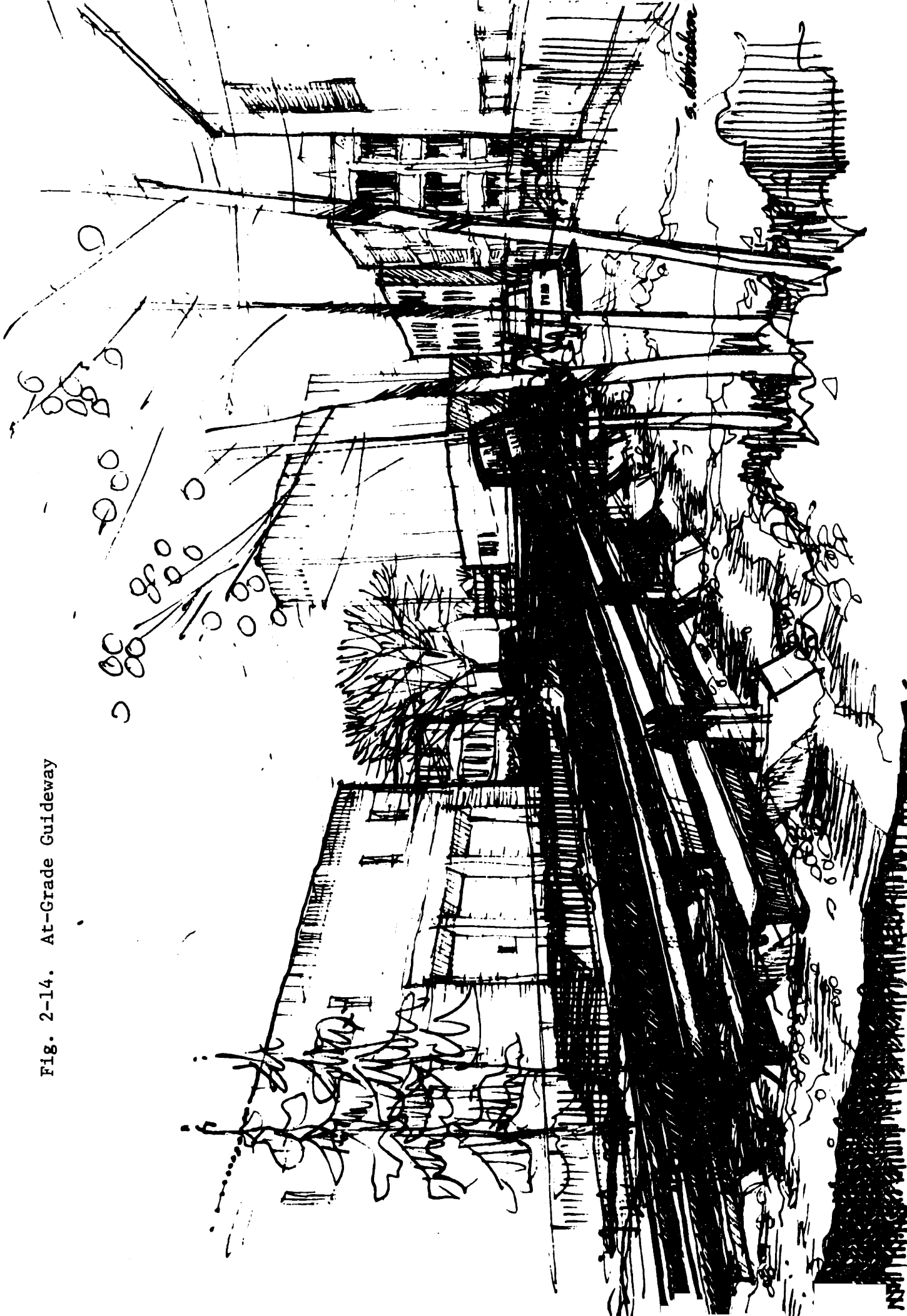


Fig. 2-14. At-Grade Guideway



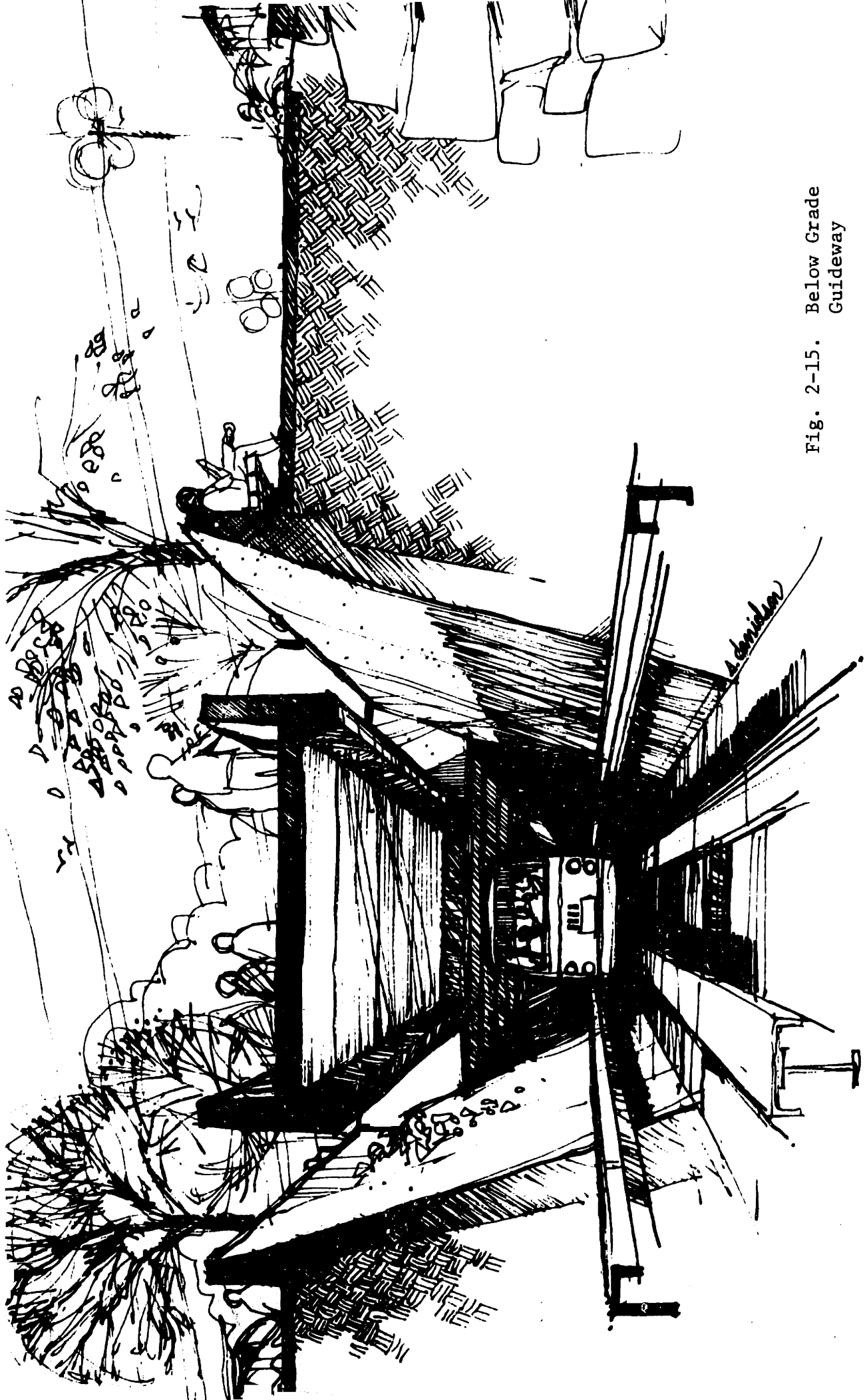


Fig. 2-15. Below Grade Guideway

SUMMARY

Dual-mode guideways allow the urban planners a fair degree of control over the auto- and transit-like characteristics of the transportation system. Dense core cities are not penetrated by wide new right-of-ways, and local streets and shopper's parking are not saturated by exiting vehicles. Local impact is minimized, while area coverage is substantial.

The preferred dual-mode auto should have conventional off-guideway performance and passenger accommodations, be controlled at a constant speed of 30,40 or 60 mph and have optimally banked curves. Vehicles have two guidance arms, located on each side in the fender well behind the front wheels. The arms pick up power, control signals, and provide regular and emergency guidance. One arm drops at switches and merges and then regrips the guiderail at the end of the maneuver.

The minimum guiderail width and height should be 2.4 m (94.56 in.) and 0.4 m (15.74. in.) respectively.

CHAPTER 3 VEHICLE GUIDANCE AND HANDLING

The vehicle control system provides the main design and development challenge for dual-mode. The necessary functions (Table 3-1) must be performed with a reliability equaling or preferably exceeding that of manual vehicles and at reasonable cost. Vehicle guidance at speed (lateral & directional control) is covered in Chapter 4; longitudinal or speed & braking control is the subject matter of Chapter 5.

TABLE 3-1 FUNCTIONS OF OVERALL VEHICLE CONTROL

- (a). Guidance of individual vehicles along line-haul segments and through switches and merges to individual destinations.
- (b). Speed control for cruising and acceleration/braking, including headway control.
- (c). Vehicle position monitoring.
- (d). Emergency speed control and override.
- (e). Queuing and sequencing of vehicles through a merge.
- (f). On-ramp merging control and at-speed inspection.
- (g). Vehicle inspection at guideway entrances.
- (h). Movement of vehicles through stations and parking garages; vehicle identification and scheduling.
- (i). Matching of customers and vehicles : private car and dial-a-bus requests.
- (j). Load balancing of alternative (parallel) guideway links to balance and utilize them optimally; rerouting of guideway traffic in the event of a breakdown.
- (k). Metering systems and customer charging, billing.

For automatic guidance, information on the changing direction of the guideway must in general be transmitted to the vehicle for appropriate response. Recent guidance schemes have relied on electronic inputs (the buried cable concept), force inputs (the steel-wheels-on-rails of Urbmobile), and vehicle-guideway lateral displacement measurement (as on the original StaRRcar). The preferred guidance scheme as explained in Chapter 2 and partially tested on the prototype car is based on contracting lateral arms sliding within a partially enclosed guiderail. Physical guidance can be achieved by a number of techniques, ranging from servo-activated front wheel steering (an "active" guidance system) to spring-mounted arms which guide on a lateral push-pull principle (a "passive" system).

Passive guidance is the simplest and most reliable form, being a "brute force" method of controlling the heading of vehicles. The front wheels would be locked straight ahead, and the auto would be directed by the lateral spring forces generated in the guidance arm when the car moves away from the guideway centerline (Fig. 3-1). The forces provide the incremental corrections in direction, similar to the effect that crosswinds have in steering moving vehicles.

Active control is achieved by transducer sensing of vehicle misalignment -- and generation of a steering correction signal to the front steering gear or power steering master

cylinder. Active control has the advantages of improved maneuverability, lower forces in the arms, and less tire scrubbing. However, active systems are necessarily more complex and hence reliability and cost become major concerns. Moreover, a poorly designed or improperly adjusted active system could result in steering lag, wandering or overreaction. (Fig. 3-2).

Active control is usefully augmented by "preview information," in effect a (noise-free) derivative signal warning of an impending curve, switch or beginning of a wander movement. Such lead information would allow vehicles to begin their corrective turning motions before the curve is actually encountered and reduces the amplitude of wander. The preview information could be in the form of a direct signal to the vehicle based on guideway directional changes or derivative data based on each vehicle's motions. The General Motors buried cable system included capability to measure both displacement and rate of change of lateral displacement. If the guideway preview information were timed to activate the steering gear at a time t_d before the curve, (where t_d is the total delay time of the arm, servo and steering linkage and of the tires and suspension) then the car will be able to negotiate all curves without swinging to the outside of the guideway and instead to travel down the guideway centerline at all times.

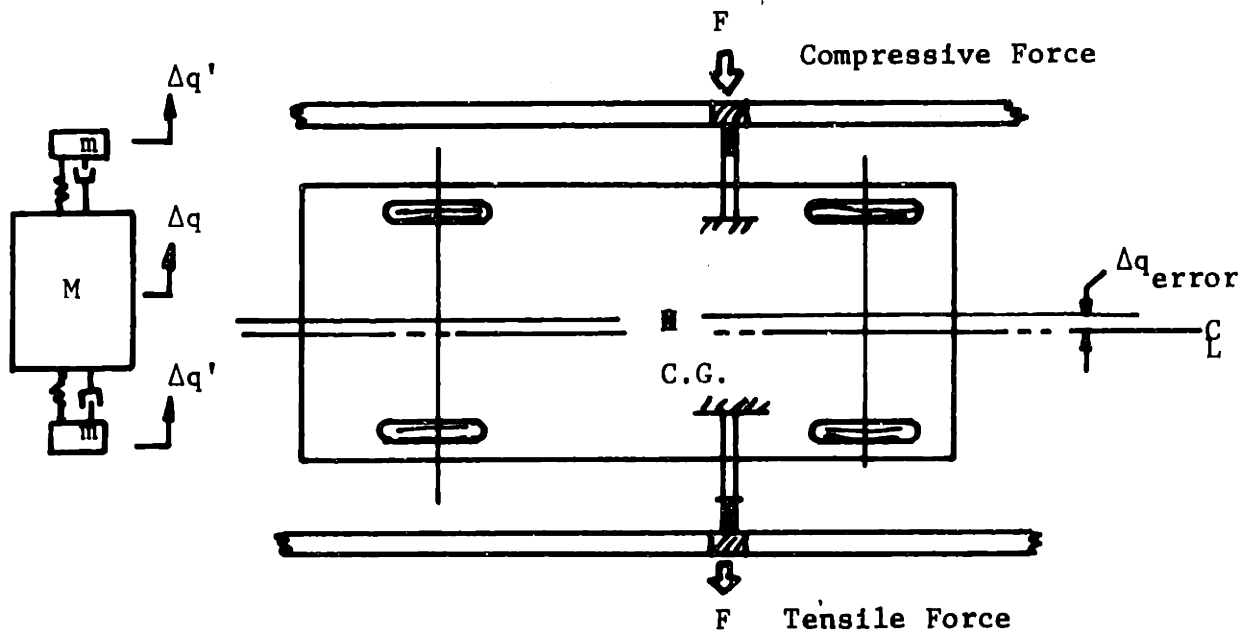


Fig. 3-1. Passive Guidance Principle

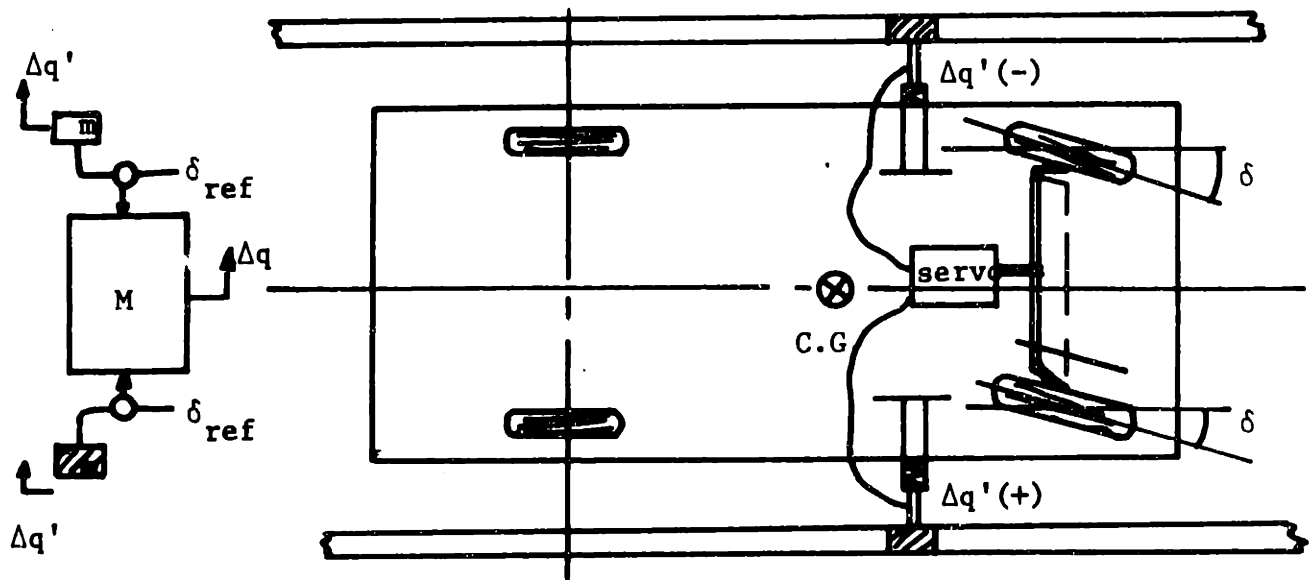


Fig. 3-2. Active Guidance System with Passive Fallback.

In practice, the passive and active system concepts will be combined to yield a fairly reliable offspring -- an active guidance system with passive fallback for emergencies. If the active system failed, the vehicle could still be guided by the push-pull action of the arms.

PASSIVE GUIDANCE SYSTEMS

Under passive guidance, vehicles would operate with a clamped steering wheel on the guideway, but the clamp would be released for regular manual steering off-guideway. The primary force inputs come from the tires, the arms and wind gusts. Mainline cruising guidance is substantially different from that at switches and merges, when only one arm is in contact with the guiderail for a short period. The forces acting laterally on the passive vehicle are (Fig. 3-3):

- * Lateral forces along the arm, F_a .
- * Frictional force in the follower, F_μ , backwards longitudinally.
- * Supportive forces and longitudinal (accel/decel) forces through the tires.
- * Lateral (steering) forces on the tires, parallel to the guideway surface, F_f and F_r .
- * Lateral wind loads, F_{wind} .

Because the guidance arms are not completely horizontal, a slight vertical component of force and a moment about the car's roll axis is generated. Furthermore, the arm retraction mechanism

15.

(modeled as a vertical air or oil cylinder connected to the arm) can have roll stiffness and damping impacts. (Fig. 3-4). Experimental test runs with a single-arm vehicle running on a gravel guideway surface has shown that the oil-damped retraction cylinder created a much smoother car ride as the car passed over normally serious irregularities in the test roadbed. Thus, the vehicle suspension could have the primary responsibility for smoothing vertical oscillations, while the guidance arms could help control the roll motions. The arms can be cross connected to function as a roll stabilizer bar while permitting fairly free vertical motion. The limitation here is the degree of increased wear absorbed by the follower pads.

Depending upon the arm loading, the follower will be subjected to heat and friction losses, and the smoothness of the guideway joints becomes critically important. The friction drag on the follower increases during the more extreme passive guidance maneuvers, and this rearward force exerts a yaw moment about the Z axis. Fortunately, this "unstable" component of force tending to steer the car off the guideway centerline is far outweighed by the primary, stable push-pull force which keeps the car in line properly. This overall stability was demonstrated many times with the test vehicle on the M.I.T. test track, under some of the most difficult conditions : a tight, largely unlubricated follower on only one side of the car with periodic rail joints which had not been ground

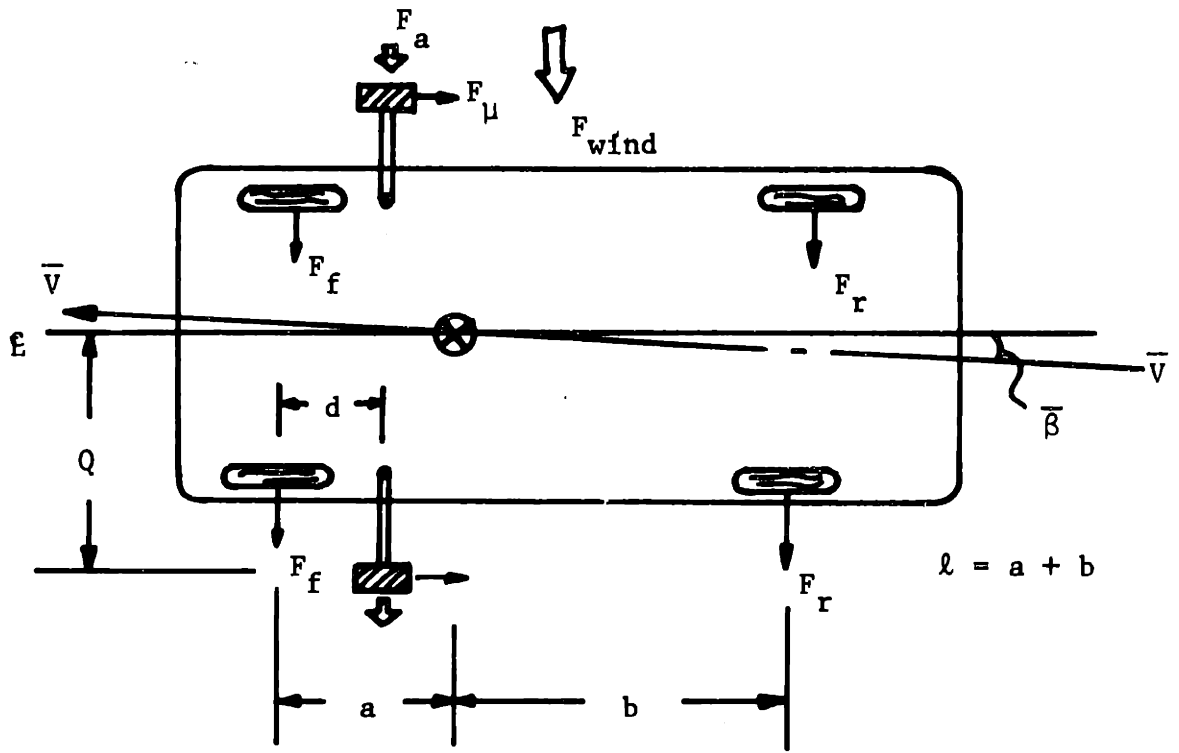


Fig. 3-3. Primary Forces Acting on a Passively-guided Vehicle

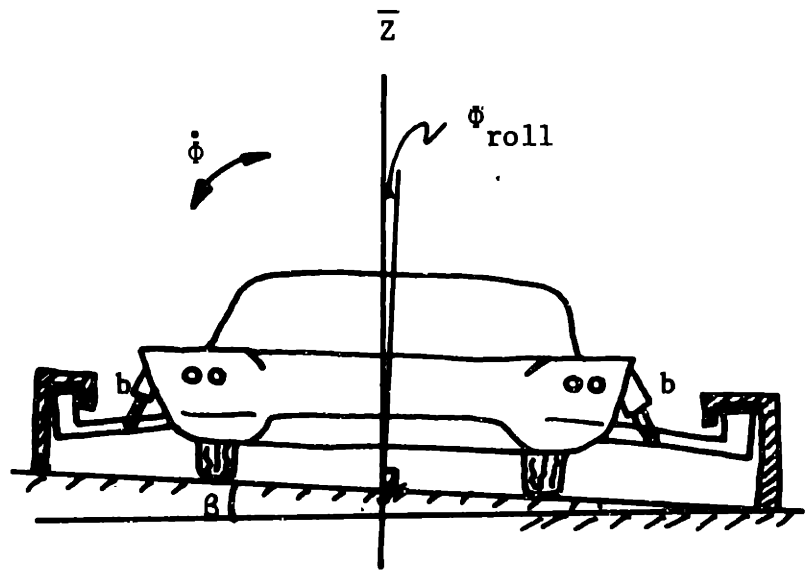


Fig. 3-9. Roll Damping Effects From Guidance Arms.

completely smooth -- with the exception of one winter's day when the test roadway was covered with glare ice and the rear wheels spun on acceleration, and the rear end slid out to the side.

Push-pull passive guidance is achieved at the expense of some tire slippage, the ordinary tire forces which cause a car to turn when the wheels are turned at an angle to the vehicle velocity. These forces are proportional to the loads on each wheel and also to the tire slippage angle, for small angles (Fig. 3-5). For any given vehicle, the proportionality factor between angle and side force is commonly called the Cornering Power, \overline{CP} , and in addition castering forces result in an aligning torque, \overline{AT} , and camber contributes to camber thrust, \overline{CT} . The predominating factor is the Cornering Power, and its linearity can be assumed up to 0.3 G lateral acceleration, far in excess of expected guideway extremes. The three-degree-of-freedom model of the automobile and its suspension includes roll steering (the front wheels cambering more than the rear wheels) and other factors to be discussed later.

If the front wheels are unintentionally locked at a slight angle, $d\delta_0$, or if the rear axle is crabbed, the passive vehicle will tend to steer and pull to one side on the arm. The force balance and moment equations are

$$2 \overline{CP} (\overline{\beta} - d\delta_o) + 2 \overline{CP} \times \overline{\beta} - 2 F_a = 0 \quad (3.1)$$

and

$$2 \overline{CP} (\overline{\beta} - d\delta_o)l - 2 (\overline{CP} \times \overline{\beta})l + 2 F_a (\ell - d) = 0 \quad (3.2)$$

where ℓ is the vehicle wheelbase. For two arm guidance, each arm carries a force

$$F_a = \left| \frac{\overline{CP} d\delta_o \ell}{(\ell - d)} \right| \quad (3.3)$$

For single arm guidance, the largest arm forces are generated :

$$\frac{\Delta F_a}{\Delta \delta} = \frac{2 \overline{CP} \ell}{\ell - d} = 307 \text{ lbs. per } ^\circ \text{ front wheels} \quad (3.4)$$

or approx. 15 lbs. per degree of steering wheel deviation

Similarly, crabbing motion due to rear axle misalignment ϵ_o causes forces in each arm of

$$F_a = \left| \frac{\overline{CP} \epsilon_o \ell}{(\ell - d)} \right| \quad (3.5)$$

The lateral forces created by an improper match of speed and banking angle result in a stable drift angle $\overline{\beta}$ (unless the tires lose traction), and the arms carry no corrective sideload. The calculated tire forces for a representative vehicle, the test 1967 Mustang, (Fig. 3.6), are a function of banking and velocity parameters.

In a low-radius curve, the lack of front wheel caster

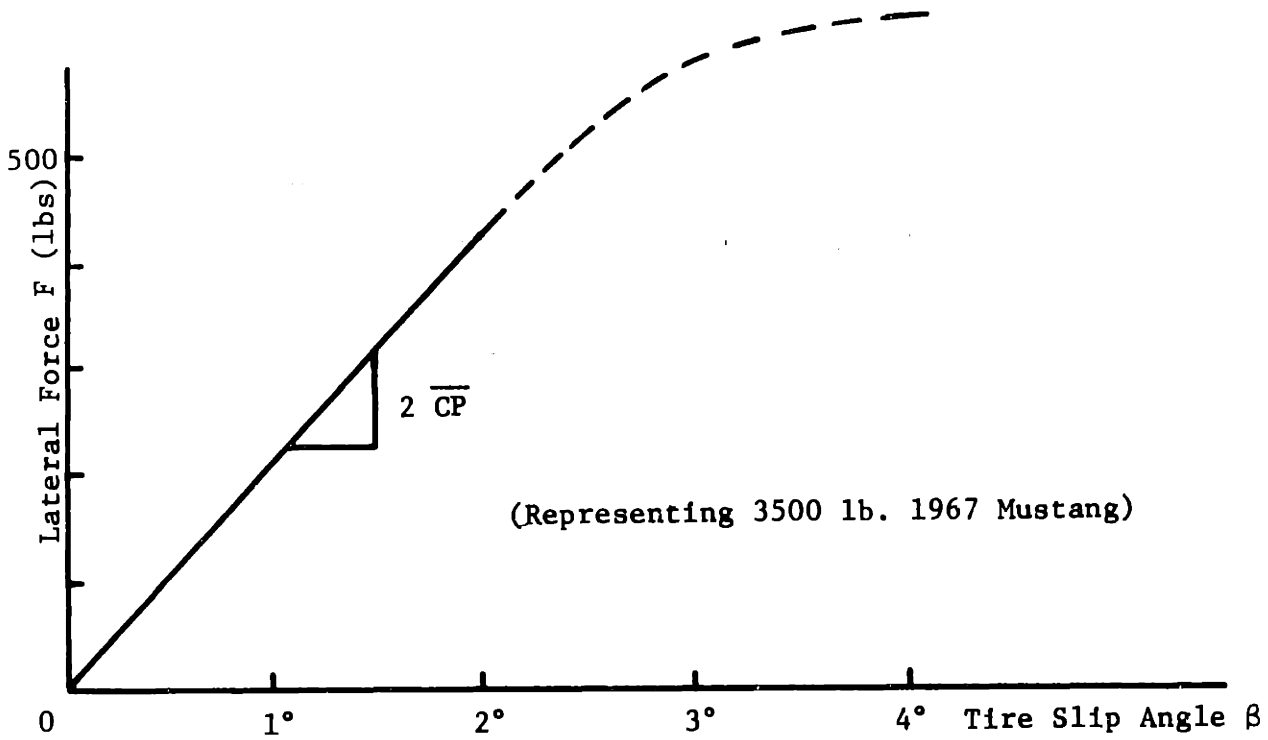


Fig. 3-5. Lateral Force Due to Tire Slip Angle, Mustang.

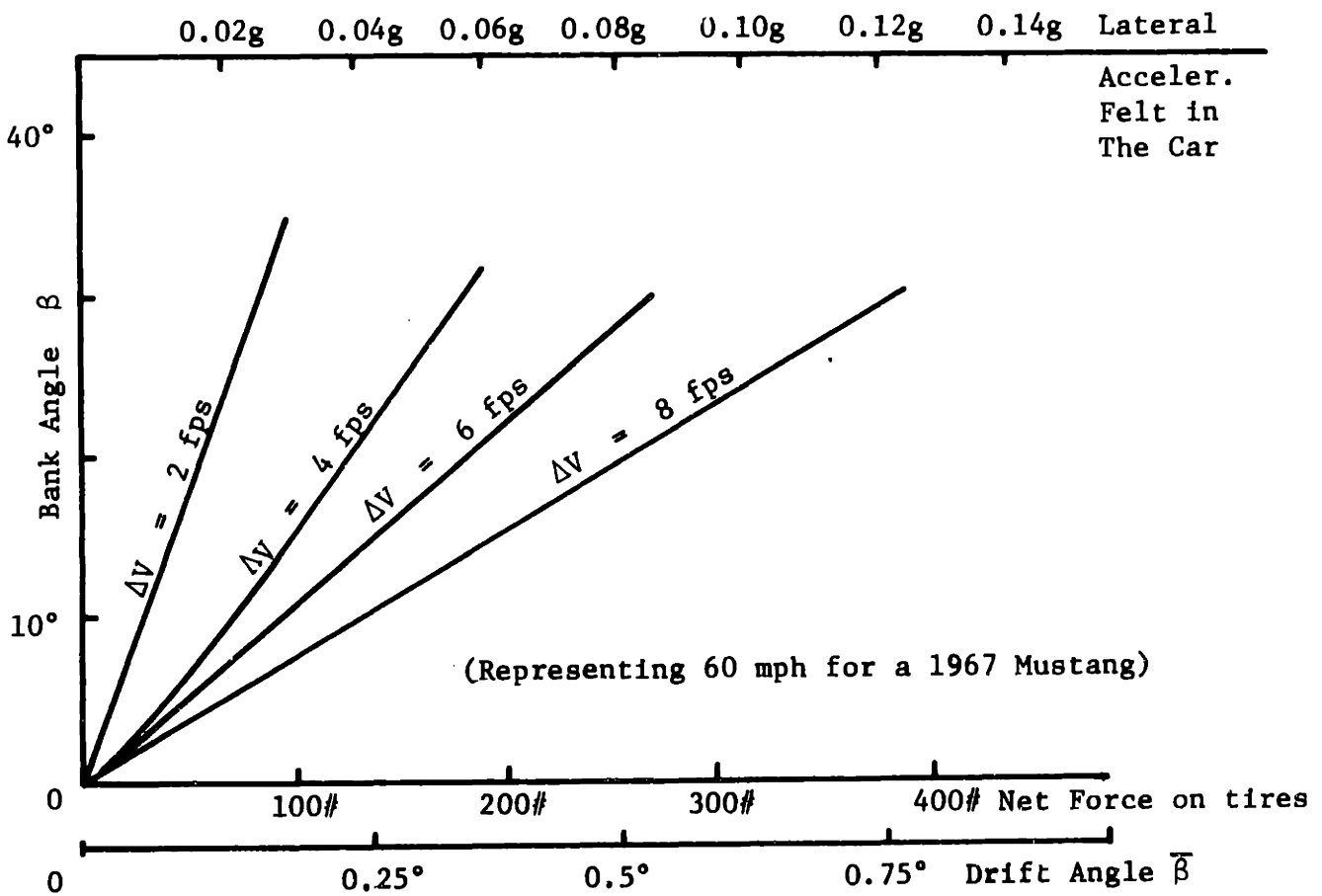


Fig. 3-6. Forces in Guidance Arms : Banking & Velocity Variations

action means that all four wheels are not -- in plan view -- perpendicular to the guideway radius of curvature and hence tire scrubbing occurs, requiring further restraint by the arms, as shown in Fig. 3.7.

For a scrub angle, δ_{ss} , on an unbanked curve,

$$\delta_{ss} = \tan^{-1} (l/\rho) \quad (3.6)$$

However,

$$\delta_{ss} = \tan^{-1} \left(\frac{l \cos \beta}{\rho} \right) \approx \frac{l \cos \beta}{\rho} = \frac{lg \sin \beta}{v^2} = \frac{lg\beta}{v^2} \quad (3.7)$$

for a curve of bank angle β and radius ρ and using small angle approximations for a speed of 60 mph. The lateral arm force generated is

$$F_a \Big|_{\delta_{ss}} = \frac{\overline{CP} l^2 g \beta}{v^2 (l - d)} = 330 \beta \text{ lbs.} \quad (3.8)$$

where β is measured in radians.

In all of the above cases, the forces along the arms, F_a , may be tensile or compressive, depending upon the disturbance and can represent the difference between the forces exerted by both arms, or the force of one arm alone. Handling under one-arm guidance will be affected by the aforementioned frictional drag yaw component, with moment and force equations of

$$- F_{\mu} q - F_a (a-d) - 2 F_f a + 2 F_r b = 0 \quad (3.9)$$

and

$$- F_a = 2 F_r + 2 F_f = 4 F_r \quad (3.10)$$

where F_{μ} is the backwards drag force and the forces on the front wheels F_f are assumed equal to the rear wheel forces F_r , for simplification.

On the Mustang, the arm loading exceeds the follower drag by

$$F_a = 2.4 | F_{\mu} | \quad (3.11)$$

If the friction force is approximately modeled as the combination of a static force due to internal pad contact pressure and a variable force due to tensile/compressive loading,

$$F_{\mu} = \mu_e (F_o + | F_a |) \quad (3.12)$$

where F_o is the pad area x the pad pressure), then the force relation for single-arm guidance becomes .

$$F_a = \frac{2.4 \mu_e F_o}{1 - 2.4 \mu_e} \quad (3.13)$$

Thus, without the need for a guidance correction, a pad contact force of 50 lbs. and a friction coefficient of 0.1 yields a residual force F_a of 18 lbs. For two-arm guidance, this residual force is zero.

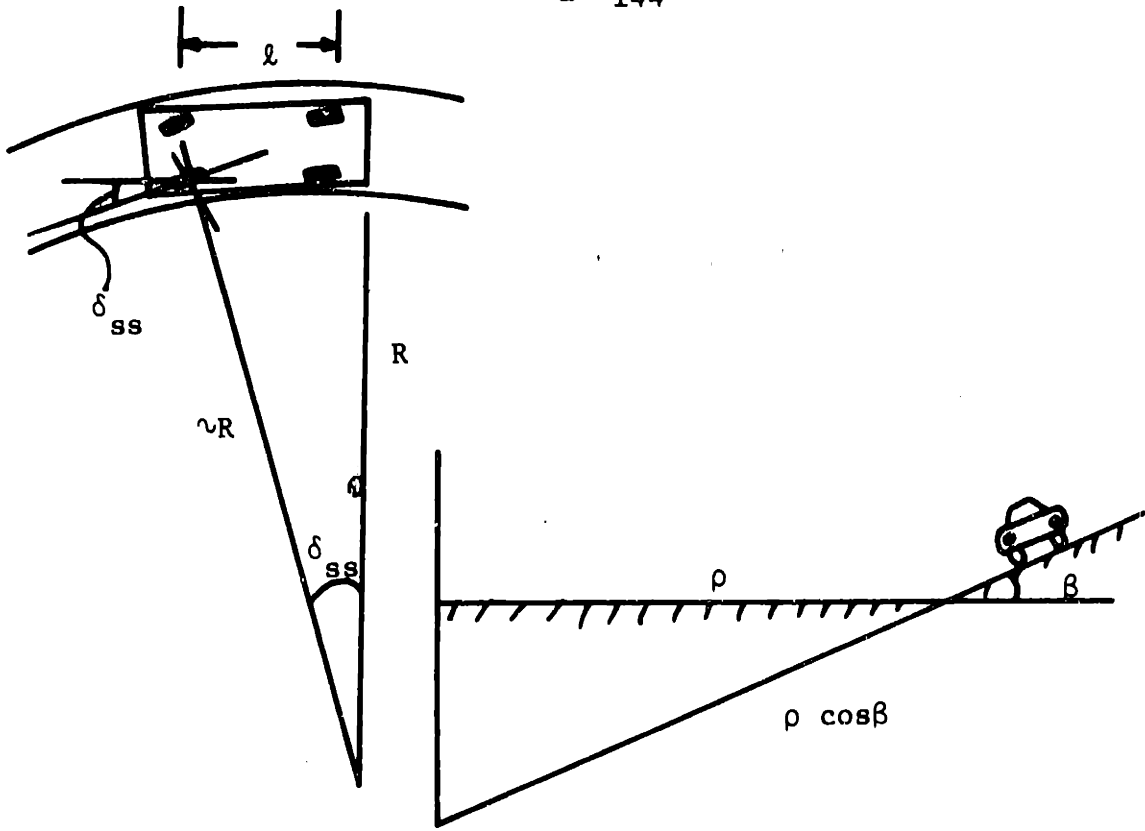


Fig. 3-7. Zero-caster Tire Scrubbing on Banked Curves

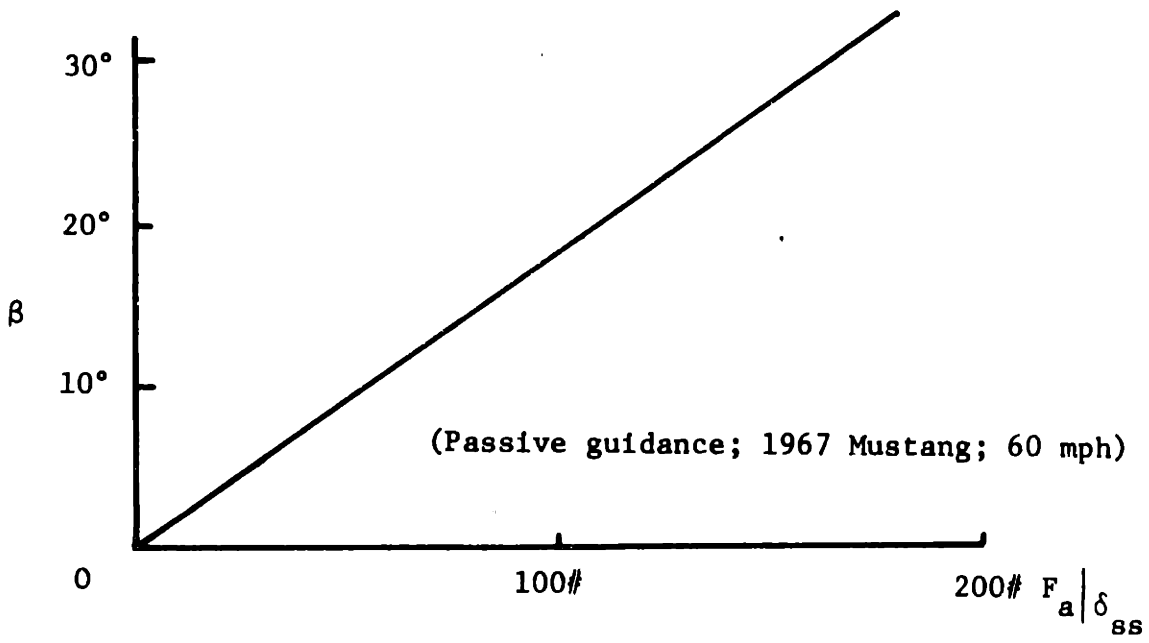


Fig. 3-8. Forces in Arm Resulting From Zero-caster Effects on Curves

Wind loadings can be resolved into headwind and crosswind components. Headwinds have an effect on a car similar to a breeze striking a weathervane. For vehicles cocked at an angle $\bar{\beta}$ to travel, the direction of the force is through the "center of pressure," which is at the front door edge according to a standard automotive rule of thumb. The center of pressure for sidewinds is typically 40 inches in front of the rear axle, and this point will be used as the calculated point of application of the net lateral gust.

The magnitude of the wind force is

$$F_w = C_D A V^2 = 60 \text{ lbs.}, \text{ for 30 mph gusts} \quad (3.14)$$

and

$$F_w = 240 \text{ lbs. for 60 mph gusts} \quad (3.15)$$

on a 1967 Mustang, where C_D and A relate to the side area of the car. Translating this data into the additional force component to F_a ,

$$F_a \text{ (wind)} = 0.7 F_w \quad (3.16)$$

The foregoing analytical results can be summarized and physically applied to the case of the test 1967 Mustang by use of the specs and parameters of Table 3-2 :

(a) Error component due to $d\delta_o$ in front wheel steering lock

$$F_a \left| \frac{d}{d\delta_o} \right. = \frac{\overline{CP} d\delta_o \ell}{(\ell - d)} \quad (3.17)$$

(b) Error component due to rear axle misalignment ϵ_o

$$F_a \Big|_{\epsilon_o} = \frac{\overline{CP} \epsilon_o \ell}{(\ell - d)} \quad (3.18)$$

(c) Velocity variations and banking error on curves

$$F_a \Big|_{\Delta V, \Delta \beta} = 0 \quad (3.19)$$

(d) Zero-caster tire scrubbing on low-radius curves

$$F_a \Big|_{\delta_{ss}} = \frac{\overline{CP} \ell^2 g \beta}{V^2 (\ell - d)} \quad (3.20)$$

(e) Follower friction drag effects (single arm only)

$$F_a \Big|_{\mu} = \frac{2.4 \mu_e F_o}{1 - 2.4 \mu_e} \quad (3.21)$$

(f) Wind gust effects

$$\begin{aligned} F_a \Big|_w &= 0.35 F_w \quad (\text{each arm}) \\ &= 42 \text{ lbs. for a 30mph gust} \end{aligned} \quad (3.22)$$

The preceding group of force components are different in concept from the dynamic forces necessary to impart yaw or roll momentum changes to the vehicle. The arms must impart yaw accelerations about the vehicle center of gravity during travel into the transitional guideway sections between straight sections and various banked curves. The same transitional phenomenon occurs on conventional highways and its physical reality is best visualized by the action of a bar of soap

TABLE 3-2 1967 MUSTANG SPECS AND PARAMETERS

Weight : Front.....1760 lbs. Rear....1550 lbs. Total...3310
 Unsprung....440 lbs.

Inertia about C.G. : Roll....492 lb-ft-sec² C.G. Height....
 Pitch..1471 lb-ft-sec² ...20.4 in.
 Yaw....2355 lb-ft-sec²

Wheelbase (ℓ).....108 in. Front and rear tread....56 in.
 b = 60 in. a = 48 in. d = 25 in.

Front roll center height...2.52 in. Rear roll ctr. height...9.36

Tires : (6.95 x 14 Goodrich 4-ply 28 psi)
 Cornering Power \overline{CP} ...Front, 118 lb./deg/tire (6750 lb./rad)
 ...REar, 112 lb./deg/tire (6410 lb./rad)
 Camber Stiffness \overline{CT} ..Front, 22.2 lb./deg/tire (1270 lb./rad)
 Rear, 17.8 lb./deg/tire (1020 lb./rad)

Suspension Rates :
 Overall K_ϕ , the roll spring constant = 40,000 ft-lb/rad.
 Roll damping rate = 1126 ft-lb-sec/rad

TABLE 3-3 BANKING GEOMETRY AND YAW FORCES
 (1967 Mustang, passive guidance)

	$t_f = 0.7$ sec.	$t_f = 1.0$ sec.	$t_f = 2.0$ sec.
β_{max}	30°	30°	30°
$\dot{\beta}_{max}$	0.83/sec	0.58/sec	0.29/sec
α_{max} (yaw)	0.30/sec ²	0.21/sec ²	0.11/sec ²
F_a max	270lbs.	189 lbs.	99 lbs.

sliding around a banked curve -- even though there is optimal banking, the soap bar will follow the curve but will not turn in yaw because there are no forces in the banked guideway to turn it in yaw.

The yaw acceleration necessary for accurate guidance through transitionals, α_{yaw} , is related to the heading angle ψ (Fig. 3-9) :

$$\alpha_{yaw} = \ddot{\psi} \cos \beta \quad (3.23)$$

Since

$$\tan \beta = v^2 / g\rho \quad ; \quad \rho \dot{\psi} = v \quad (3.24)$$

Then,

$$\alpha_{yaw} = \frac{g \dot{\beta} \cos \beta}{v} \quad (3.25)$$

and for small banking angles,

$$\alpha_{yaw} = \frac{g \dot{\beta}}{v} \quad (3.26)$$

A reasonable first assumption for design purposes is that the transitional curve produces a sinusoidal time (distance) variation of the bank angle as the vehicle moves through the switch or curve. The geometry of banking and heading changes is developed in some detail in Chapter 6, including comfort considerations, and the results are summarized here.

The maximum yaw acceleration and hence $\dot{\beta}$ and $\ddot{\beta}$ will

depend upon both β_{\max} and the rate of curvature transition, as in Table 3-2. The highest value of banking rate, $\dot{\beta}$, for a "comfortable" curve having a maximum bank angle β_{\max} (constant curvature) is (Fig. 3-10)

$$\dot{\beta}_{\max} = \frac{\beta_{\max}}{2 t_f} \quad (3.27)$$

where t_f is a measure of the abruptness of the curve transition, or the time to travel along the transition segment. For the simplest model of the car, with 50/50 weight distribution and equal tires all around and no wind, the general moment and force equations

$$2 F_a + 2 F_r + 2 F_f - F_w = M a_c \quad (3.28)$$

$$-2 F_a (a-d) - 2 F_f (a) + 2 F_r (b) - F_w (w) = I_{zz} \alpha_{\text{yaw}} \quad (3.29)$$

reduce to

$$2 F_a = M a_c = 4 F_r \quad (3.30)$$

$$2 F_a = \frac{I_{zz} \alpha_{\text{yaw}}}{(a-d)} = -900 \text{ lbs.} \quad (3.31)$$

with the yaw forces in passive guidance supplied entirely by the guidance arms.

A composite summation of the forces from Eq. 3.17 to 3.22 and Fig. 3.10 is shown in Fig. 3.11 for the Mustang case.

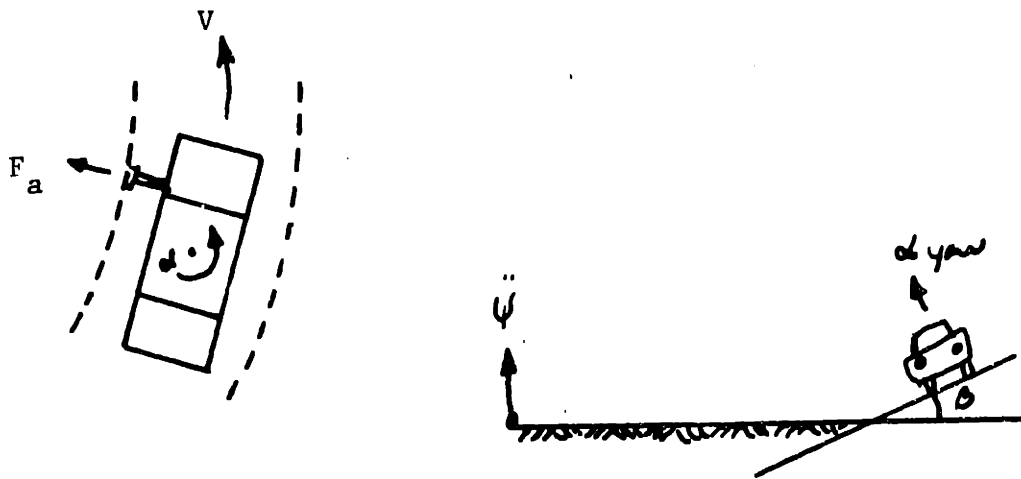


Fig. 3-9. Yaw Acceleration and Heading Angle

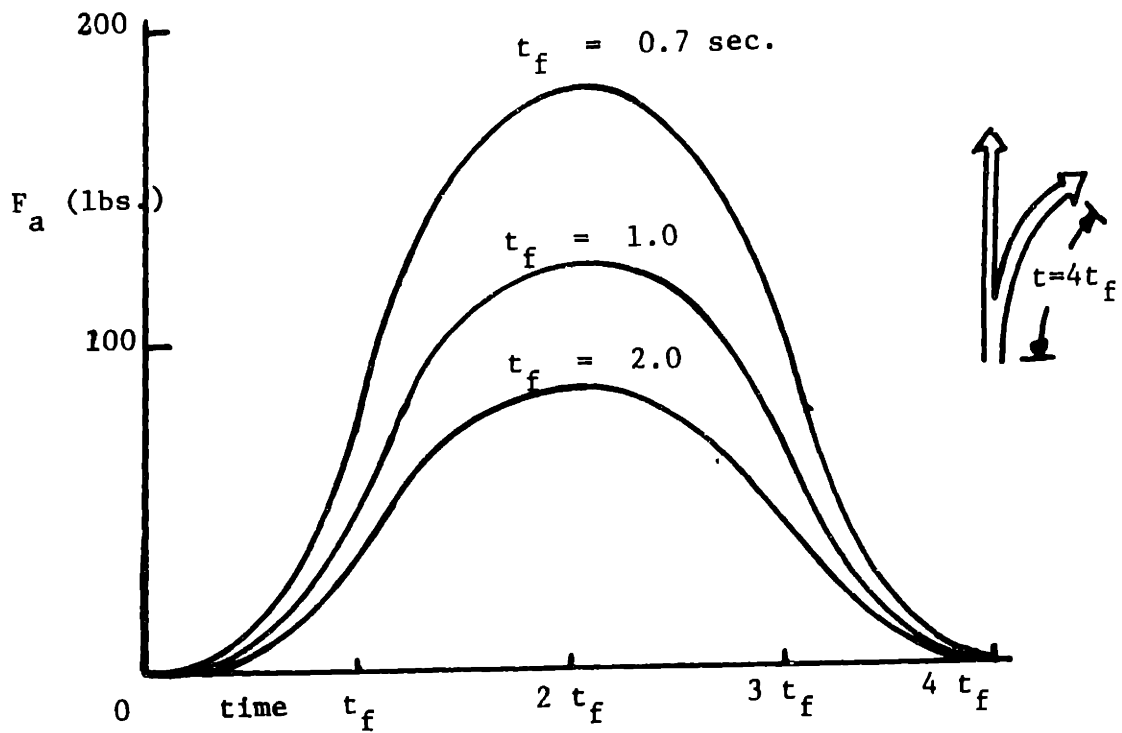


Fig. 3-10. Yaw Forces in Guidance Arm for Sinusoidally Banked Switch or Curve. (1967 Mustang; Passive guidance)

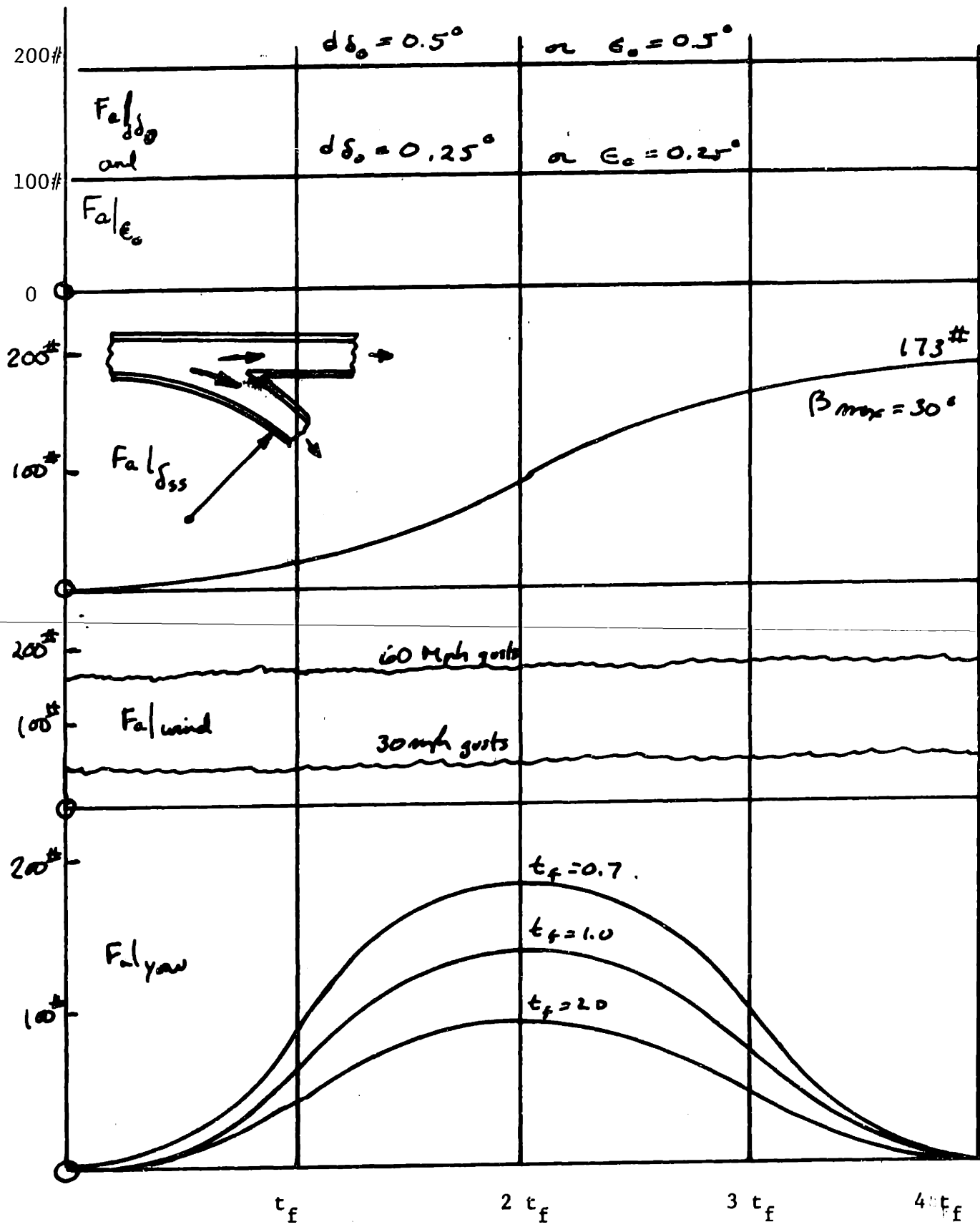


Fig. 3-11. Summary of Double Guidance Arm Forces on 1967 Mustang (Passive guidance; front wheels locked ahead).

The maximum force F_a attained is determined from the maximum of the relation

$$F_{tot} = F_a [d\delta_o, \epsilon_o, \text{wind}] + 300 \frac{\beta_{max} (\omega t - \sin \omega t)}{2 \pi} + 325 \frac{\beta_{max} (1 - \cos \omega t)}{2 t_f} \quad (3.32)$$

which includes both dynamic maneuvers and the yaw, zero-caster, and banking/velocity variation components. The worst possible case depends upon the value of t_{crit} , which from Fig. 3-11 is approximately 0.51 sec, and the overall maximum force under passive guidance at 60 mph for $t_f = 1$ sec. is

$$F_{a \max} = 832 \text{ lbs.} \quad (3.33)$$

Aerodynamic interactions between closely following cars can affect vehicle guidance and stability. The air current disturbances and vortices create, for 10-foot headway spacings, directional inputs of an unknown magnitude and duration, but the impact should be less severe than that of buses and trucks on expressways. Wind tunnel tests should be able to determine the significance of these effects.

Vehicles subjected to severe bottoming and rolling motions will produce special suspension steering effects, such as roll understeer. These factors can be reduced by good guideway design and adjustment to be independent of frost heaves and soil settling, with smooth and continuous joints. Vehicles traveling through highly banked curves would tend to squat down slightly on their

suspensions, but the directional control consequences should be minimal. Conceivably, roll effects could be significant for sharp transitional segments between different levels of banking, when roll accelerations and roll inertia cause the sprung body to roll on the suspension.

The most abrupt turns, as analysed in Chapter 6, result from a straight-line travel transition to a constant 30° banking, as calculated for various elapsed times of 2.8, 4.0 and 8.0 sec. for the maneuver (which are also in the order of increasing comfort). The roll moment equation for the moving vehicle is

$$K_{\phi} \phi_{\max} = I_{\text{roll}} \ddot{\beta}_{\max} = I_{\text{roll}} \left(\frac{\pi}{8} \right) \frac{\beta_{\max}}{t_f^2} \quad (3.34)$$

with $K_{\phi} = 40,000$ ft-lb/rad.

Thus,

$$\begin{aligned} \phi_{\max} &= 0.28^{\circ} && \text{for } t_f = 0.7 \text{ sec.} \\ \phi_{\max} &= 0.14^{\circ} && \text{for } t_f = 1.0 \text{ sec.} \\ \phi_{\max} &= 0.03^{\circ} && \text{for } t_f = 2.0 \text{ sec.} \end{aligned} \quad (3.35)$$

The maximum roll angle is less than one degree and passenger comfort should be generally unaffected by *suspension* roll motions in transition guideway sections, while the actual *guideway* roll motions discussed in Chapter 6 become the controlling factor in terms of passenger comfort.

Tanner¹ has reported calculations that indicate guidance

arm length changes during roll do not exceed 0.18 in. per degree of roll :

Roll Angle ϕ	Change in length of Arm, Δq_{arm}
+ 0.05 rad (2.85°)	+ 0.5 in.
- 0.05 rad (-2.85°)	- 0.25 in.

There is also a yaw constraint on guideway travel, a limit to the drift angle a vehicle can sustain and not scrape the lateral guiderail. For a maximum arm deflection of 3 in. and a guideway inside gauge of 94.56 in., a car 78-in. wide front and rear would have opposite front and rear corners clearing the rail by 1 in. and 3 in. respectively, when the drift angle is 4°. The likelihood of this drift angle occurring normally is remote, since such a maneuver amounts to a skid condition. Skidding aspects in terms of guideway design and emergency procedures are discussed in Chapters 6 and 7.

Overall, the advantages and disadvantages of passive guidance are

(+) ADVANTAGES.....

- * Simple and inexpensive to make
- * Reliable
- * Fewer modifications to vehicles, esp. steering systems
- * No transducers, pumps, servos, etc.
- * No-lag response to guiderail inputs

(cont.)

- * Easier replacement and maintenance
- * The steering wheel does not turn inside the car; manual inputs are safely blocked out.

(-) DISADVANTAGES.....

- * Tire scrubbing and large forces in arms on curves
- * Higher frictional forces, wear & heating in the follower pads
- * Greater difficulty of positioning the follower during a merge or switch for regripping guiderail.
- * If an error in steering results from locking the column or linkage, the car will pull to one side.
- * Limited low speed maneuvering where sharp turns are necessary, as in stations or entrance/exits
- * Guiderail joints and irregularities will be sensed more readily by the passengers
- * Entry alignment problems?

ACTIVE GUIDANCE SYSTEM HARDWARE

Active guidance systems steer the front wheels by servo control during automatic modes, and in manual operations, the active guidance components disengage and deactivate themselves from the basic manual steering system.

A buried-cable active guidance system was tested extensively by RCA and General Motors Laboratories in the 1950s. On an existing roadway, a single cable was buried in a shallow trench just beneath the surface and energized to generate a magnetic path signal for tracking cars. (Secondary cables,

arranged in interconnected loops, were laid in 13 ft x 5 ft. wide rectangles, spaced 2 feet apart, to regulate the speed and spacing). Any deviation of a vehicle from the cable path is sensed by two pick-up coils tuned to the road frequency. These detector coils are attached to the front of the car, straddling the cable, and the pair of coils working in opposition senses both the direction and magnitude of error. A compensating computer receives the path-error signal and also takes into account the vehicle velocity and front wheel steering angle at any instant. Then the computer commands the electro-hydraulic steering servo to adjust the front wheel angle to return the car to its correct course.

An important feature of the RCA/GM controller is the use of the path error derivative or rate of change, as well as the path error itself. Continuous controller adjustment is now possible, to keep the vehicle from overshooting the cable centerline and oscillating about the correct path. Variable ratio steering is also feasible, so that at low speeds a small signal results in a relatively large change in front wheel angle.

For dual-mode lateral arm guidance, the steering linkage is controlled by guidance arm inputs and preview information, while the vehicle may respond directly to lateral wind gusts and road disturbances (Fig. 3-12).

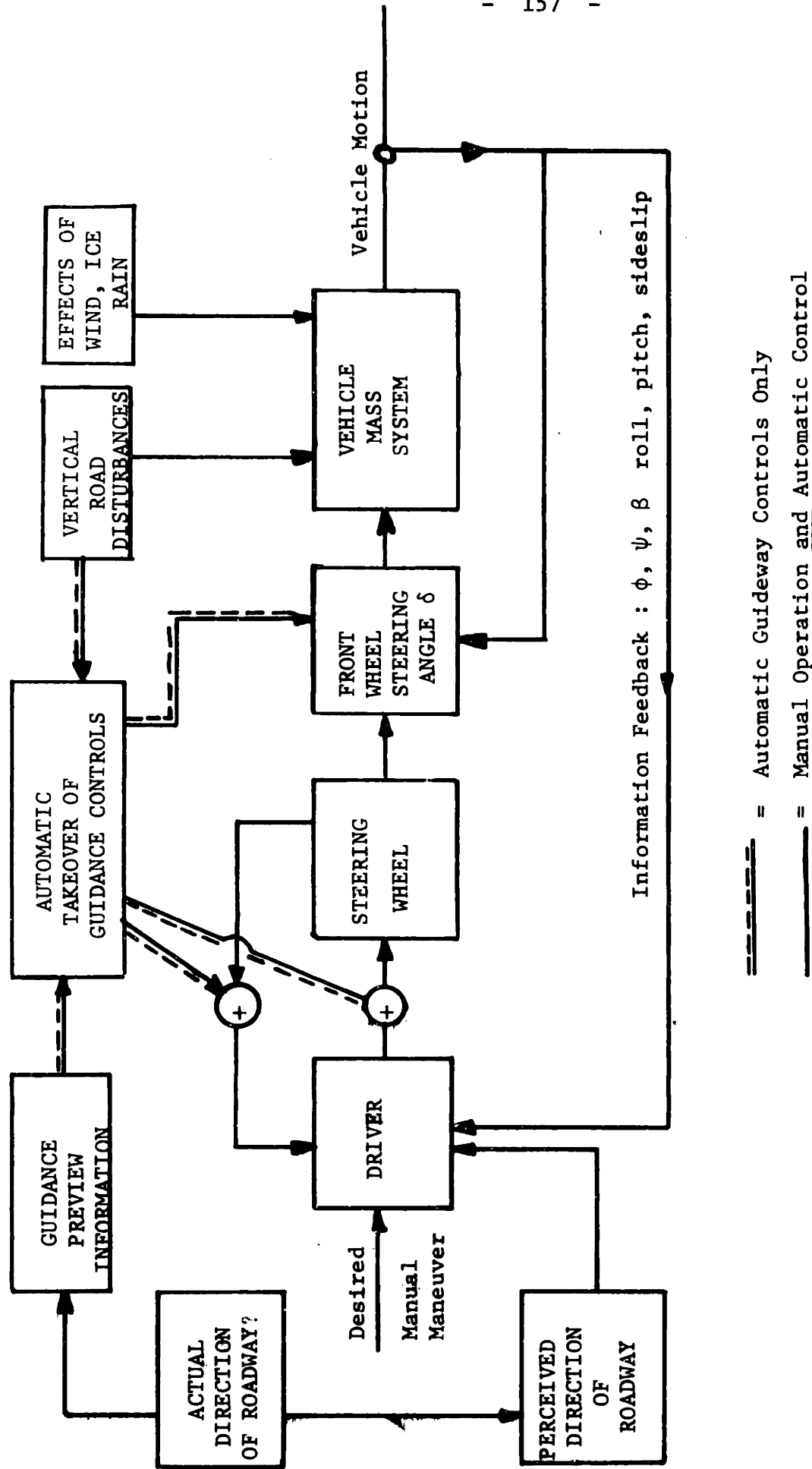


Fig. 3-12. Relation Between Manual Driver Steering Inputs and Automatic guidance control

A number of hardware options appear feasible for detecting and correcting vehicle excursions from the guideway centerline, employing an active telescoping arm that yields a displacement input with from an LVDT or similar transducer, or from a fluid flow change. The *electrical* transducer signal activates a solenoid spool valve or alternatively the spool valve is driven directly by the telescoping arm displacements (Fig. 3-13, 3-14). *Fluid flow* variations are directed to the power steering system, esp. the steering cylinder, or to an auxiliary cylinder attached to the steering linkage. (Fig. 3-15).

During regular operation, the guidance arms register displacement errors of voltage v_1 and v_2 at the transducer, or fluid displacements ΔV_1 and ΔV_2 from the cylinder. These error signals are averaged by a summation box, resulting in a net error signal, v_{12} and ΔV_{12} respectively. Ideally, the guiderails should be so assembled that inherent warp or curvature (including heat expansion, if necessary) is opposed to and cancels out the lateral warp of the rail on the other side of the guideway. This arrangement reduces the noise signal inputs to the steering system and results in improved response. During switches, only one arm steers the vehicle, and the summation would become a simple transmitting node. Noise inputs from the rail become harder to filter out, during the short section of the merge or switch, and guidance is not as smooth.

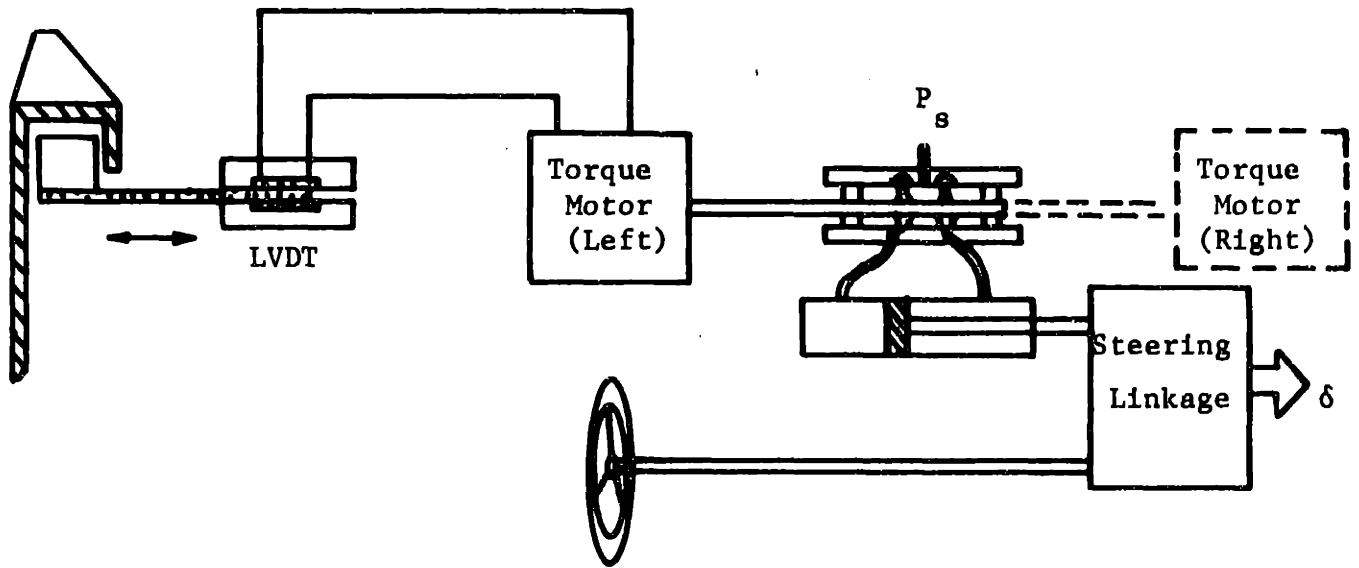


Fig. 3-13. Displacement Signal Control, LVDT and Spool Valve

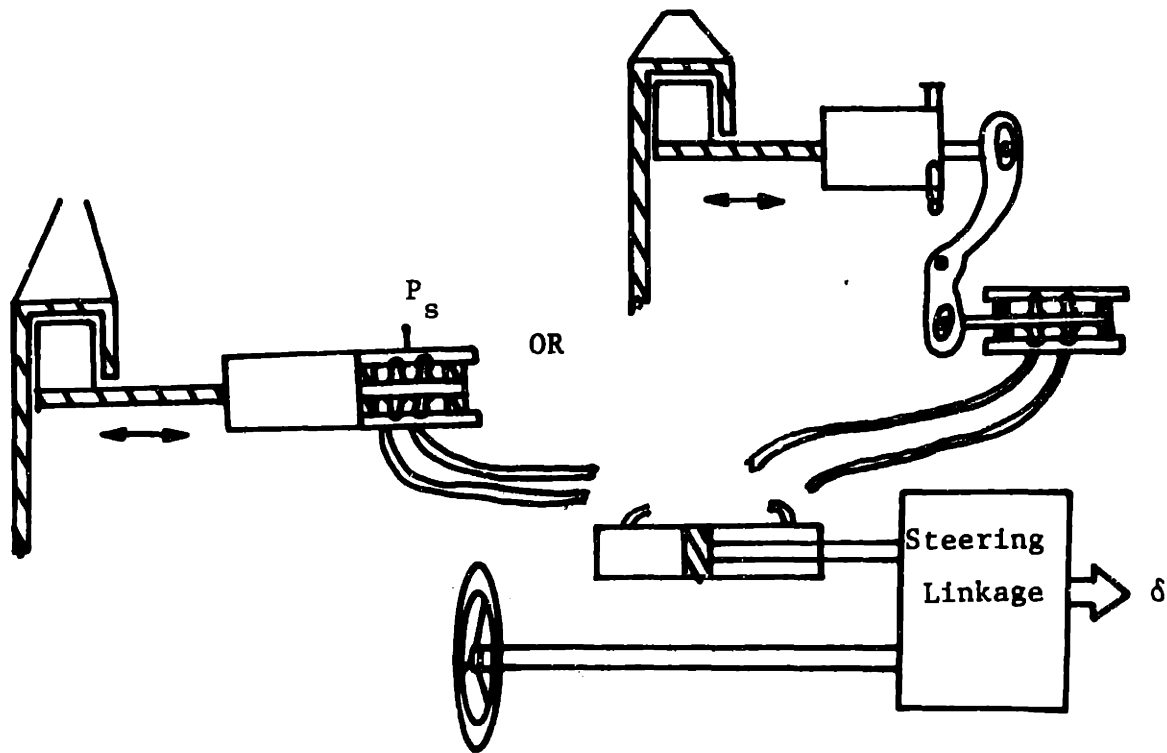


Fig. 3-14. Displacement Signal, Mechanical Link & Spool Valve

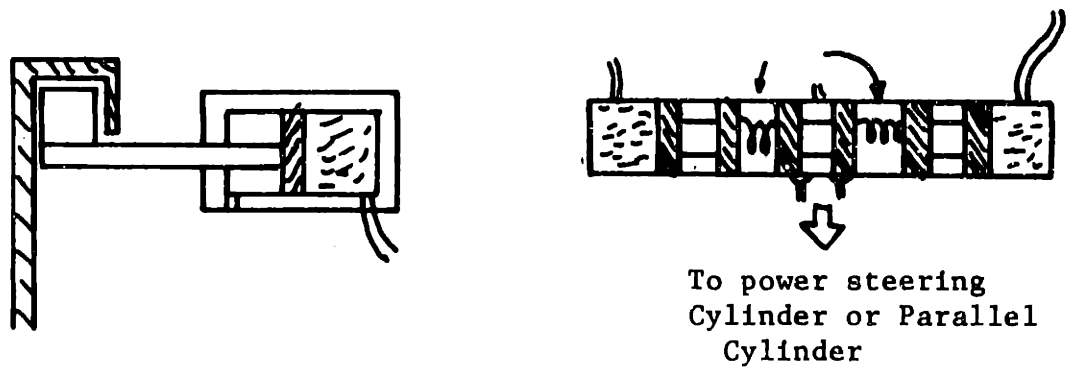


Fig. 3-15. Fluid Flow Guidance Input

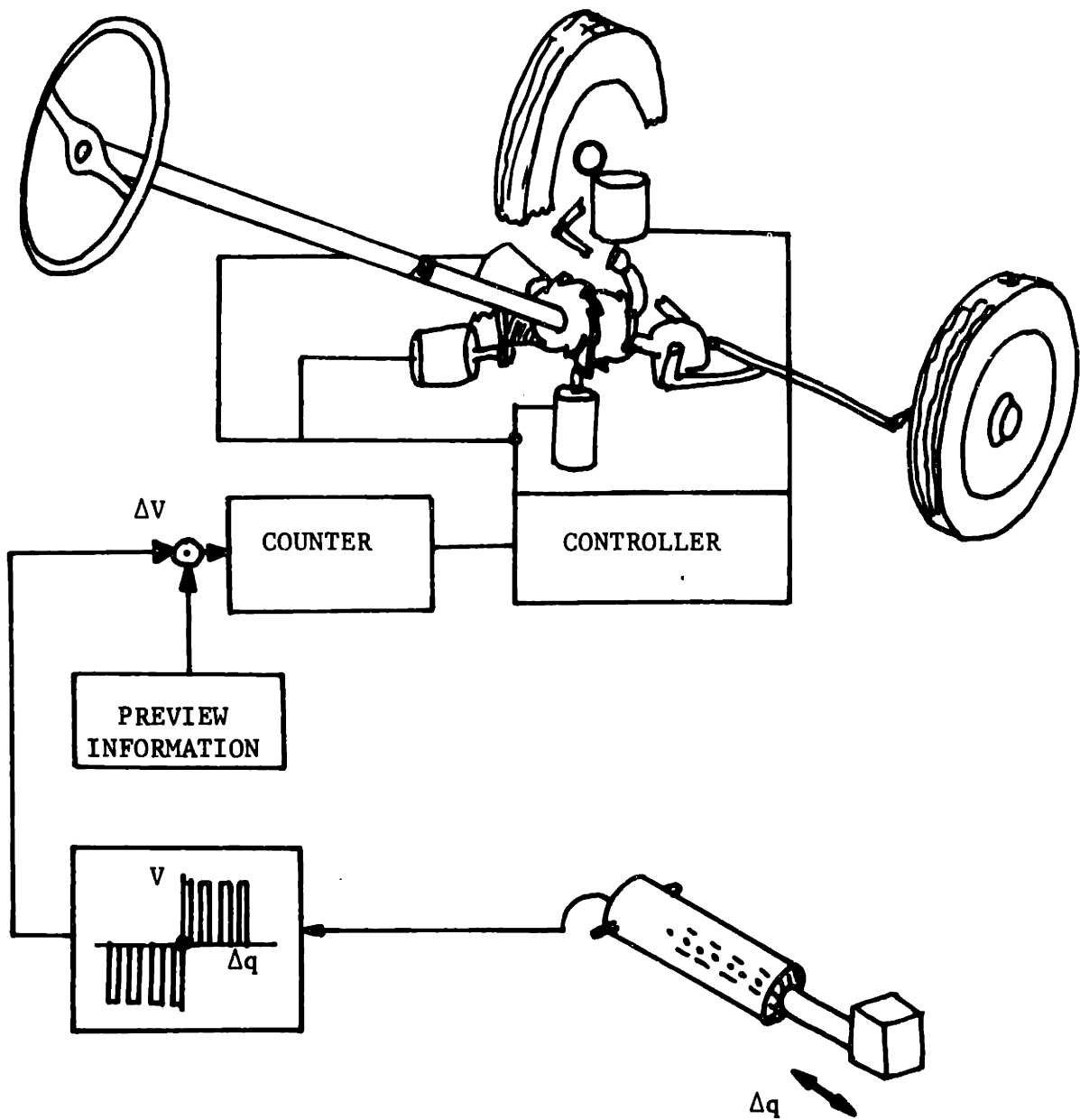


Fig. 3-16. Bang-bang Control of Steering Linkage.

If a rate sensor is added to the displacement transducer, the noise input from rail and follower chatter variations must be reduced by close attention to smooth sliding and joints.

The automated power assist can feasibly be attached to four likely locations within the manual steering system :

- (a). the power steering valve (the gasoline engine must be operating to provide pressure)
- (b). the power steering actuator cylinder (or additional parallel cylinder)
- (c). the tie rod
- (d). the idler arm - Pitman arm

Because of the different modes of operation, the automatic control attachments must not interfere with manual driving, nor manual inputs with automatic guidance on the guideway. In manual driving, the guideway steering cylinder is either short-circuited or the linkage is shifted to a neutral position.

The basic mechanical linkage from the steering wheel to the front wheels must remain always continuous for safe manual driving. As on present cars, the power steering system is connected in parallel, not in series. Hence, active automated guidance results in the steering wheel being rotated, and the guidance control system must be able to prevent the driver from imparting force inputs to the wheel rim. The objective is zero-compliance to manual wheel rim inputs, and two different types of controller appear able to provide this function :

- (a). Bang-bang control plus a clamp on the linkage -- small incremental impulses are given to the linkage with sufficient energy to counteract 10 to 40 lbs. manual force on the rim.
- (b). Continuous control from a high pressure fluid system (no air pockets or compliant springs).

One of the simplest mechanical devices for bang-bang-plus-clamp control is a two-way, high-speed magnetically operated ratchet, powered by solenoids. During manual travel, the ratchet spring releases and freewheels. However, steering response times during automatic control might be unacceptably slow and a positive displacement rotary torque motor mounted on the steering shaft might offer more responsive performance. A feasible hydraulic system includes a reversible positive displacement pump (e.g. a swash plate type) driving a cylinder actuator connected to the tie rod. Speed, accuracy and reliability are not the only critical factors : the steering linkage in manual mode must respond completely normally, with no extraneous inputs or resistance.

A zero-compliance fluid system using incremental fluid flow as the guidance control input and working directly between the guidance arm cylinders and the tie rod is handicapped by its fundamental lack of compliance, esp. to rail variations and vehicle roll or bounce. Moreover, leakage -- either internally or externally -- is a problem, and so is the establishment of a consistent null point in the steering system (so that the vehicle always returns to dead center and does not gradually creep off to

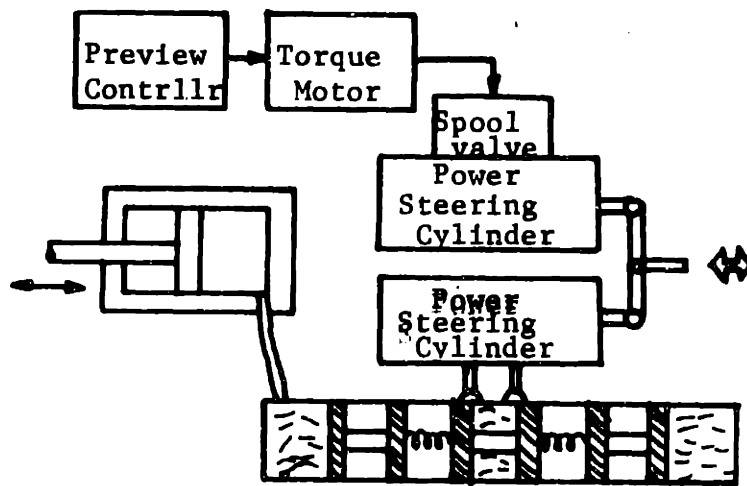
one side). With linkages or LVDT's, the null point is easier to maintain.

Incorporating predictive guidance inputs requires either a servo connection to the steering linkage or an addition to the arm displacement signal. All-fluid systems need an auxiliary servo leading to the steering actuator cylinder (Fig. 3-17a), while link servo systems are similarly afflicted. LVDT systems, especially those with bang-bang control, can be combined with a weighted summation box to provide a balanced response to both actual displacement error and predictive signal (Fig. 3-17b).

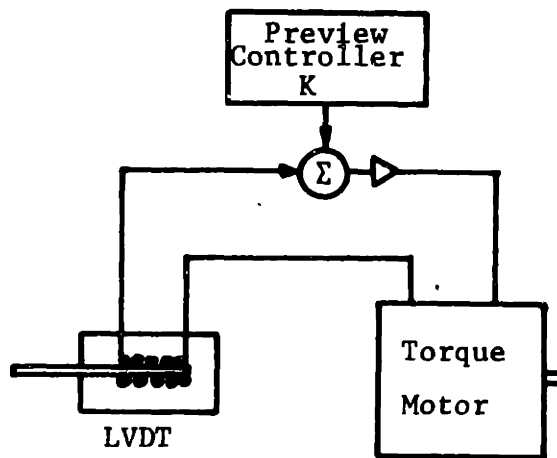
Predictive signals contain information about the approaching guideway -- its curvature and derivatives -- while each vehicle servo system includes special parameters accounting for the individual *vehicle* weight and handling characteristics. However, such special variables as passenger loading, tire inflation, wind loads and tire adhesion cannot be included.

ACTIVE GUIDANCE ANALYSIS

The force and geometry diagram for the active controller (Fig. 3-18) assumes that the arms are strictly transducers and do not carry force loadings. Limitation of the guidance error within specified limits, namely $\pm 3 - 4$ in., becomes most critical for the widest vehicles. The goal is a reasonable one, since the buried cable system employed by General Motors was able to track



(a) Fluid System



(b) LVDT and Weighted Summer

Fig. 3-17 ab. Combination of Measured Arm Displacements and Predictive Inputs.

within + 2 to 3 in. with a two-inch additional outswing on curves.

Automotive vehicle handling is a very complex but poorly developed science, and only approximate models are available. Considered as a rigid body, an automobile has six degrees of freedom -- translation and rotation about each of three axes. In actuality, there are numerous masses, springs and dampers of generally non-linear behavior, having complex interrelationships. However, the behavior of an automobile can be reasonably predicted by a linear model which takes into account only roll, yaw and lateral translations. A three-degree of freedom analysis has been developed by Larrabee² and demonstrates significant differences in handling response compared to the simpler two-degree of freedom model.

The lag components of the system include the transducer-servo link and the dynamic effects associated with vehicle yaw inertia and tire/suspension damping. Because four-wheeled vehicles steer about their rear wheels, the lead term created by the forward location of the guidance arms is measured from the rear axle centerline. Travel down the guideway produces a vehicle heading angle ψ_v , which may differ over time with the guideway heading angle, ψ_g , with the result that the guidance error, ψ_e , is detected by the arm transducer, and the error finally is nulled (Fig. 3-19).

The control system includes a third-order lag term,

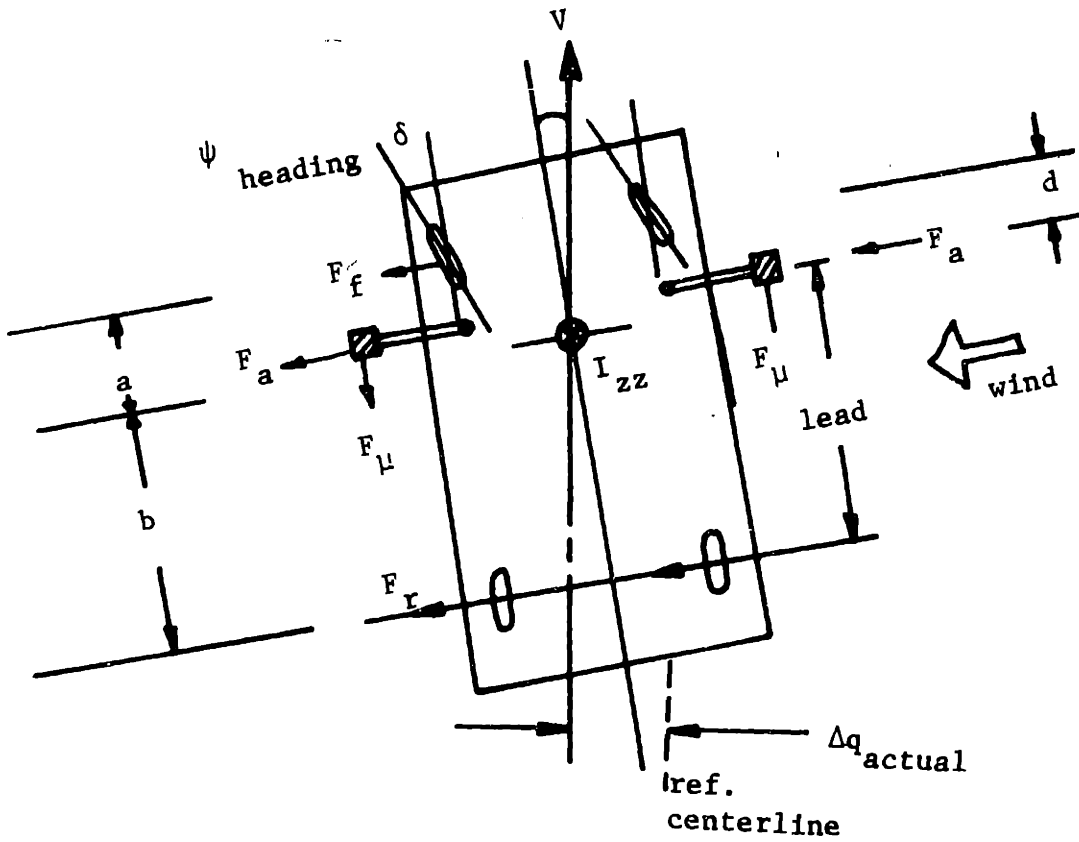


Fig. 3-18. Force and Geometry Diagram : Active Guidance

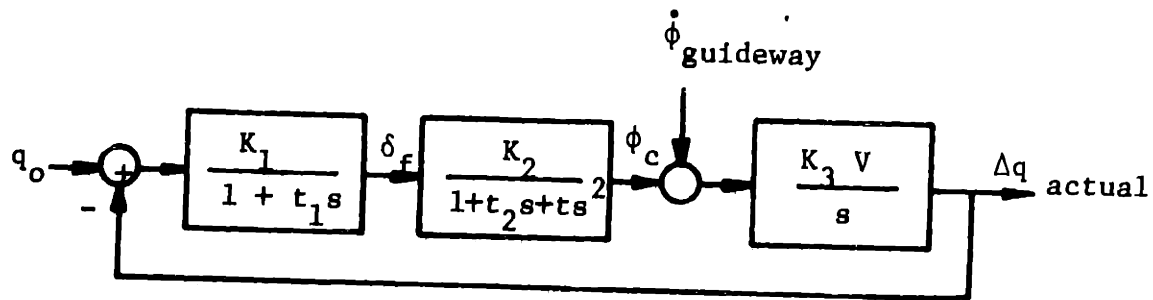


Fig. 3-19. Block Diagram : Active Controller

with several types of delays having varying significance -- signal processing or filtering, servo-mechanical lag (between sprung follower and steering cylinder), lag in the steering linkage, and vehicle handling response lag. The manual vehicle handling response has already been calculated for representative two- and three-degree-of-freedom cases by Larrabee, who estimates the former to exceed the latter by 50% in vehicle turning rate. The three-degree, steady-state results are (Fig. 3-20)

$$\phi / \delta_{ss} = - 1.167 \quad (3.36)$$

$$\frac{d\psi}{dt} / \delta_{ss} = + 4.31 / \text{sec.} \quad (3.37)$$

$$\bar{\beta} / \delta_{ss} = - 0.934 \quad (3.38)$$

The equivalent time constant for this response is 0.4 sec. For simplicity, the vehicle can be modeled as an underdamped second-order system with a damping ratio of 0.6.

The guiderail will contain certain irregularities even after adjustment -- such as lengthwise warping, joints and possible scale build-up. The smaller ripples can be absorbed by the springs in the follower pads (of the order of 0.1 in.) while larger irregular inputs could either be filtered or physically damped out, to prevent a rapidly fluctuating series of guidance signals from actuating the servo-steering linkage. The estimated frequency of oscillations from lateral rail

warping, with the guiderail posts acting as pins, is

$$f_r = \frac{V}{\lambda} = \frac{V}{2L_p} \quad (3.39)$$

where a guiderail post spacing $L_p = 10$ ft at 60 mph yields a frequency of 4.4 Hz. The corresponding period $T_r = 0.23$ sec. compares with the vehicle handling response period of about 1 second. From observations after test assembly of the 200-foot prototype guiderail, a lateral accuracy of ± 0.25 in. could easily be maintained.

From the follower pad to the steering linkage, a total mechanical/hydraulic delay of less than 0.1 sec. appears both desirable and feasible. The GM experience again suggests no major problem in controller delay. The full three-degree-of-freedom model is sufficiently complex to require computer solution, but a simple representation of the vehicle and controller as a second order feedback system will allow preliminary analysis and calculation of vehicle excursions and tracking accuracy (Fig. 3.21).

For a minimal delay stable controller, the primary response factors are controller gain and arm location (lead). Excessive gain will result in the vehicle lurching and hunting from side to side as the front wheels over-correct, so that continuous oscillation or instability may result. Insufficient gain will cause the steered wheels to compensate insufficiently

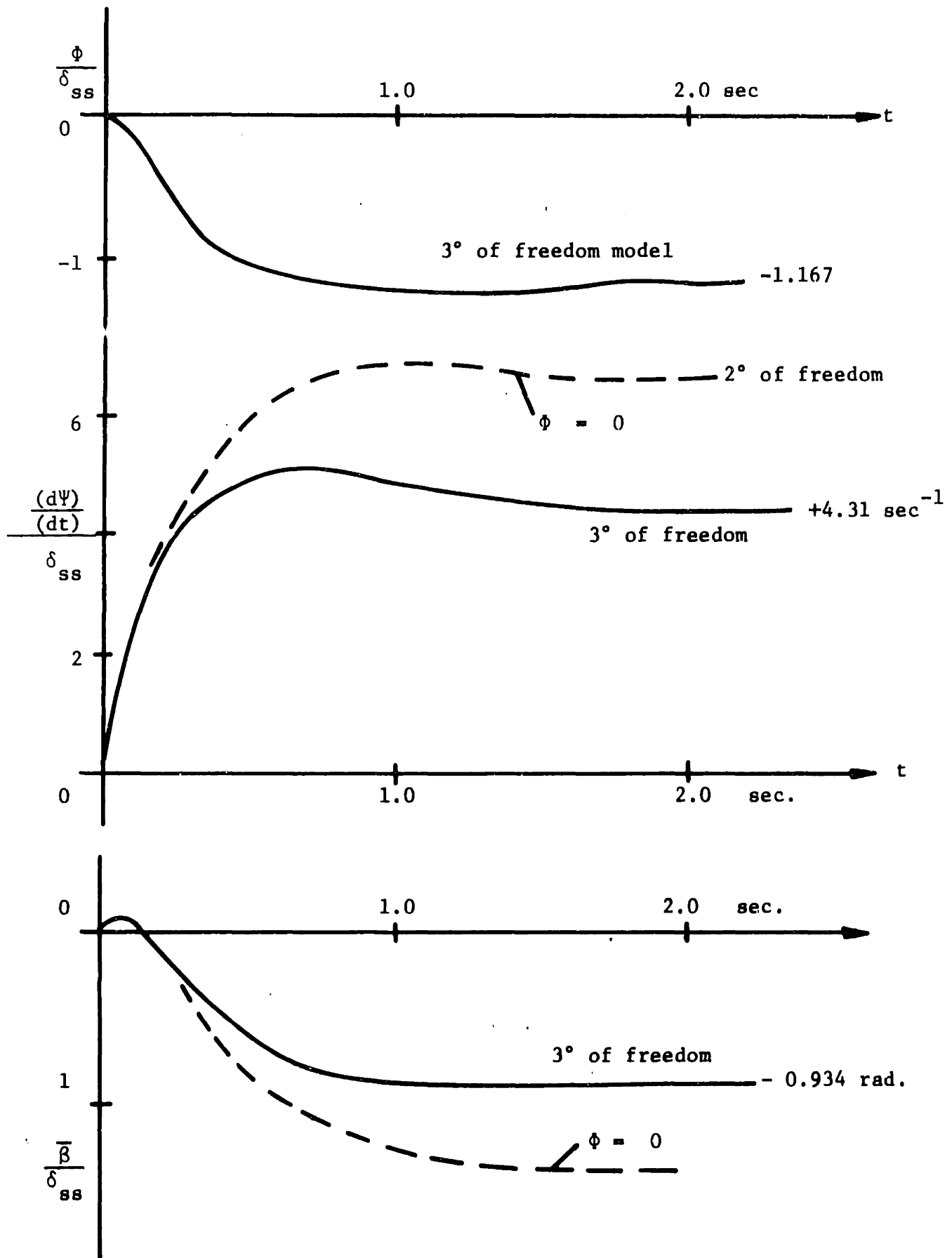


Fig. 3-20. Response of a Representative Automobile to a Step Change in Front Wheel Angle δ (from Larrabee)

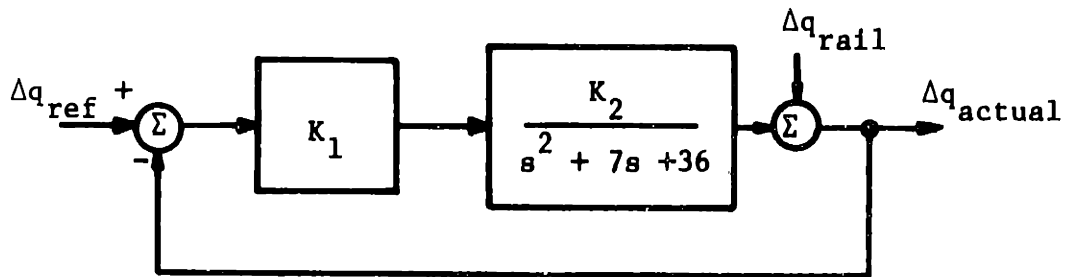


Fig. 3-21. Linear Active Guidance System : Simplified Model

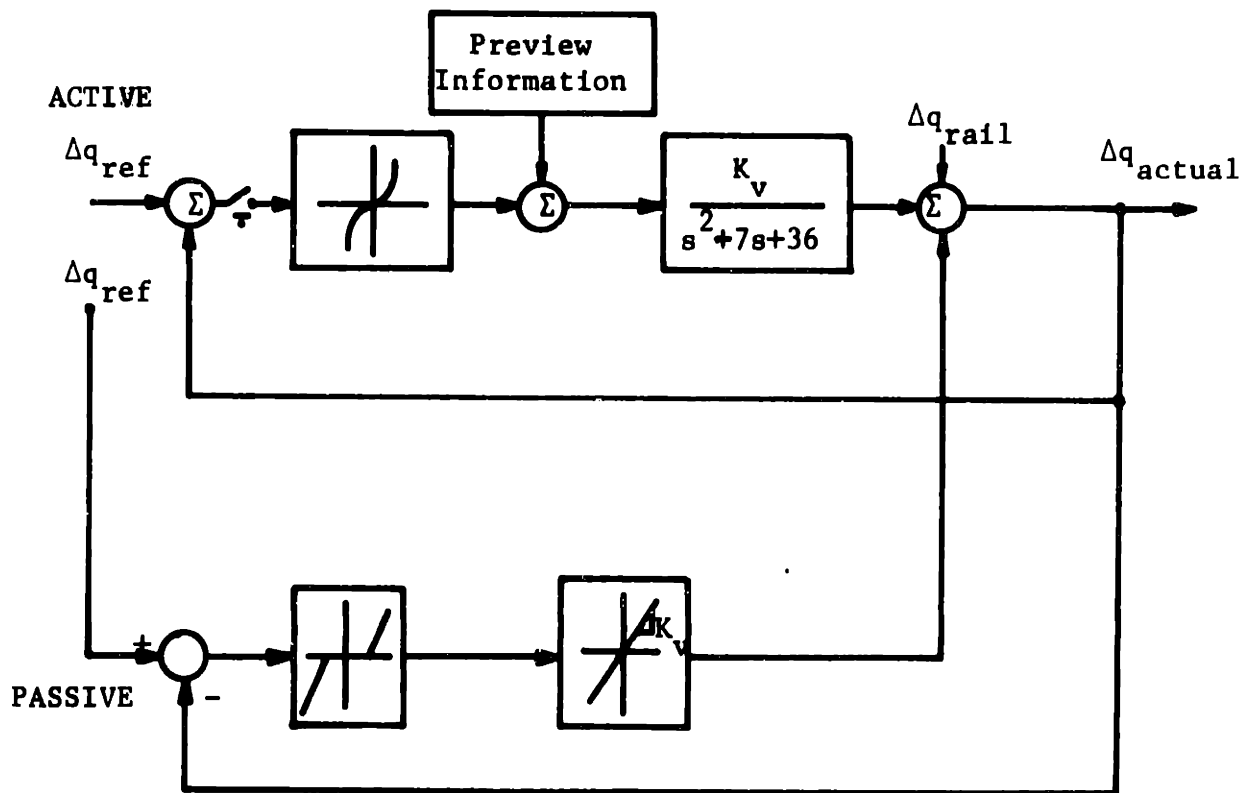


Fig. 3-22. Active Guidance System, including noise filter, Sampled data control, non-linear arm transducer, partial passive control for large excursions.

for heading error, so that the vehicle will bottom out rapidly on its passive arm stops. Controller gain may also have to be modified at switches and merges, under one-arm guidance conditions.

A variable speed guidance gain is incorporated in the new Citroen SM, by a hydraulic power steering circuit regulated by a speed sensor on the transmission. The arrangement provides heavy and quick power assist at low speeds, yet drops the pressure and assist at higher speeds when steering motions are less severe. A certain degree of non-linearity as a function of arm displacement may be needed also, to provide low gain at near-centerline tracking, and higher gain at more extreme deviations. Further tests need to be conducted to establish to what extent controllers can operate linearly or non-linearly with stable response.

In a recent computer simulation, Tanner³ used a three-degree-of-freedom digital state-space simulation of vehicle and controller dynamics, with δ proportional to arm extension. He found that except for one run with a high gain of 80 the active guidance system is stable. At speeds near 100 mph, the damping in the yaw-sideslip equations becomes quite small, so that it appears instability will occur for speeds well above 100 mph. The most important stabilizing factor, the forward arm location, also increases damping substantially.

GUIDANCE EXPERIMENTS WITH THE PROTOTYPE VEHICLE

Speeds of up to 20 mph were attainable on the 200-foot test section of the M.I.T. Guideway. A standard 1967 Mustang hardtop, the prototype vehicle has been arranged to run with and without steering feedback and in both cases the system is stable. Test runs were possible both in purely-passive, free caster situations and for activated power steering.

Without the steering feedback, if the front wheels of the car are held in the straight ahead position, the friction of the arm causes the car to turn slightly toward the rail before reaching equilibrium. If the wheels are left free to camber there is minimal tendency for the spring to compress, except as a result of unpredictable inputs such as roughness of the road or crosswinds.

The steering feedback is achieved by connecting the main hydraulic arm cylinder to the power steering cylinder. This connection is direct and quick, and in the computer simulation is assumed to be pure gain (approx. 8 radians/foot of arm compression, according to Tanner). With the feedback system operating, the wheels seek a position which causes zero net arm displacement. A full set of tests has not been completed.

Several simple tests were performed with the feedback controller in operation. The car initially was started at a displaced angle to the guiderail and then later with a distance

displacement, and finally with an initial δ_0 . In all three cases, the vehicle returned to its equilibrium position in the space of 20 ft.

SUMMARY

The vehicle control problem is one of guidance, switching and speed control. Cars can be guided by lateral arms operating passively (push/pull) or actively (front wheels steer), with an active system having emergency passive fall back capability to carry at least 832 lbs. of dynamic load for short periods of time.

The experimental vehicle traveling on the straight 200-ft. test guideway was stable except on very slick ice, under passive control. Active systems can be either electrical, fluid or mechanical linkage, with an electrical system with capability for accepting "preview information" on the sharpness of any impending turn and programming the vehicle to turn properly.

CHAPTER 4 GUIDERAIL, GUIDANCE ARMS AND SWITCH DESIGN

The guideway interacts with vehicles through (a) contact between the tires and the roadway, and (b) gripping between the guidance arm and the guiderail. This latter contact is the unique feature of the automated guideway and constitutes the focus of this chapter : arm, follower and rail.

The multiple functions of the guidance arms and guiderail (Tables 2-1 and 2-2) require that the design tradeoff process be quite complicated, subjective and empirical. The focus of the interaction is at the follower, which is defined as the extremity of the arm actually in contact with the rail and is analogous to the human hand. For design development and evaluation of the follower and arm, a checklist of relevant factors is provided in Table 4-1.

* * * * *

TABLE 4-1 FOLLOWER AND GUIDANCE ARM EVALUATION

1. Ease of follower insertion and actuation
2. Ease of clamping, unclamping and removal; rapid reaction time
3. Resistance to binding in all directions
4. Overall compactness; high effective pad area
5. Aesthetics; ability to fit within vehicle sheet metal
6. Weight and strength, reliability and accident vulnerability
7. Complexity/simplicity; number of moving parts
8. Follower heat dissipation, wear, power loss and insulation
9. Cost
10. Failure modes; failsafe operation & emergency shear & release
11. Sensitivity to weather and vandals
12. Power pick-up efficiency, arcing; protection of conductors
13. Quietness of operation
14. Lack of vibration or resonance; maintenance of pad pressure
15. Wear adjustments

The switching logic of the arms will depend upon the design functions of the follower and rail. A three-position magnetic switch could incorporate an electromagnet located above the rail, pulling the follower upwards for straight-through travel and pushing it down for separation at a switch (Fig. 4-1), although the use of lightweight, non-ferrous metals in the follower is largely precluded. The regripping action might be less precise and reliable, with the additional possibility of power and signal discontinuities affecting the performance of vehicles passing through the regripping region of a merge. Clearly, the "dim-lights" transit phenomenon of coasting through a merge must be avoided.

If the switching logic is carried in the vehicle, there are two options for gripping the rail :

- (a). the arm is raised and lowered to channel it into different rail funnels (which thereafter lead to the continuous (grip) or discontinuous (no-grip) conditions), using a fixed sliding follower, or
- (b). the arm could be raised or lowered on vehicle command and the follower would be articulated to collapse or release its grip on the rail.

Switching logic -- in terms of the "division of labor" between vehicle and guideway -- depends on the coordination of scheduling, merge/switch location and the moving individual vehicle. In some

design concepts, the switching operations can be performed without major coordination problems between guideway and vehicle (as in the case of the magnetic switch), whereas in other designs, the vehicle arm and follower motion would have to be closely synchronized with guiderail location at a switch or merge.

At switches and merges, the disengaged arm would need to be suspended horizontally so that it did not contact the guideway surface. A ski-contoured skid plate would prevent damage in the event the arm dropped too low or struck a foreign object or snow buildup. The vertical accuracy of the free guidearm is limited by the suspension travel of the vehicle, because the follower and guidearm are mounted to the sprung mass of the vehicle. This vertical variation can be assumed to be + 4 inches.

Regripping at switches involves a funneling device, while merges entail scoops underneath a continuous rail. These engaging aids must be provided to assure easy and reliable re-engagement of the rail by 60 mph vehicles (Fig. 4-2). In switches, the follower enters an exposed rail end and can be fully expanded upon entrance. However, at merges, the follower must enter the standard rail from the bottom in a collapsed state and then expand. In both instances, the vertical and horizontal positions of the follower must be controlled during the re-engagement process, to prevent damage to the follower.

The scoop and funnel sequence (Fig. 4.3) begins with

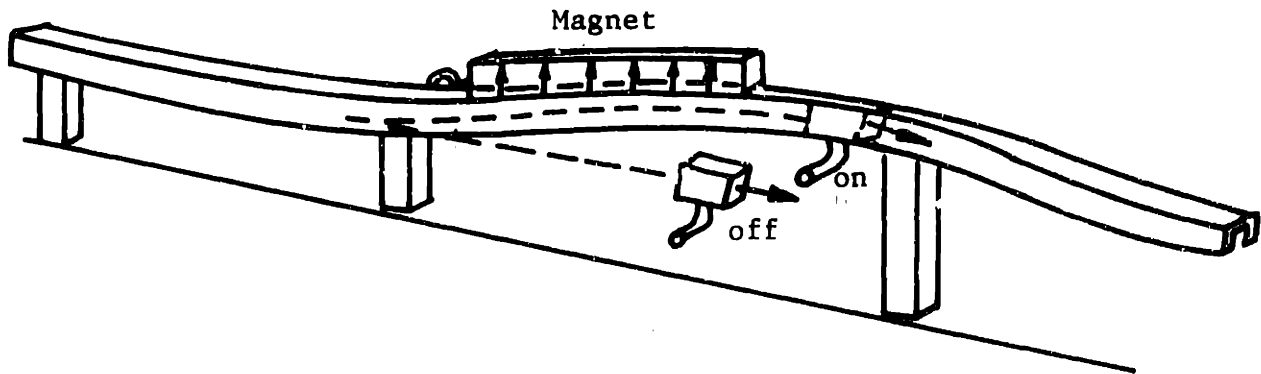
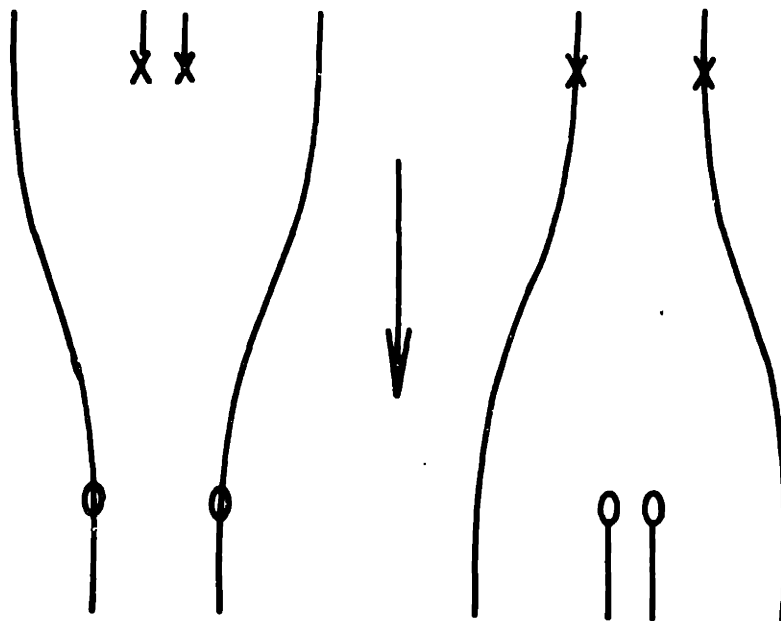


Fig. 4-1. Magnetic Actuation of Guidance Arm Gripping and Release



X = Rail Released by Follower

O = Rail Engaged by Follower

Fig. 4-2. Switching and Merging

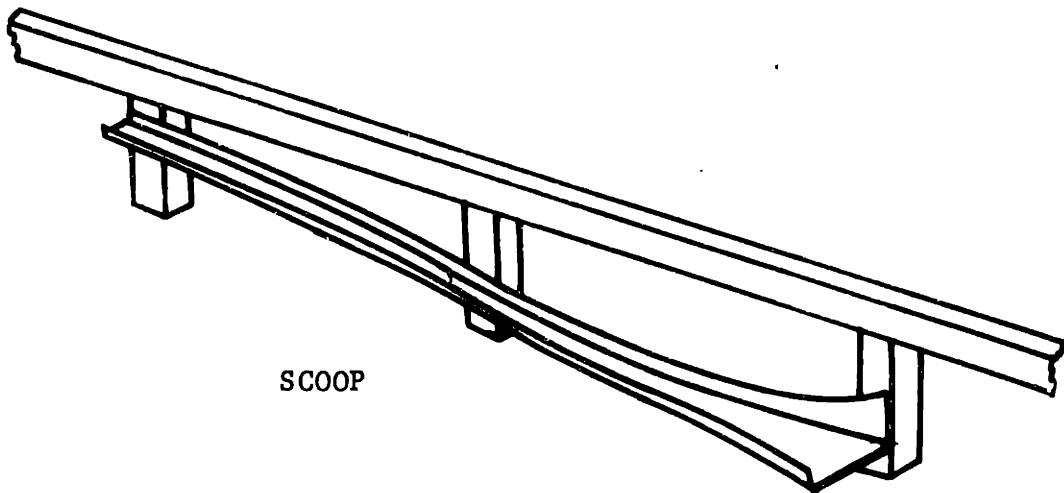
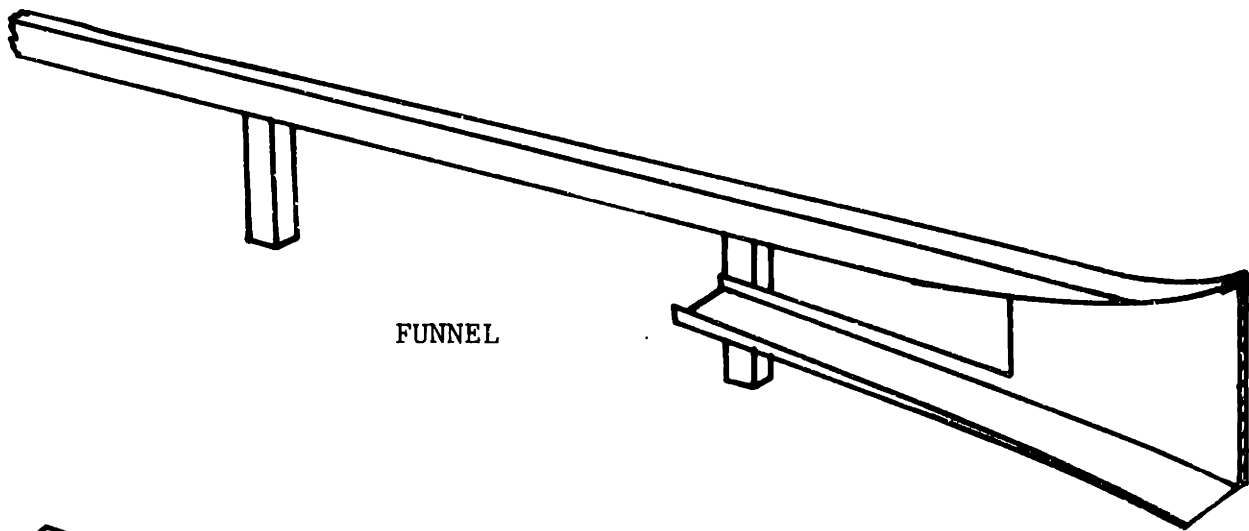
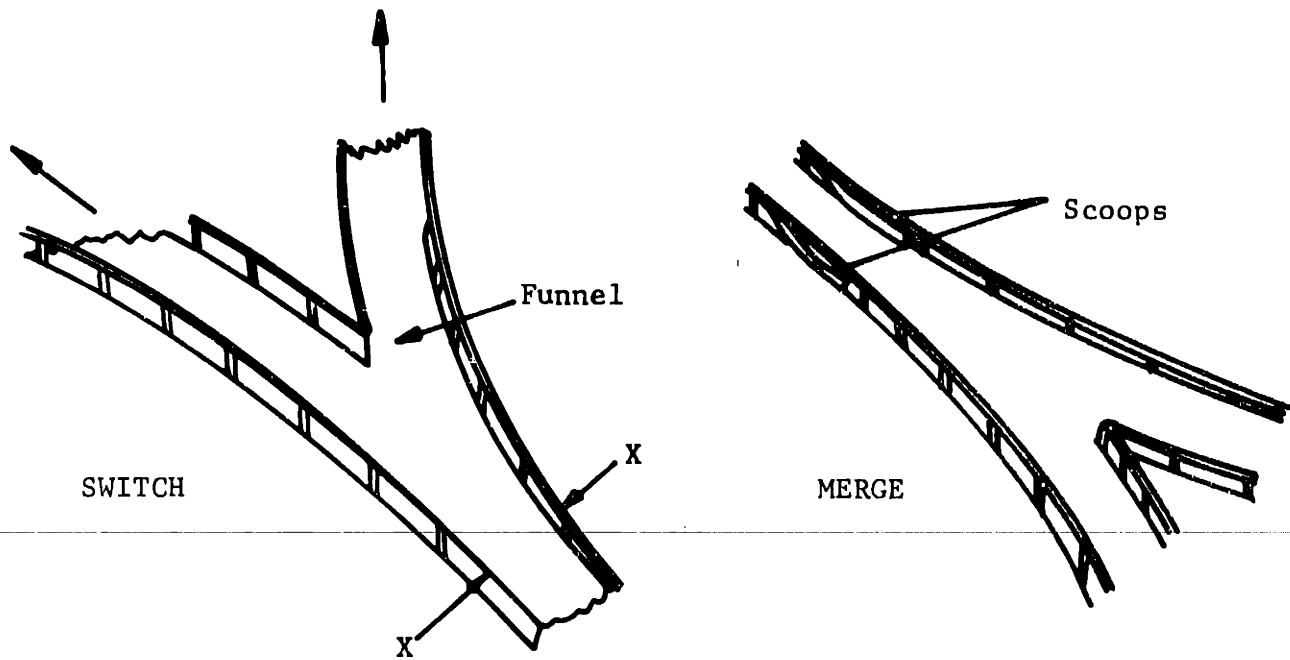


Fig. 4-3. Switch Funnels and Merge Scoops for Regripping

horizontal and vertical positioning of the follower, ending with a vertical rise into the guiderail cavity via insertion from below. Upon insertion, both sides of the follower have been at ground potential and no electric power is transmitted through this arm. The inner collector then passes to an electrically insulated floating section and finally to the normal inner rail. Upon proper contact with the guiderail, the power pickup and signal reception function of the arm would be reactivated and the vehicle would return to two-arm guidance.

The lateral position of the free follower during switching is accurate to about ± 1 inch, but a servo failure could increase this deviation to ± 3 in. Thus a funnel/scoop should have a width of at least six in. and a height of at least 8 in.

SWITCHING LOGIC SYSTEMS

Guidance arm switch logic and signaling are conceptualized within the four schemes outlined in Fig. 4-4, three involving table-lookup, and the fourth a sequential memory of turning movements. Table-lookup by the guideway, with the initial information signal being either vehicle number or desired destination, is fundamental to the first two (Fig. 4-4a,b). Two-way communication would be required. If the table-lookup occurs on the vehicle (Fig. 4-4c), given the initial input of a switch number or location, the vehicle itself decides the proper arm motions. A single one-way communication would be required, but every vehicle must carry the table-lookup

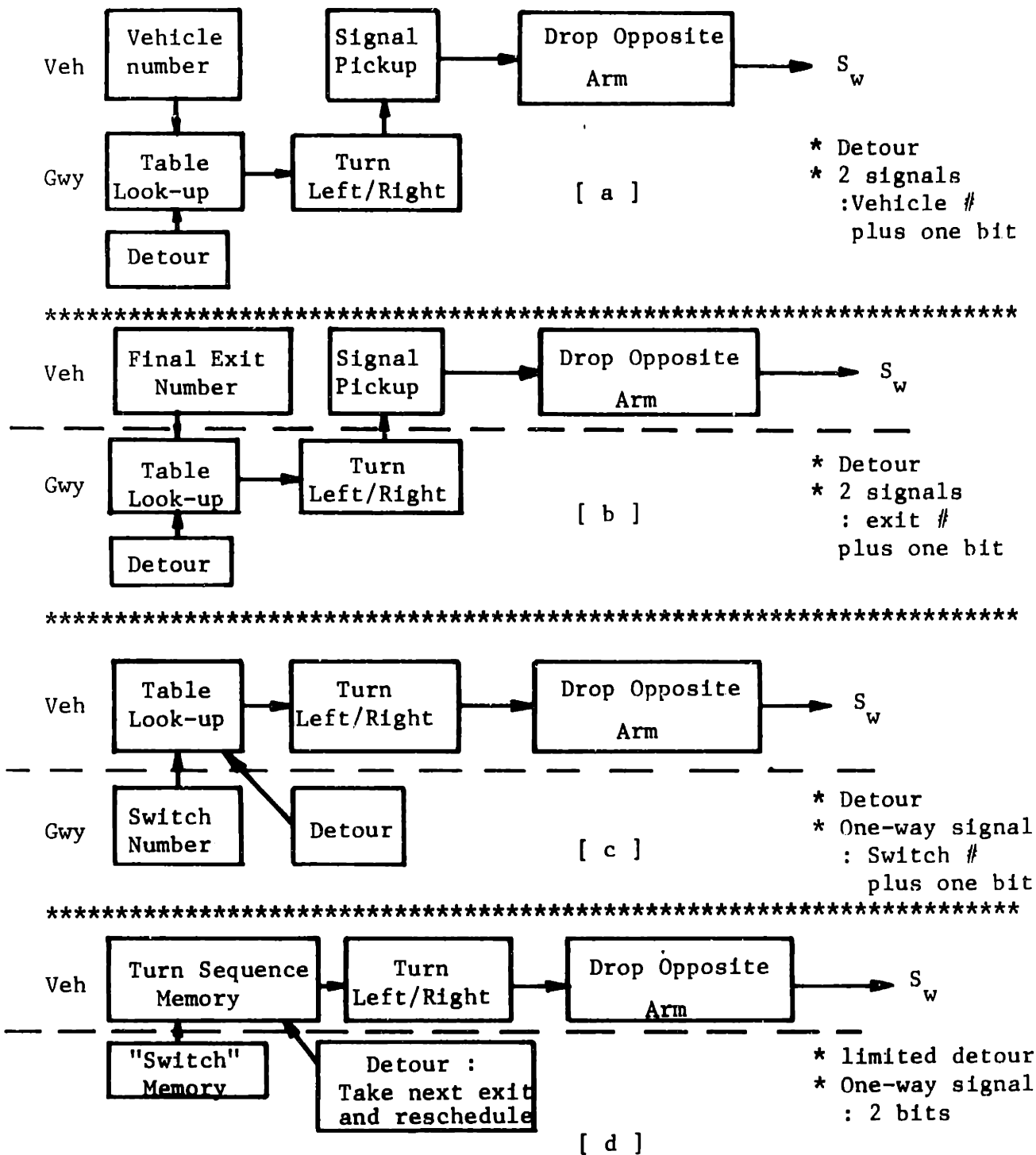


Fig. 4-4. Vehicle-Guideway Switching & Communication Logic :
Options

circuitry.

The fourth version (Fig. 4-4d) requires full scheduling at the entrance of every vehicle motion and does not permit in-transit detours. The vehicle stores the binary switch decisions in sequential order, turning left or right as required. Only single one-way communication is necessary, but final destinations must be dialed immediately upon entrance, analyzed and programmed into the turn sequence memory of each vehicle. Detour movements are restricted, especially the efforts to program vehicles through the system to balance traffic via alternate routing.

Reliability of the switching process is critical to the success of a dual mode system. If an arm fails to release or to regrip properly, the car consequently must rely on one-armed emergency guidance to reach the next regripping point or exit. Since most exits would be to the right, the switching signal could be "binary Left/No Left," so that in the absence of a signal or its proper reception, the car automatically steers to the right. If an arm failed to disengage on command at a switch, an emergency disengage sequence is initiated -- with a secondary activation system attempting to separate the follower from the rail. If this method failed, the opposite arm activates to release, and the vehicle takes an intentional "wrong turn" while in-transit troubleshooting is attempted.

Depending upon which follower is defective, the vehicle eventually exits to the right or left or at an emergency stop/breakdown area.

If both followers are defective or if there is insufficient time to release the opposite follower, the guidance arms could be structured asymmetrically, so that upon a given heavy tensile load on the follower, a shear pin at its base releases, causing the follower to spring apart and release its grip. With most exits to the right, the left follower should have the emergency shear mechanism, thus optimizing the chances for exit at the earliest possibility. The shear mechanism should also be sensitive to high drag forces, such as the jamming of the follower against the lip of a misaligned rail joint. The follower would collapse rapidly, but would have to be reassembled off-guideway.

Regripping failure occurs if the follower becomes jammed in or against a funnel, or if the arm misses contact with the funnel entirely. The jam release would be similar to the drag force shear device mentioned above.

Fortunately, the two-arm redundancy of dual-mode vehicles allows for continued control in the event of trouble or failure in one arm. Cars might need to be diverted from their original destinations, but they would be less likely to become stalled on the guideway and back up traffic.

In summary, the overall guidance strategy is :

- (a). Two-arm guidance up to the split in a merge or switch.
- (b). A right-turn pattern is followed if a left-turn signal is not received; single-arm guidance begins.
- (c). The opposite turn is made at a switch if the arm does not release its grip; in the event of emergency shear release in the follower, no regripping occurs and the vehicle continues under single-arm guidance to the nearest exit.
- (d). Active guidance shall prevail unless vehicle excursions become excessive -- then combined active and passive guidance controls regulate vehicle heading. A malfunctioning active system might have an automatic return to straight-ahead steering reaction, so that balanced passive guidance can control the vehicle.
- (e). Predictive steering inputs may be necessary for guidance through ~~the~~ more sharply banked curves.
- (f). Steering linkage control should be by parallel actuator cylinder or by solenoid-controlled ratchet mechanism; A linkage mechanism in the arm or a spool valve/LVDT-type transducer is preferred over direct fluid displacement transducers in the guidance arms.

RAIL SHAPES AND DESIGN

The guiderail performs many guidance and safety functions, but it is also potentially one of the most dangerous elements in the guideway system. It provides both guidance reference and electric power, thus posing a shock hazard. Care must be taken to protect passengers and pedestrians who for any reason might find access onto the guideway. In the Pittsburgh Transit Expressway program, the several alternatives discussed for reducing the phase-to-ground shock hazard of their 3-phase system all used conductors isolated from ground and a fourth conductor provided

at stations to ground the vehicles. This eliminated shock hazards when disembarking passengers caused a phase-to-ground leakage.

The rail must be designed to reduce both the shock hazard and the possibility of service deterioration due to weather effects, including rain, icing, slush buildup and mud spray on the rail. These concerns are important factors in evaluating the two basic approaches to the guiderail gripping design:

- (a) the guiderail may retain the follower, or...
- (b) the guiderail may provide surfaces against which the follower can be forced.

These two approaches can be mixed (i.e., horizontal retention, vertical forced location, etc.) or either can be used exclusively. Internal retention of the follower means that all reference and current collection surfaces are on the interior of the rail beam, while the external rail has these functions on the exterior (Fig. 4.5).

Compared to the internal rail, the external rail is more susceptible to environmental contamination, presents an increased shock hazard, and is more liable to damage of the reference surfaces in the event of accident (unless a substantial external shield is provided). The primary advantage of the external rail is that it maintains greater structural strength and integrity, since it need not be penetrated by the follower. Building an internal rail of stronger cross-section is less expensive than the additional fabrication and installation of the protective

shields, as required for the external rail. Thus the internal rail design is preferable overall.

Maintaining and establishing contact with the rail could be achieved either by positive gripping action of the rail surfaces or by forced contact transmitted through the guidearm with vertical and/or horizontal actuators. The use of the forced-follower method in the horizontal plane must be ruled out because of the totally inadequate mechanical backup of passive guidance, in case of guidance servo failure, especially in switches. (Fig. 4.6).

Although forced-follower location is feasible in the vertical plane (and is being used for most transit current collectors presently operating) as in Fig. 4.6c, the continuity of the sliding contact is uncertain because of the considerable dynamic forces generated during travel, both vertical and horizontal. Due to the need to compress the lateral sprung pads of the follower, approx. a 5° vertical taper is required of the channel iron. Thus, either tensile or compressive emergency loads on the arm would tend to push or pull the follower down and out of the channel. Any attribute of chatter in the follower or tendency to disengage leads to intermittent power, and arcing/inductance effects which severely impair performance.

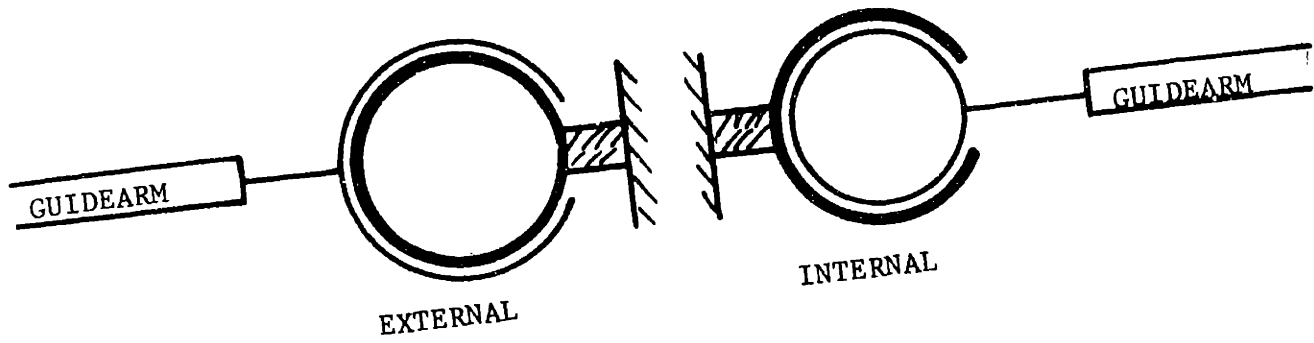


Fig. 4-5. The Two Rail Gripping Types

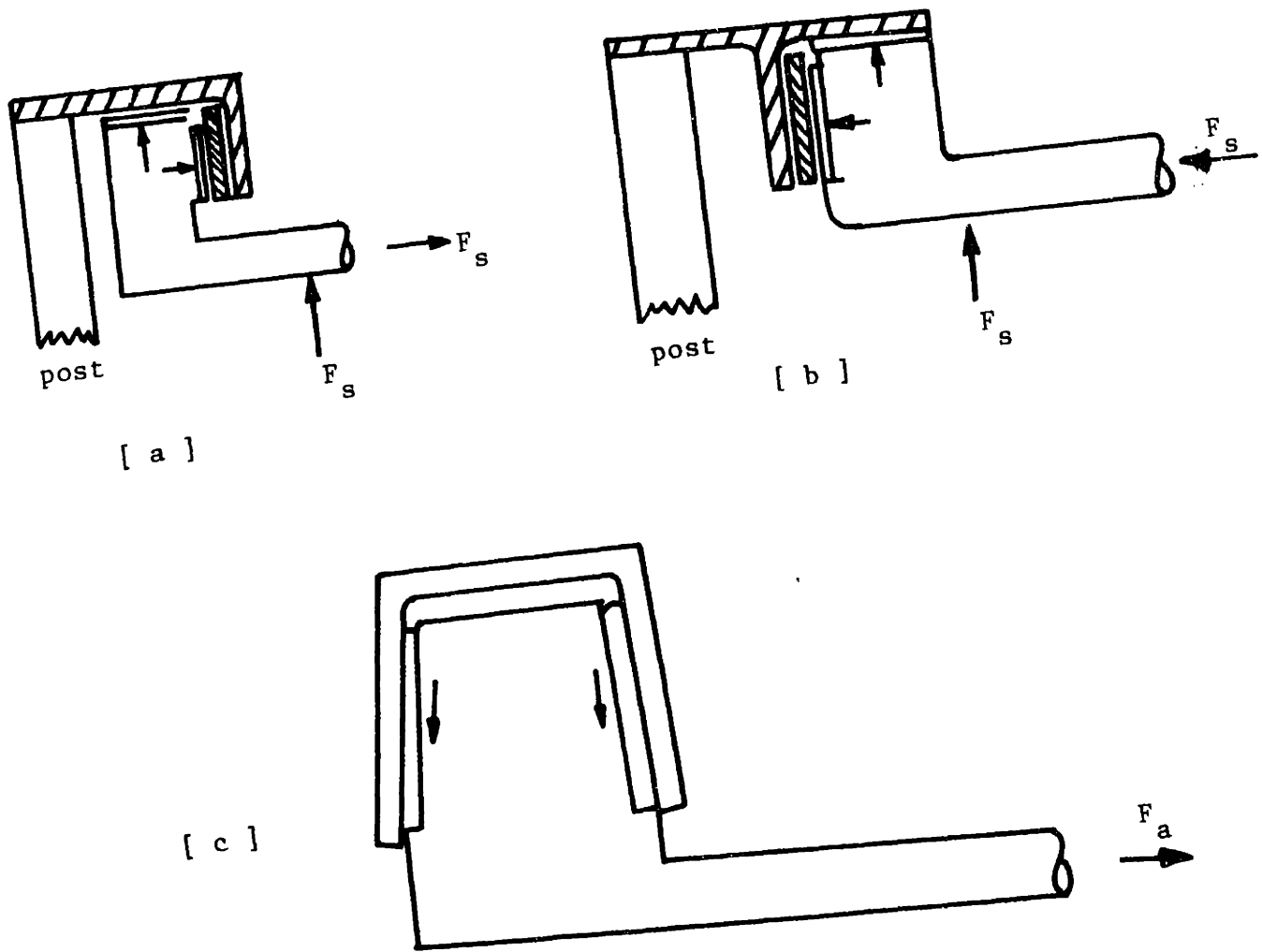


Fig. 4-6. Maintenance of Follower/Rail Contact by Spring Forces F_s in the Guidance Arm

Positive follower retention is a fundamental necessity for safe operation, particularly if it means that access to the live power rail is possible only through the underneath opening. In order to keep the inside of the guiderail free of foreign matter from precipitation to leaves and dirt, there should be gravity clearance of all the internal faces. This requires that the bottom of the guiderail be open and that all faces be sloped to prevent accumulation of foreign matter.

A four-directional gripping action is necessary for regular operation, and release of the rail is achieved by removing support from one or more directions to permit withdrawal of the follower. Various follower and rail configurations have been considered to date (Fig. 4.7), and others are still being analysed. The preferred arrangement chosen for initial design and test development has been the diamond-shaped section, with all sliding faces at least 60° to the horizontal so that grit and scale buildup is minimized. The follower is of hexagonal cross-section (Fig. 4.8) and is completely enclosed by the rail, with no sliding surfaces having outside exposure. The diamond shape provides a V-channel which self-centers the follower in the channel and reduces the tendency of the follower to separate from the rail.

The several variations on the diamond shape (Fig. 4.9) have been considered in terms of simplifying the follower design

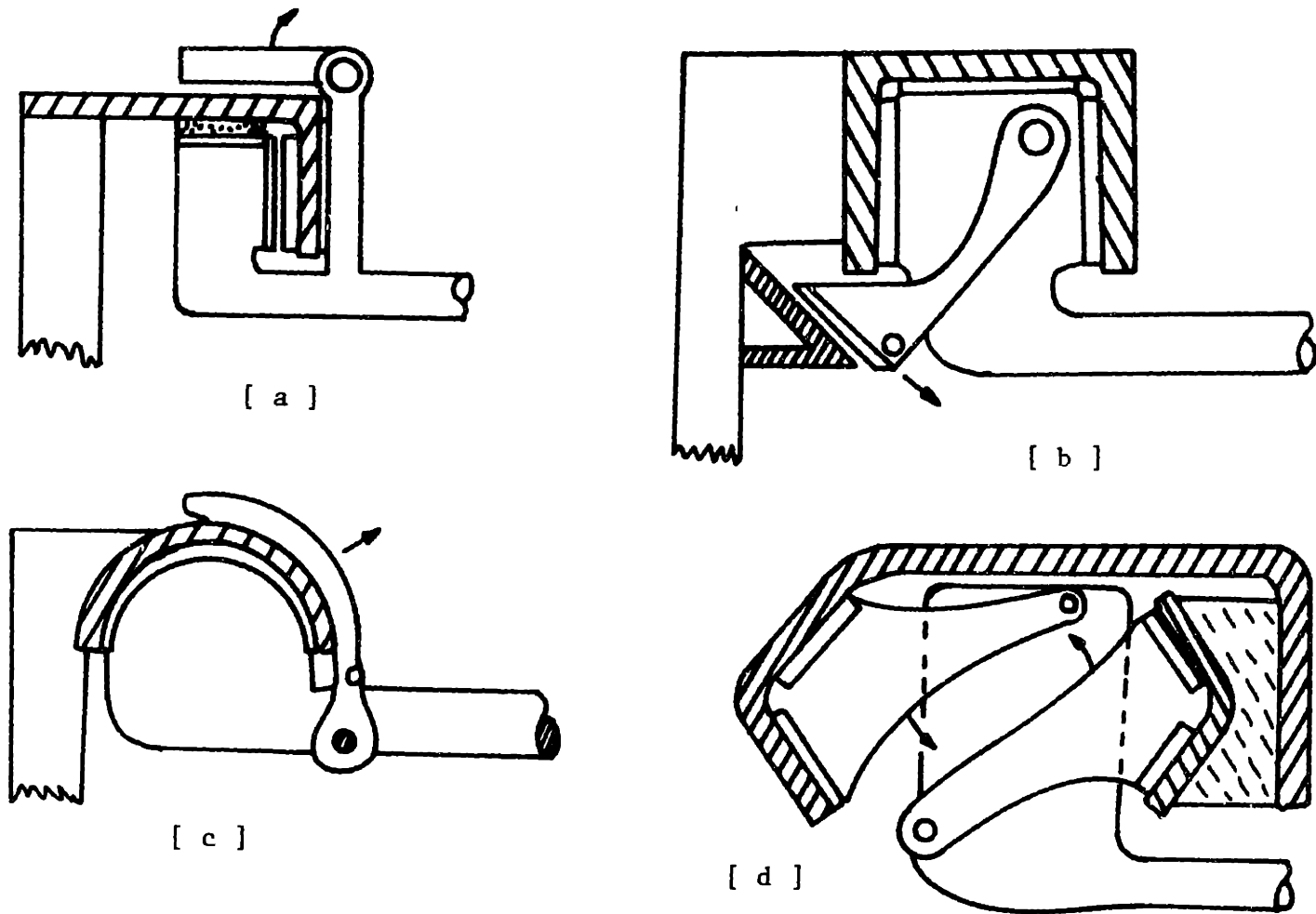


Fig. 4-7. Guiderail Cross-sections : Alternative Configurations

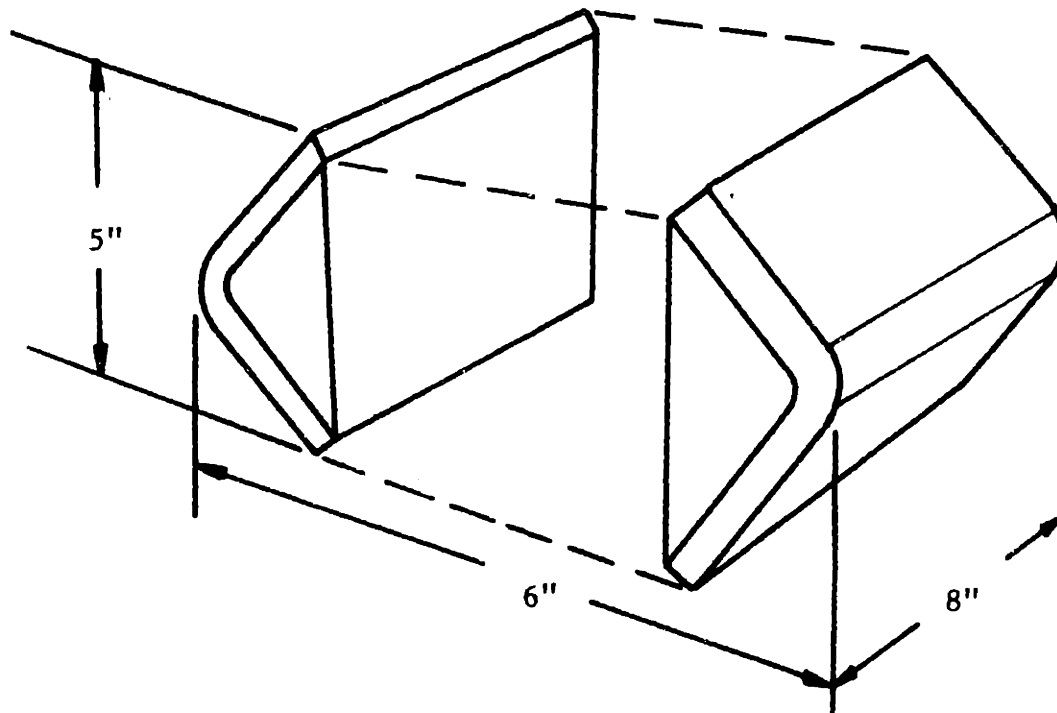


Fig. 4-8. Approximate Follower Dimensions

and ease of electrical insulation & guiderail adjustment to compensate for wear or misalignment. Rail shapes having curved wearing surfaces are inappropriate because of non-uniform wear and consequent electrical contact problems. The asymmetrical shapes, (d, e, and f) show a tendency to rotate inside the rail under vertical load, while shapes (a and c) were not used in the prototype because of fabrication complexity. At this stage of development, shape (c) appears the most promising in terms of simplified follower and ease of insertion.

The basic design task for the hexagonal collapsable follower can be described in terms of translating or pivoting the pads so that the maximum horizontal dimension is less than the 4-inch width of the guiderail gap -- in order to permit the follower to drop out of the rail. Geometrically, at least six possible methods can be employed to collapse the pads (Fig. 4-10), although types II and V must be ruled out because one side of the follower is fixed and hence unprotected from the cutting edge of the guiderail gap when the follower is withdrawn or inserted. The necessary contraction and expansion action requires the pads to withdraw behind insulated protective end plates (Fig. 4-11).

Actuating linkages must be designed to move the pads as desired, while the follower assembly is suspended and articulated to permit three-degree-of-freedom motion of the

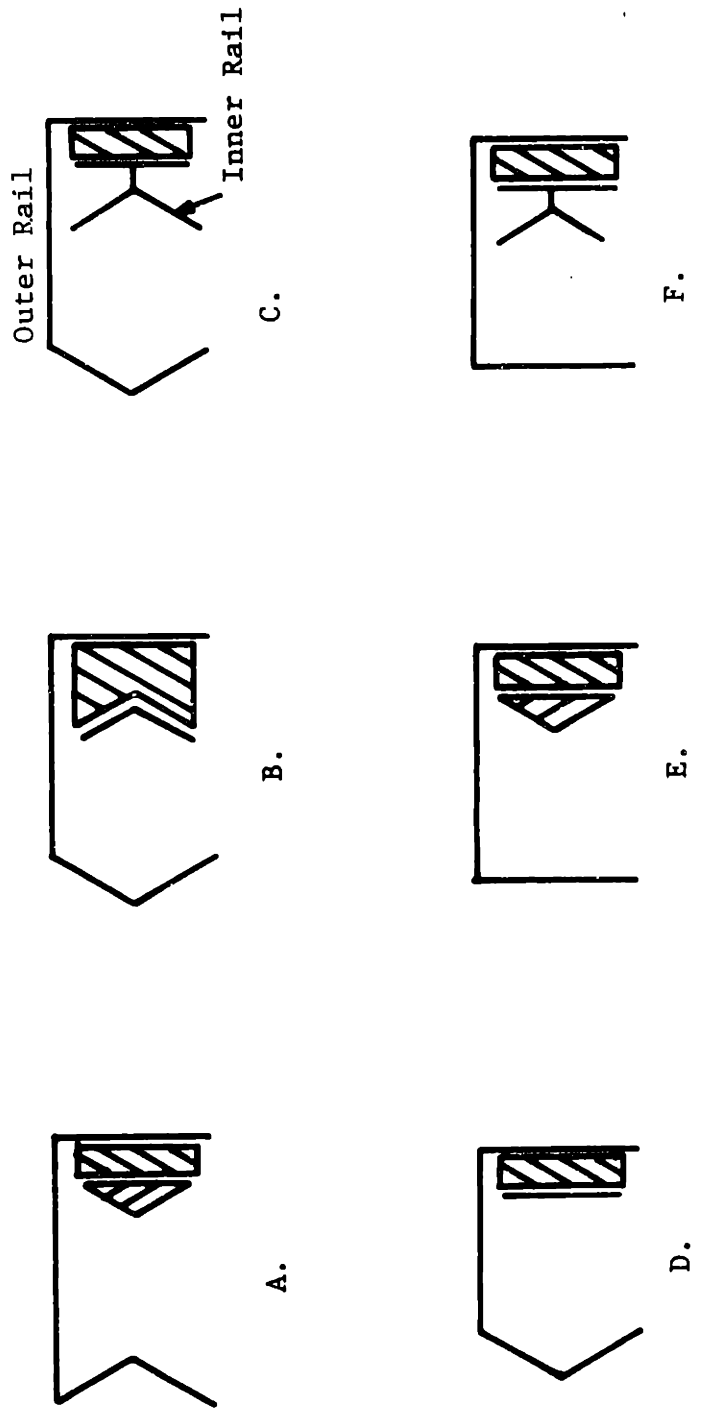


Fig. 4-9. Possible Rail Cross-sections. Basic Diamond Shape

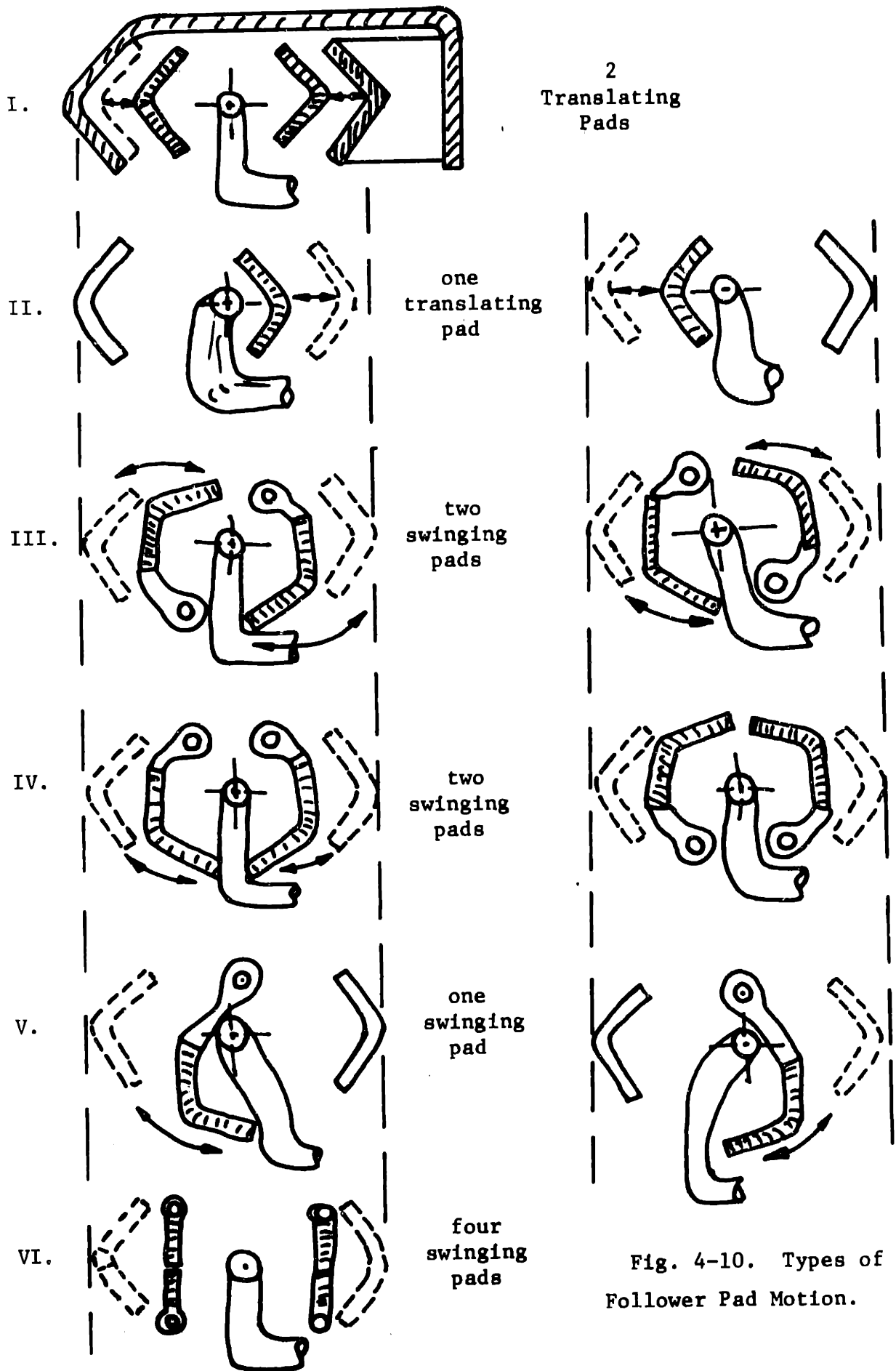


Fig. 4-10. Types of Follower Pad Motion.

vehicle in roll, pitch and yaw. In roll, the angular range Ψ can be determined from geometry (Fig. 4-12a) for ± 1 in. of guideway vertical variation and ± 4 in. of vertical vehicle motion or bounce :

$$\Psi = \tan^{-1} \left(\frac{5}{20} \right) = \pm 14^\circ \quad (4.1)$$

In pitch, two factors contribute -- nosedive during braking (or a flat tire) and the drop in the guiderail at stations (see Chapter 8). Allowing for a 4-inch suspension rise in the rear and 4-inch drop in the front, a dive angle

$$\zeta_d = \tan^{-1} \left(\frac{8}{198} \right) = \pm 4.2^\circ \quad (4.2)$$

results, while the relative guiderail pitch is

$$\begin{aligned} \zeta_s &= \tan^{-1} \left(\frac{dh}{dx_{\max}} \right) = \tan^{-1} \left(\frac{H_o \pi}{L} \right) \\ &= \pm 14.7^\circ \end{aligned} \quad (4.3)$$

where (Fig. 4.12b)

$$h = H_o \left(1 + \cos \frac{\pi x}{L} \right) \quad (4.4)$$

and $H_o = 15$ in., $L = 15$ ft. Since ζ_d would normally subtract from ζ_s , the necessary pitch freedom is only $\pm 14.7^\circ$.

In yaw (Fig. 4.12c), the maximum permissible drift angle for a narrow vehicle is

$$\bar{\beta} = \tan^{-1} \left(\frac{2}{15} \right) = \pm 7.4^\circ \quad (4.5)$$

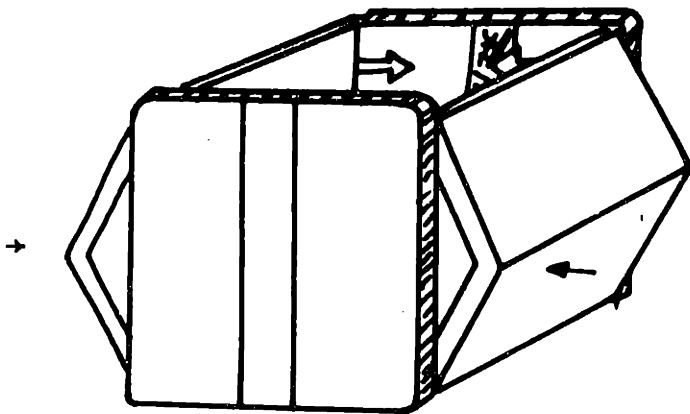


Fig. 4-11. Collapsible Follower with Protective End Plates

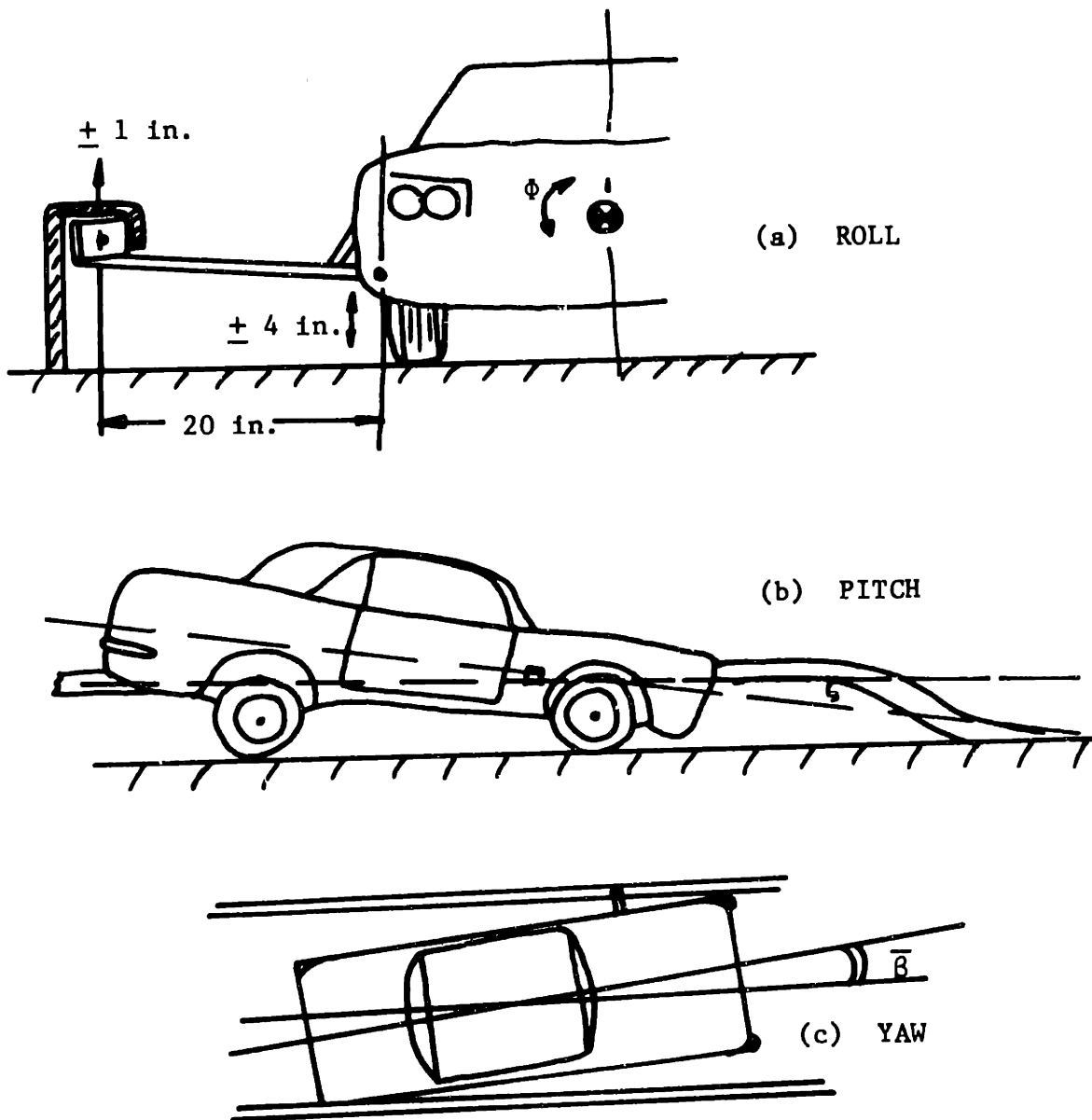


Fig. 4-12. Pivoting of Follower to permit Vehicle Excursions in Roll, Pitch and Yaw.

These necessary degrees of freedom can be achieved by wrist action in the follower, with a ball joint centered in the follower or a set of pins and gimbles arrangement. The ball joint concept is cleaner and more compact, but the pinned joints appear to offer better strength and simpler location of the rotation stops. Two preliminary designs for collapsible followers have been developed based on a Type I pad movement with ball joint suspension (figs. 4-13, 4-14, and 4-15), and another on a Type IIIa movement with double gimbles suspension. A plexiglass model of the former was constructed, and a wood model of the latter, but both encountered actuation problems. Finally, a static non-articulated test model of the TYPE IIIa follower was designed and constructed, with the intent of simulating a collapsible follower in ordinary travel (See Fig. 2-5 to 2-8 and Appendix B).

Because power pickup occurs through the guidance arms and followers, sliding contacts for both guidance and power pickup have been chosen over the options of roller contact, an air pad arrangement or magnetic suspension. For sliding contacts, Zimmerman¹ calculates that the rail wear for a guiderail subjected to moderate traffic is 6.7×10^{-4} inches per year (see Chapter 5 on wear). Wear in the follower will depend upon yearly use, arcing and the material used in the pad.

The most appropriate slider materials appear to be

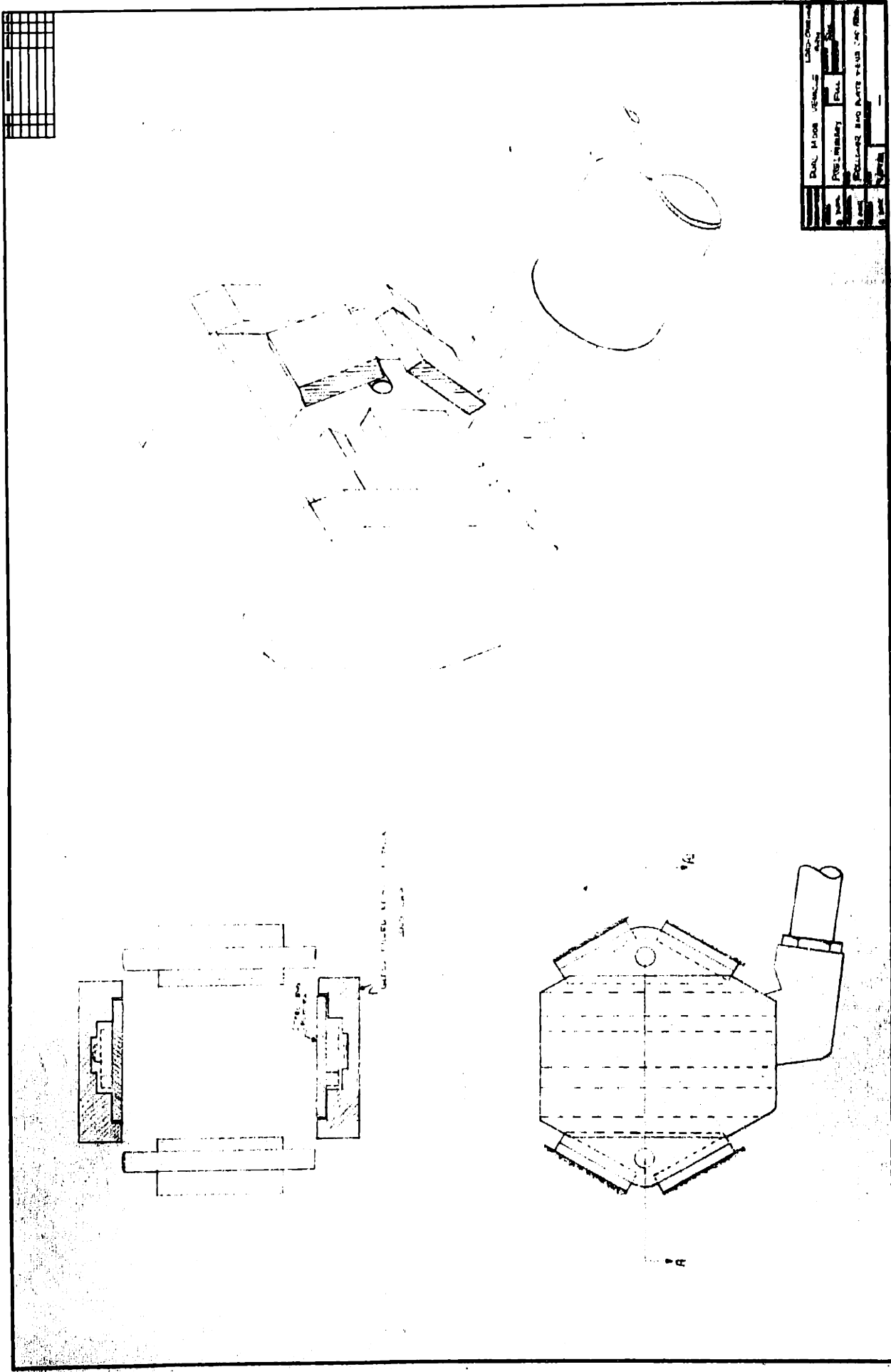


Fig. 4-13. Guidance Arm : Follower with Link and Ball Joint Suspension

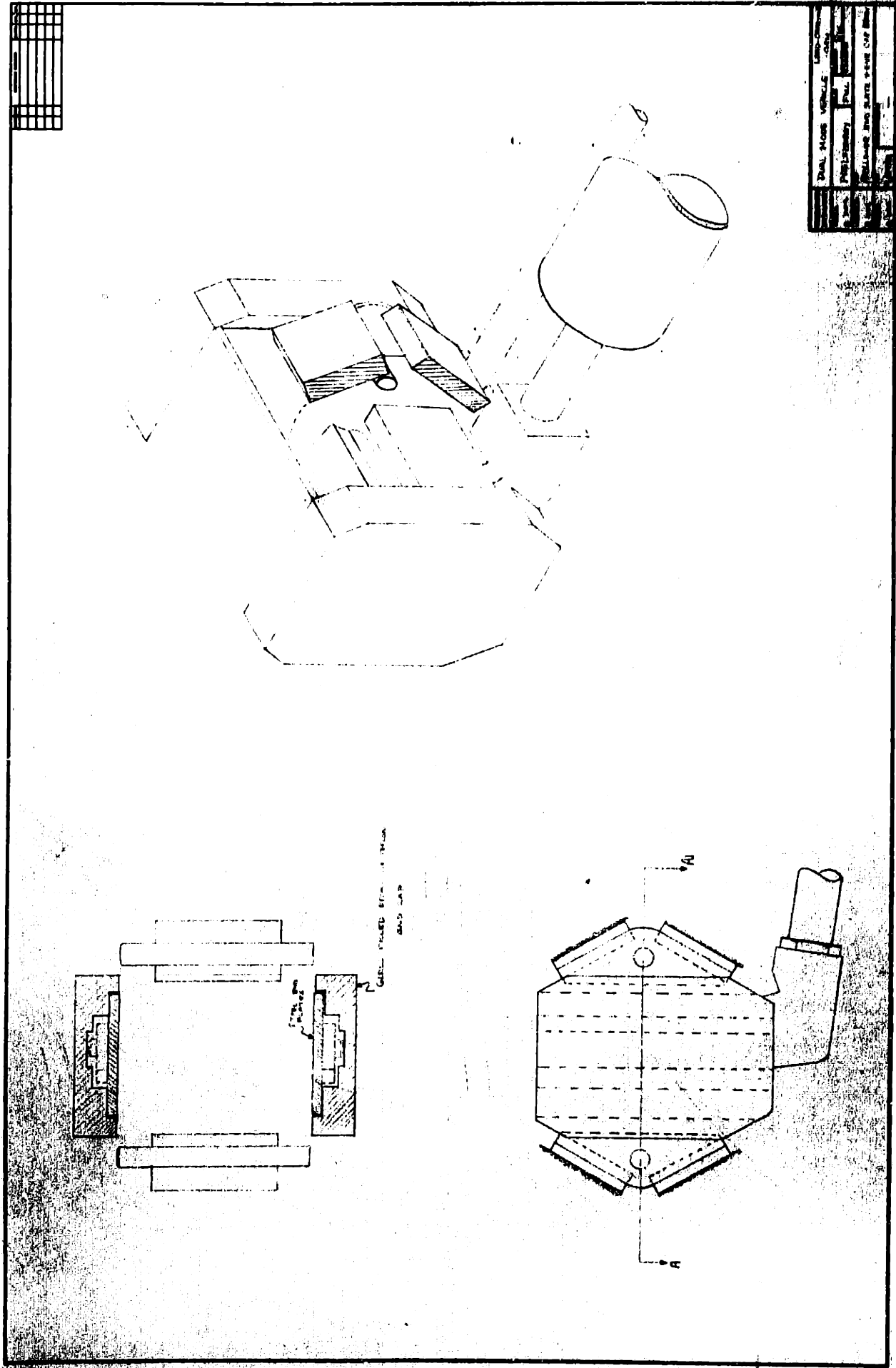


Fig. 4-13. Guidance Arm : Follower with Link and Ball Joint Suspension

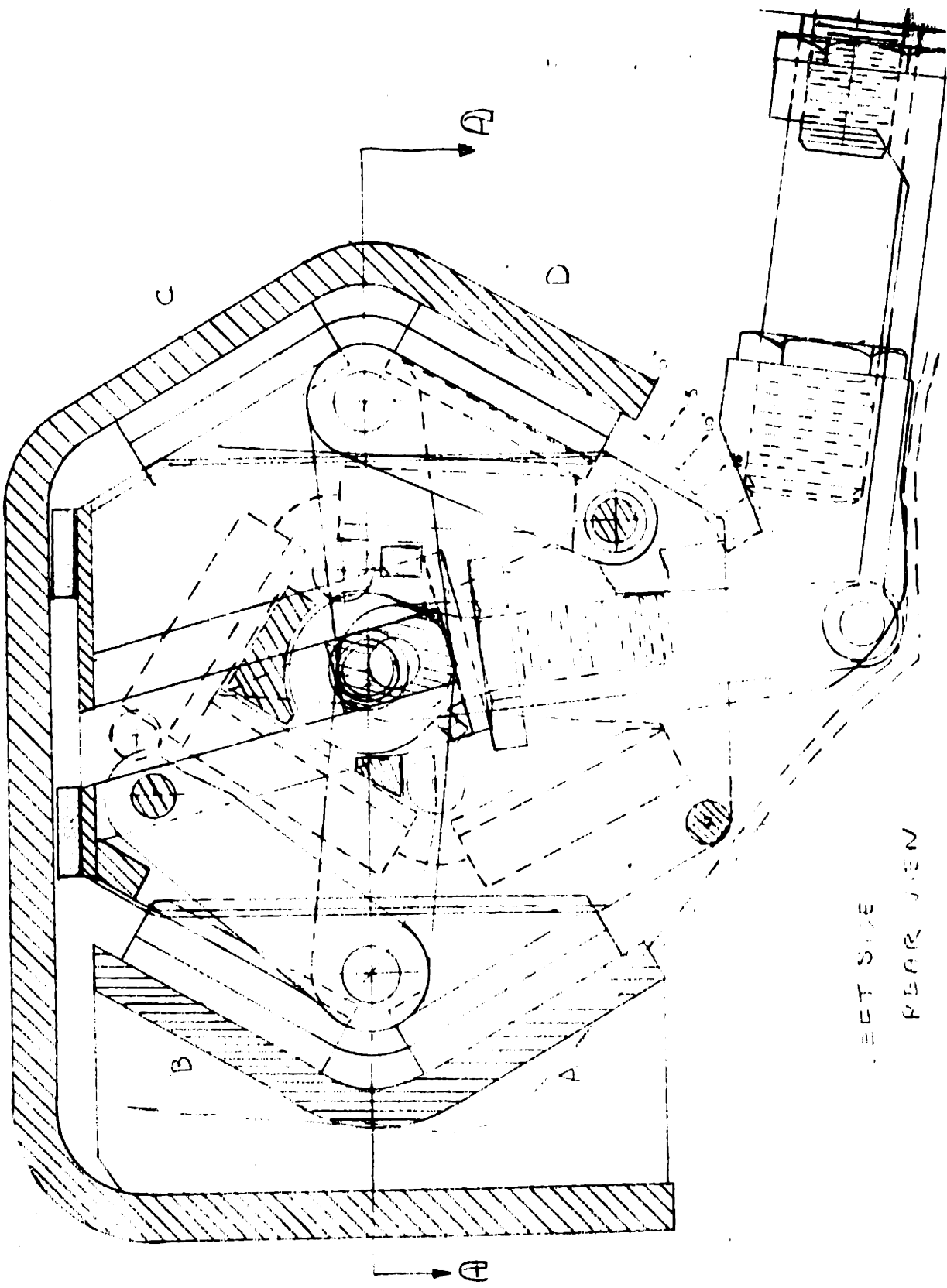


Fig. 4-14. Follower with Link and Ball Joint Suspension : End View

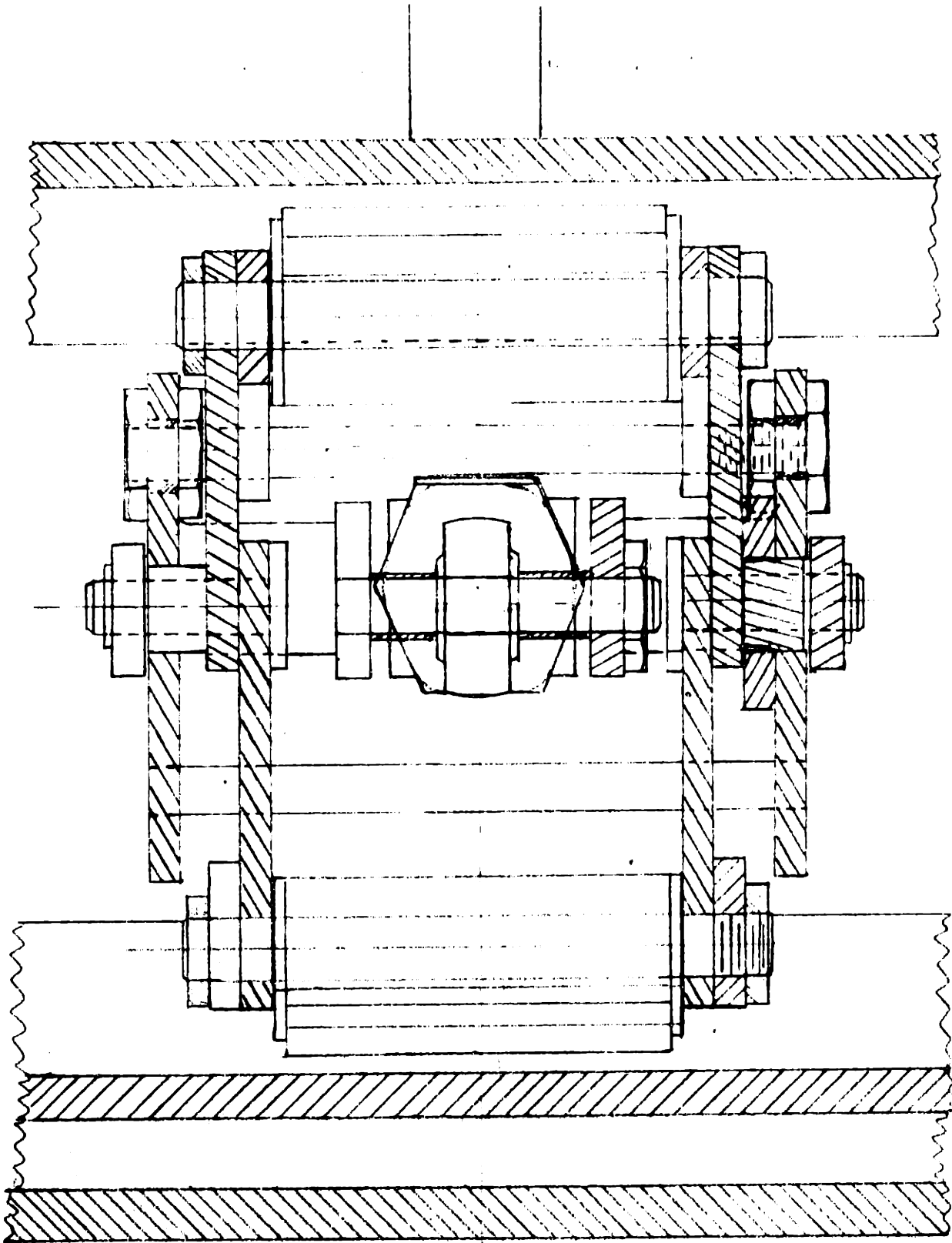


Fig. 4-15. Follower With Links and Ball Joint Suspension : Top View

cast-iron-on-steel, graphite-on-steel and copper-graphite-on-steel. For cast iron, $\mu = 0.3$, vs. 0.1 for graphite, with additional lubrication possible. With average arm loadings during passive guidance of 200 lbs. plus constant pad pressure forces of 10 psi x 15 in.² = 150 lbs, the instantaneous power loss is 16 and 5.6 HP for cast-iron and graphite respectively. A pad pressure of 10 psi compares to 30 psi on the smaller-area MBTA trolley pickups, and laboratory tests will be necessary to simulate electrical and loading conditions for wear, arcing and power losses.

Good contact and a low wear/noise rate are best achieved by suspending each follower pad independently, allowing each of the four follower pads to adjust to small unevenness and joints in the rail and promising area electrical contact rather than line or point contact. In the prototype, with two pad assemblies per arm, the swing arms were sprung at a rate of 100 lbs. per in. using Belleville washers, but a complete "floating suspension" was not provided.

ARM DESIGN

The movable pads can be actuated either by linkages or by a cam mechanism within the follower, each in turn powered by a compact hydraulic cylinder. This cylinder has several possibilities for location : axially within the follower, vertically within the follower, or on the guidance arm (connecting

to the follower by a sliding linkage). The arms have two main operating alignments, one for cruise and the other for passage through a guideway station (Fig. 4-16), and (Fig. 4-17). The arms must be able to swing down to curb level at stations and then collapse into the front fender well, behind a small fender door. For longer arms (on narrow or low cars) a double-pivoted arm (Fig. 4-16) offers better compactness and a smaller fender door. However, a pair of actuators would be needed for each arm, and binding/strength considerations become important. The simplest arm design is a single pivot type, with an A-frame attached near the frame rail and carrying the telescoping cylinder (Fig. 4-17). The single pivot option was chosen for the prototype system on the Mustang, with the pivot point located low and just outside the sheet metal line. The original steel fender was replaced with a fibreglas model because of ease of workmanship. The upper door flap was actuated by linkages controlled from within the vehicle, and the lower part of the door flap was attached directly to the cylinder/A-frame assembly. A single hydraulic actuator connecting the A-frame to the cowl raised and lowered the arm. The geometry of the arm during roll and lateral displacements is shown in Fig. 4.19.

For vehicles undergoing modification, the arm/follower mechanism would come as a single unit, including a supporting steel box, which could be welded into the fender well cavity.

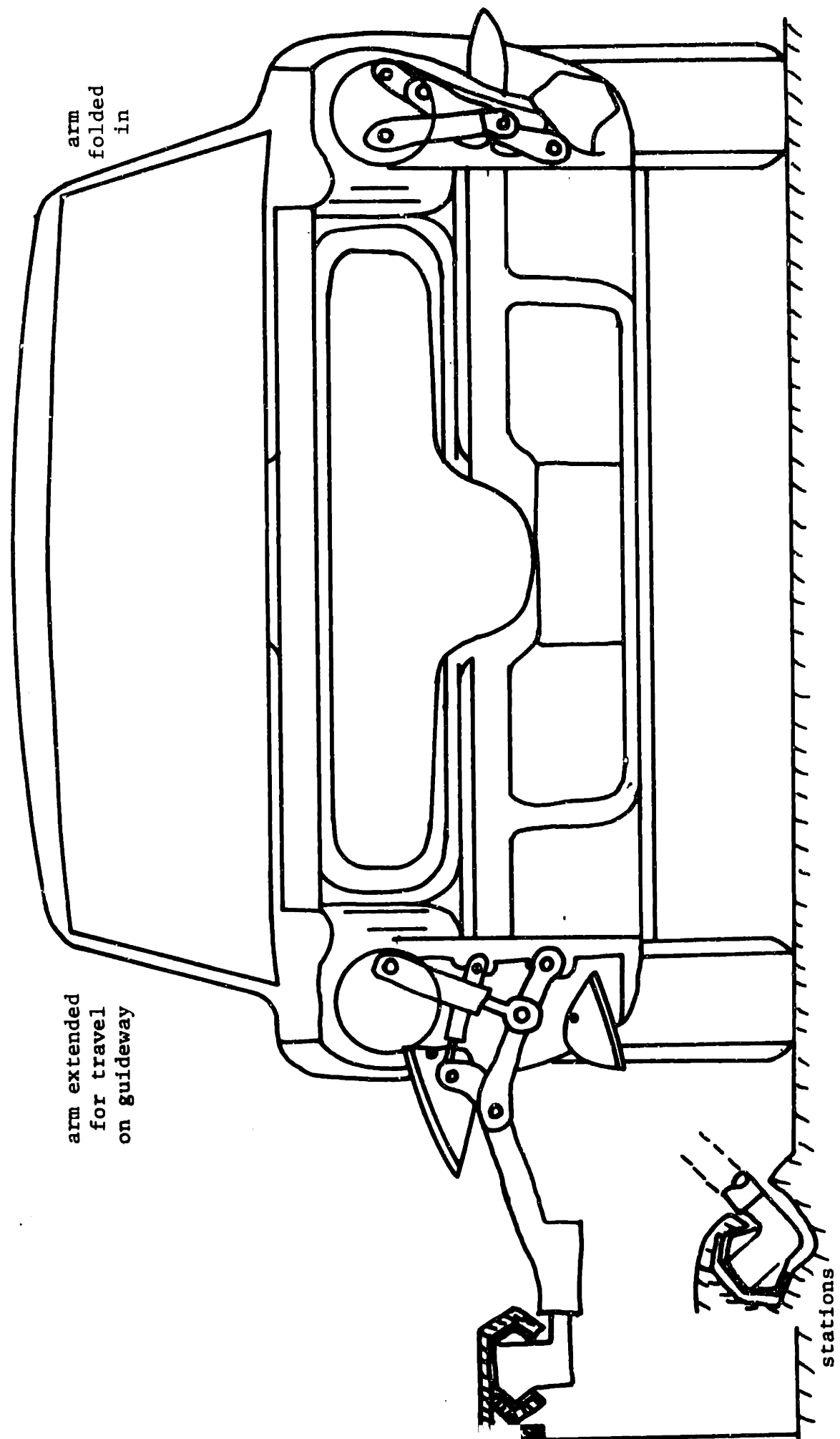


Fig. 4-16. Guidance Arm : Double Pivot and Cowl Location

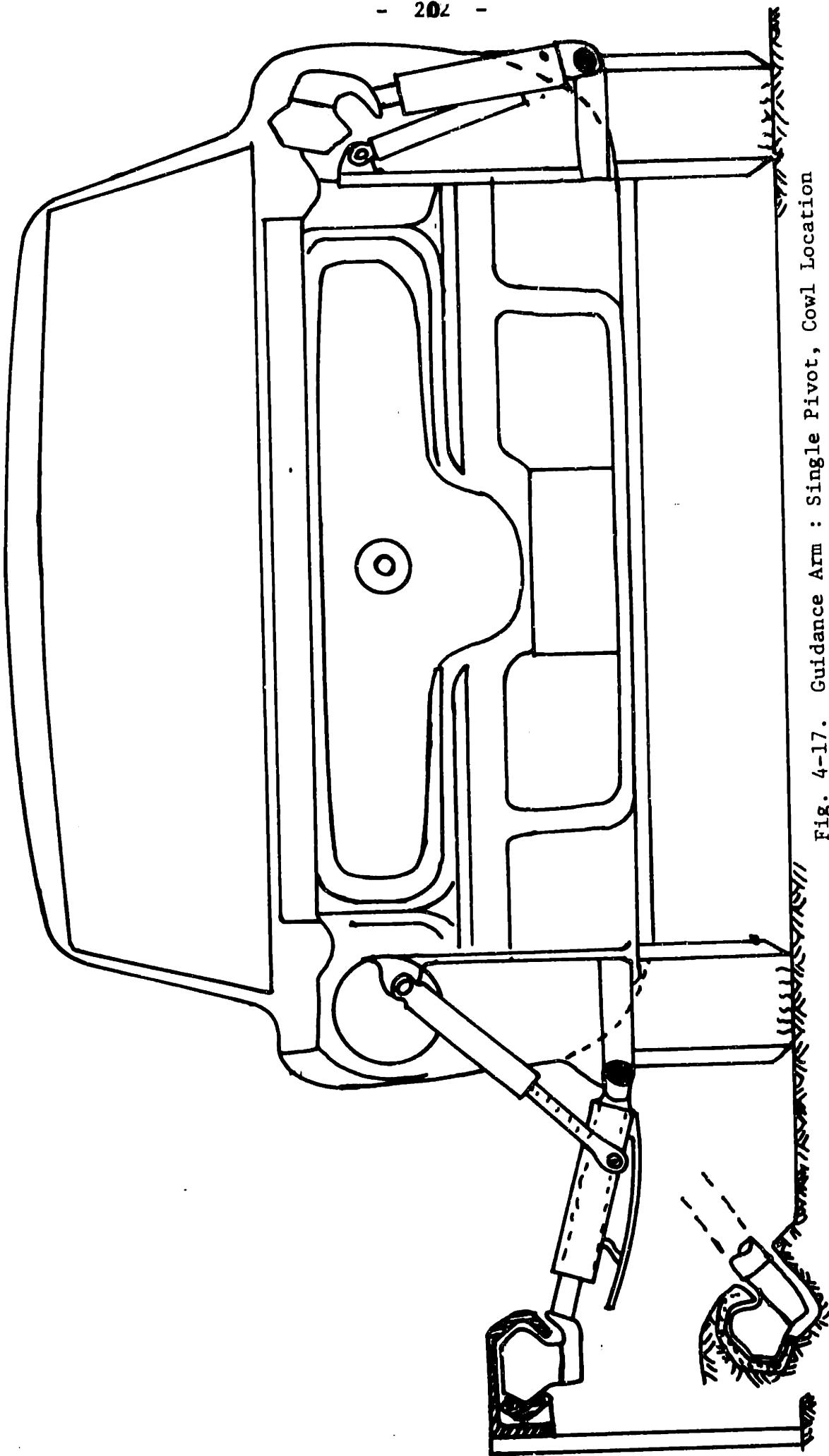


Fig. 4-17. Guidance Arm : Single Pivot, Cowl Location

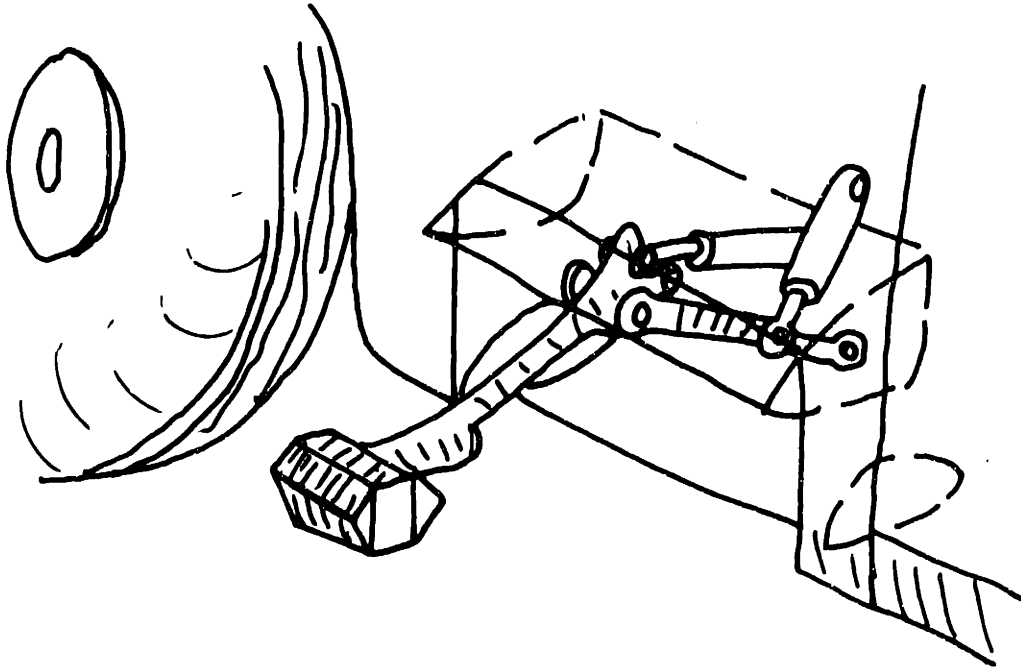


Fig. 4-18a. Double Pivot Arm : Extended.

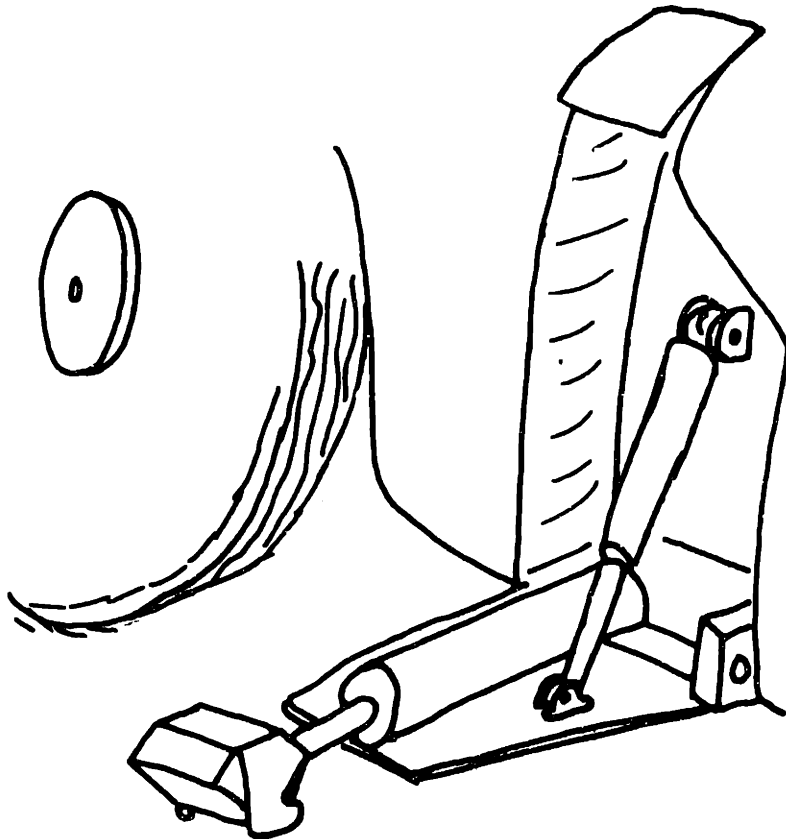


Fig. 4-18b. Single Pivot Arm : Extended.

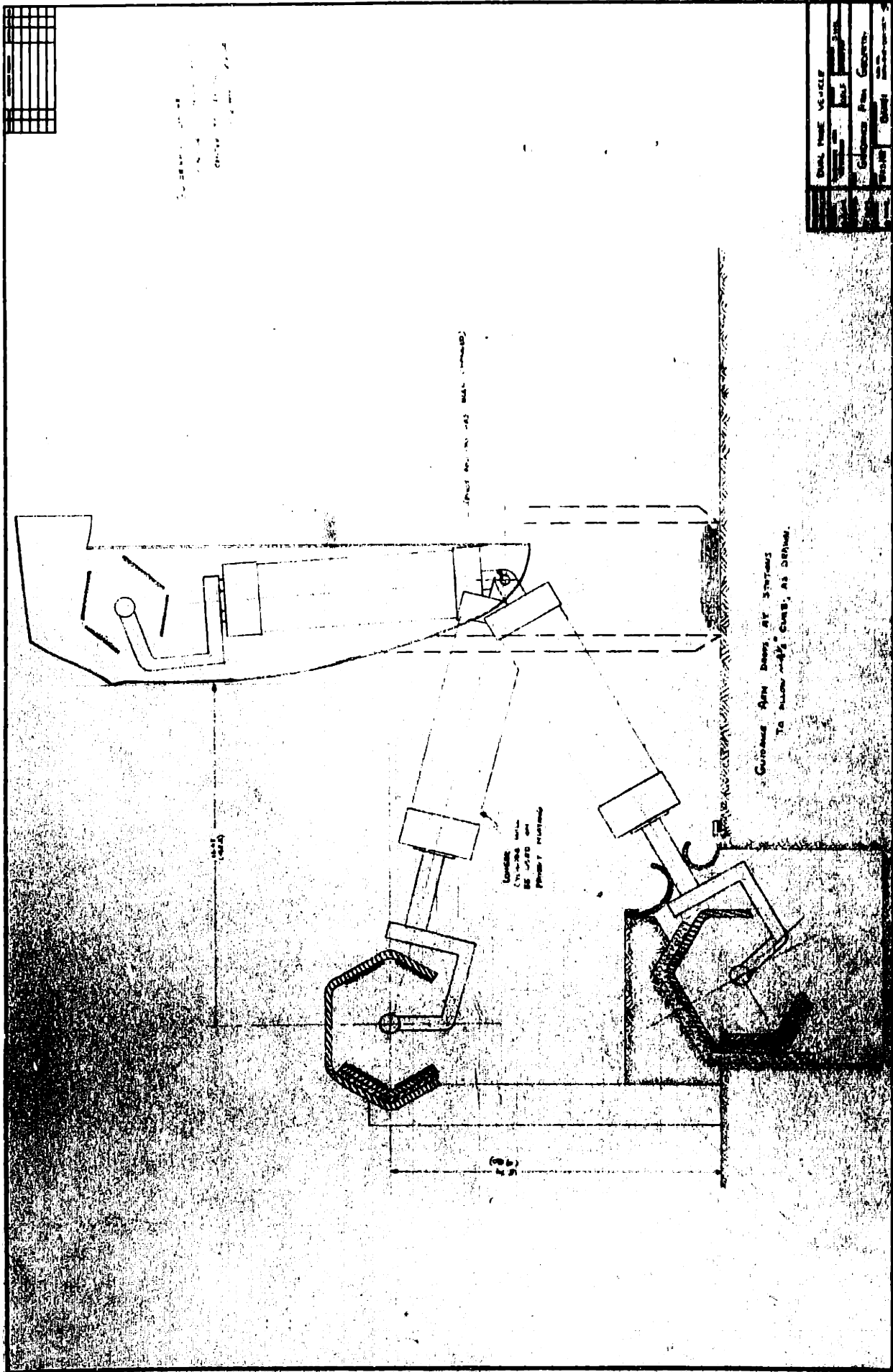
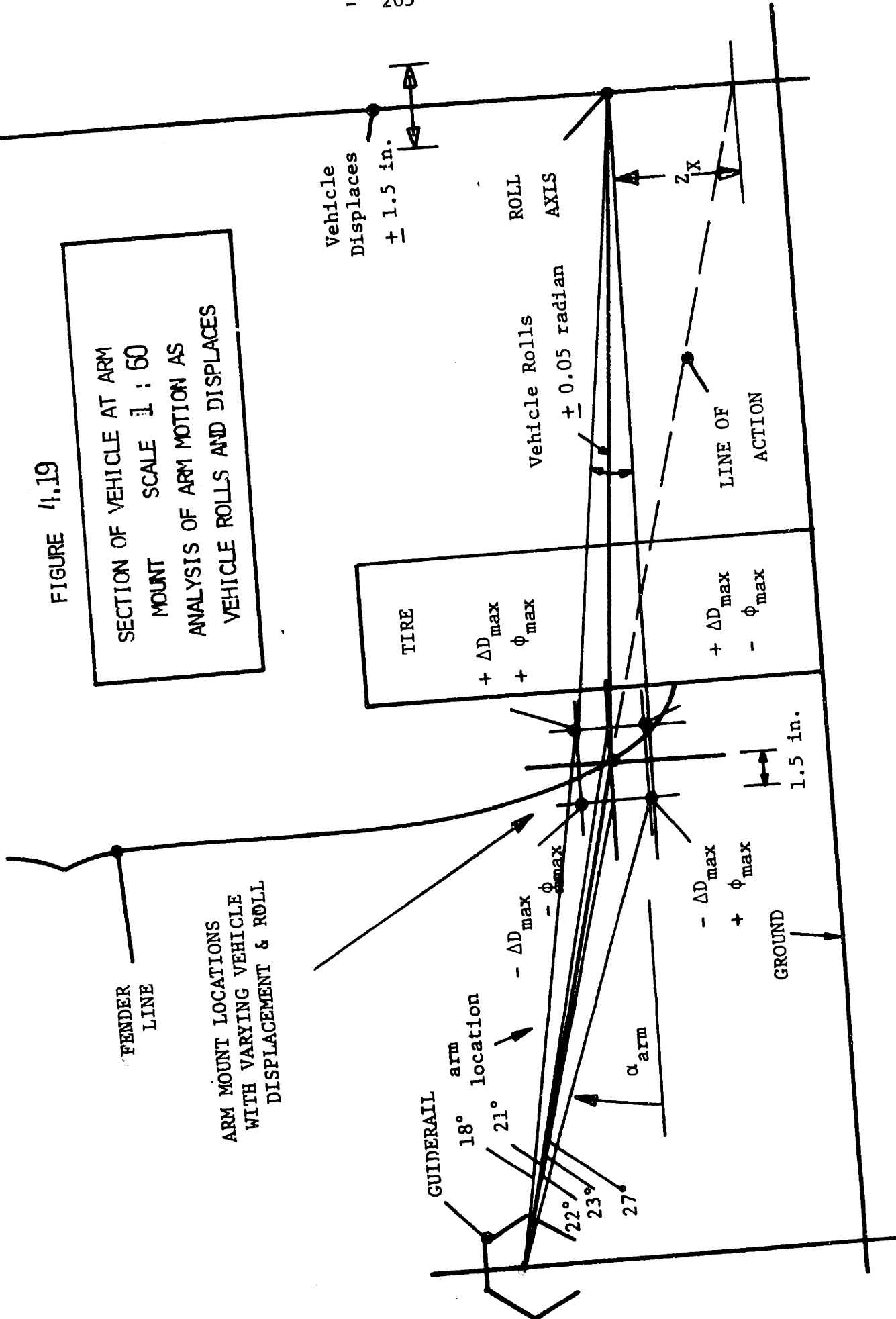


Fig. 4-18c. Single Pivot Guidance Arm : Drop to Curb Level at Stations

FIGURE 11.19

SECTION OF VEHICLE AT ARM
MOUNT SCALE 1 : 60
ANALYSIS OF ARM MOTION AS
VEHICLE ROLLS AND DISPLACES



The stock fender would have the arm door cut in it and the edges rolled under, then a ready-made door flap would be attached at the top of the fender and the lower door flap, part of the conversion package, is attached to the guide arm. A higher priced option would include new fenders as part of the whole dual-mode option, and the fenders could be slightly restyled to give special identity to the dual-mode car.

RAIL EXPANSION JOINTS

The guiderail is subject to temperature variations which require periodic expansion joints. In question is the type and spacing of joints for guideways. For an average North American city, temperatures of structures vary from a low of -30°F to $+120^{\circ}\text{F}$, so that a full 150° range should be provided. A 20-ft. steel rail would have a length variation of $20 \times 8.4 \times 10^6 \times 150^{\circ} = 0.25$ in. Similarly, a 100-ft. and 500-ft. section have variations of 1.25 and 6 in. respectively. At 60°F , the expansion gap is 0.75 in. for a 100-ft. length.

A number of choices are possible :

- (a). The simple open gap, possibly of the "tar strip" variety, using a visco-elastic substance between the ends of the rails.
- (b). Interweaving or "meshed finger" type familiar on many modern bridge;
- (c). A diagonal gap, which reduces the abruptness of the gap.

(d). Sliding-type bypass joints, as used on the Japanese Tokaido line (large 20-ft. joints located every mile).

(e). No joints -- with expansion taken by bowing out of rails on curves or in compression; controlled buckling. (Fig. 4-20).

The expected conclusion drawn about the simple gap -- and verified by tests performed for BART and the Westinghouse Transit Expressway, -- is that this joint is unsuited for high speed, efficient current collection. The diagonal gap is appropriate for a complex cross-section like the guiderail, while the bypass becomes very difficult to orient and function. In general, any joint must be properly insulated and carry electric power without serious losses or arcing caused as followers traverse the gap.

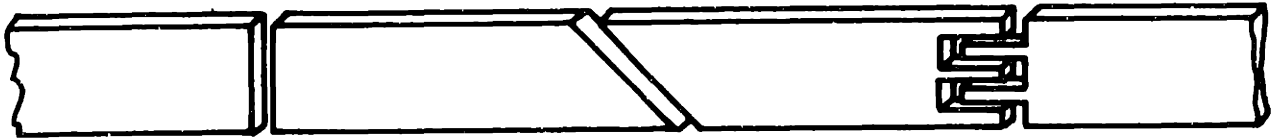
THE PROTOTYPE RAIL

The decision on the shape of the preliminary guiderail was made in mid-July 1968, and the designs for the prototype begun. On the basis of initial studies, control dimensions for the sliding surfaces were set, with the guiderail center set at 17.5 in. above ground reference. Both the outer and inner rail sections were bent on a brake from 3/8 - inch hot rolled steel. Because of the limited lengths of available brakes and the ease of handling and assembling shorter sections, 10-ft. long sections were specified. The working drawings for the test rail are included in Appendix A. The inner rail section has studs welded at two-foot intervals passing through punched holes in the outer rail, with insulating bushings and washers used to provide

1. SIMPLE
GAP

2. DIAGONAL
GAP

3. INTERWEAVING



4. BYPASS

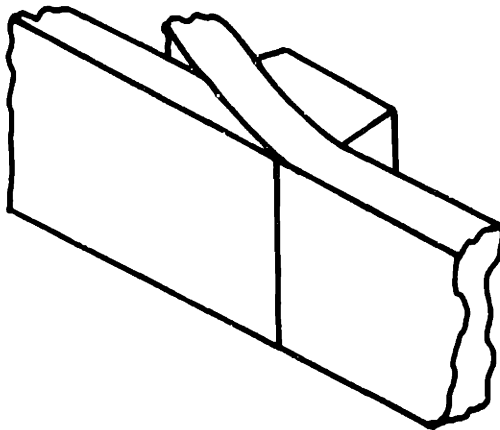


Fig. 4-20. Types of Expansion Joints

electrical insulation. In early November 1968, a broach was designed to remove scale and smooth out the joints, and was completed by early 1969. No attempt was made in the prototype installation to test expansion joints or electrical power supply to the rail, although some rail resistance and insulation tests were performed. The test car was mainly a vehicle to test the stability of straight-line passive and active guidance, follower friction, arm design and actuation, and rail design & assembly.

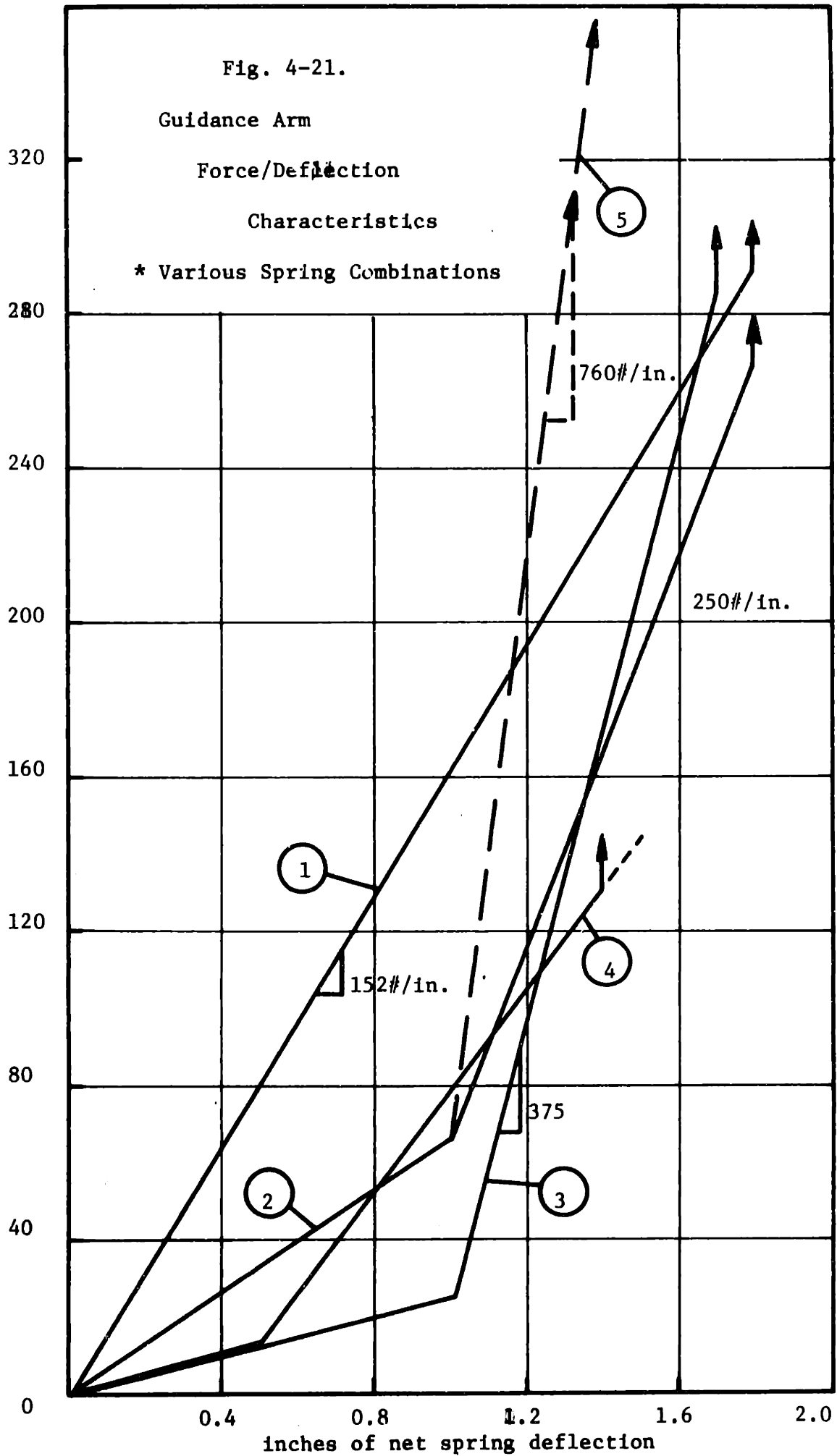
The prototype steering system employed a commercial hydraulic oil cylinder of 2-in. internal diameter as the main telescoping element of the guidearm. The cylinder was fitted with internal springs on either side of the piston to maintain the piston in the center of its travel when no lateral forces are applied to the car. After the cylinder was filled with automatic transmission fluid, it became possible to monitor arm position (by volume of fluid displaced) and arm velocity (by pressure drop across an orifice), and also to vary the degree of arm damping by valve regulation. The first test cylinder has single springs on each side of the piston, with a constant spring constant of 152 lbs./in. However, the resulting piston stroke and overall length became too great to inclusion of the arm within the fender cavity upon retraction. A new spring configuration was tried which maintained the ± 2 in. of arm travel, while reducing the overall cylinder length. Fig. 4-21

shows the force/deflection relations for a variety of coil spring combinations yielding a non-linear spring constant. Combination #2 was judged best, because of its moderate initial softness and final spring force equivalent to the original constant K spring.

The first trip down the guideway with the prototype was a rather harrowing experience, because the "boiler-plate" passive version of the articulated follower had just been installed and the rail had yet to be broached. Initial stick-slip and tightness because of scale buildup on the rail, with limited lubrication, combined with bottomed springs in the follower to create a very high friction situation. Some of the Belleville washers were removed to improve pad springing, and after rail broaching, up to 75-80 runs have been made, with the only serious incident being the spin-out on glare ice. Despite this condition -- caused by an inexperienced and lead footed test driver -- the shear pin snapped as planned and was replaced within a matter of minutes. Since then the car had been run successfully on ice, in the rain and through mud.

Most of the runs were made using the existing ICE power, but by 1970 an electric motor drive had been installed on the rear of the differential and a battery pack installation in the trunk was used to simulate guiderail power. For these 10-20 runs the car was propelled down the guideway by electric power and

Lateral Load on Single Arm, F_a , for Passive Guidance Test.



lateral arm guidance. The ride is quite smooth, and is marred mainly by the audible click of passing joints. Since the test rail had simple gap joints and partially sprung pads, a diagonal gap with improved pad springing should substantially resolve this problem. There also remains the possibility of on-site welding of the rail similar to railroad welding procedures.

SUMMARY

Guidance arm extending from the cowl area on both sides of the car contact the guiderail through a sliding follower attached to the end of each arm : active gripping and ungripping actions permit switching and merging operations.

The preferred rail has a diamond-shaped cross section and the follower is inserted from underneath. The high voltage inner rail is shielded by the surrounding outer rail and is protected from direct weather effects and debris. Of the numerous methods of articulating the follower pads and suspending the follower relative to the guidance arm, the pivot model appears to be stronger than the ball-joint suspension model and has been used in non-articulated form on the prototype guidearm. To date, cast iron pads with limited springing have been used, although low friction pads composed of copper-graphite appear to be a promising choice. Problems of wear, heating and reliability will need to be fully resolved for good performance.

When not in use, the arms fold out of sight into the body metal of the car. At stations, the arms and the rail drop down to curb level to allow access to the vehicle.

CHAPTER 5 POWER AND SPEED CONTROL

During manual operation, the conventional car engine drives the dual-mode vehicle with comparable performance to current autos. On the guideway under automatic control, an on-board auxiliary electric motor accelerates and propels the car at cruise, with the gas engine shut off and the transmission in Neutral. Alternatively, a smaller electric motor could work in series with the ICE powerplant, with the ICE at constant throttle, and the electric motor providing incremental power for accurate speed control. In either case, electric power and control signals are taken up through the lateral followers and the arms, so that on-board batteries will not be required.

ACCELERATION AND CRUISE

During acceleration, under pure electric power, the motor is overloaded 3x or 4x its constant duty output for 60 mph cruise. Thus a 30 HP motor (adequate for rolling and aerodynamic drag at 60 mph) could deliver 90 to 120 HP for acceleration up ascending ramps. Appropriate safety factors allow for uncertain design variables such as passenger/baggage loading, headwinds and possible slippery conditions of the guideway surface.

For the general case of a passenger car moving up an incline (Fig. 5.1), the force equation in the direction of travel is :

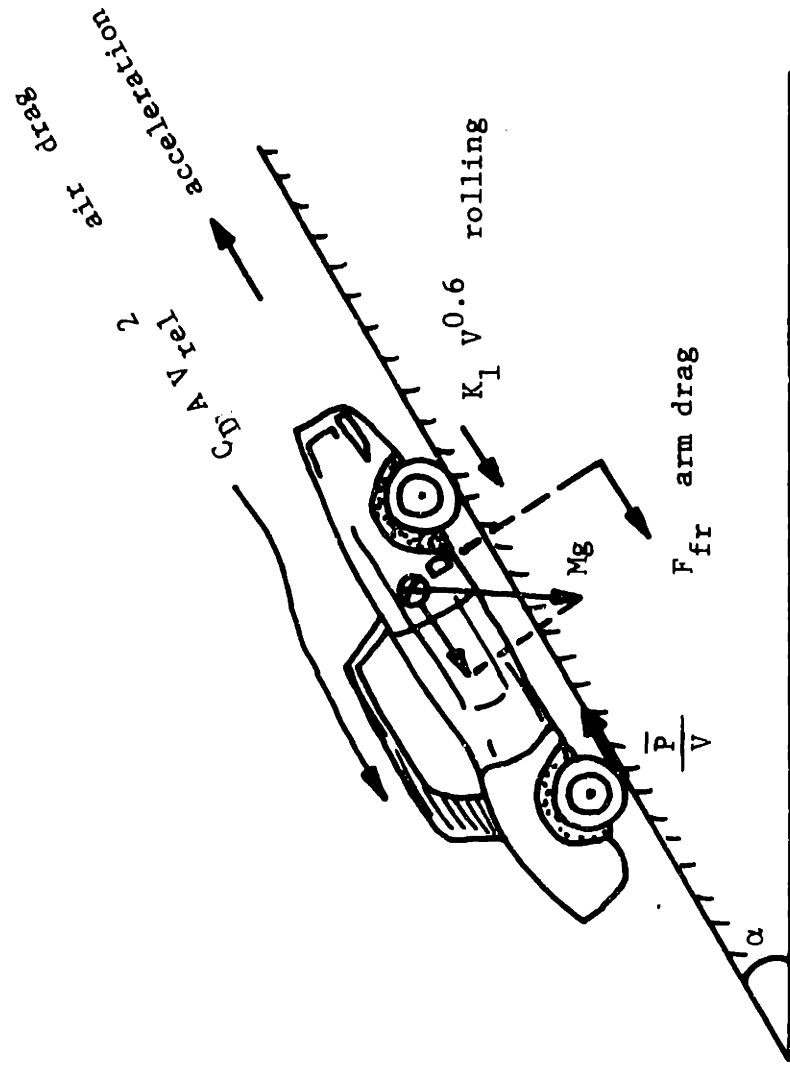


Fig. 5-1. General Forces on an Automobile Accelerating Up an Incline

$$\bar{P}/V - mg \sin a - K_1 V^{0.6} - \frac{\rho}{2} C_D A V_{rel}^2 - F_{fr} = Ma_{acc} \quad (5.1)$$

(power at wheels) (incline) (rolling friction) (air drag) (Friction drag of arms)

where the parameters are defined in Table 5-1 for the case of a 1967 Mustang. For 60 mph cruise and 10 lbs. drag in the arm, the minimum power for level travel is the sum of arm friction, rolling friction and air drag (Fig. 5-2) or 31 HP. At 40 mph, the cruise power is only 12 HP. The maximum power condition for a 60 mph headwind, 8.7% slope and 30 lb. arm drag is 230.5 HP at 60 mph for a loaded car of total 5,000 lbs. weight. For 40 mph this requirement drops to 140 HP). Clearly, the guideway must be designed to ensure that the combined effects of high speeds, headwind exposure and steep slopes do not occur simultaneously.

TABLE 5-1. PHYSICAL PARAMETERS FOR 1967 MUSTANG

Dry weight = 107 slugs (3450 lbs.)	Rolling Parameter K_1
Max. load = 1500 lbs.	= 3.94 (fps units)
Max. weight = 154 slugs (4950 lbs)	

Conventional Gas engine power (6-cyl) : 120 HP max.

$C_D A$ (air drag parameter) = 0.014 sec² / ft²

The maximum speed attained by a conventional Mustang with 100 road HP available during upramp guideway acceleration depends upon the ramp slope, vehicle loading and headwind velocity. Assuming

a simplified power/torque curve* and analysis developed by Larrabee¹, one can calculate the unloaded car on an 8.7% slope reaches 60 mph in under 22 seconds while a loaded vehicle will attain a maximum speed of only 54 mph under such grade conditions (Fig. 5-3). For lesser ramps, especially downramps and ramps or decreasing slope, the acceleration is brisker and the ramp length much reduced (Fig. 5-4 and 5-5).

MOTOR DRIVE ARRANGEMENTS

If the driveline efficiency is assumed to be 90 %, a motor of at least 35 HP constant rating is necessary to maintain 60 mph cruising speeds. The auxiliary electric motor could be located in a number of places, based on criteria of efficiency, drivelines reliability, minimal vehicular modification or loss of space, ride/handling effects and cost. The necessary power equipment comprises the electric motor, motor controller, shafting/gearing/belts, cable connectors, and power collector pads on the arms. The main options are illustrated in Fig. 5.6 -- wheel motors,

* The calculation technique assumes a constant torque region (constant acceleration of 0.3G) from 0 to 33 mph, and constant 100 road HP thereafter. For a comparison check, a 120 bhp 6-cylinder Mustang accelerates from 0 - 60 mph in 15.5 sec. (*Consumer Reports*, August 1966), compared to 10.5 sec. for the constant torque/constant power calculations above. For climbing a 9% grade, the maximum speeds are 60 MPH ICE and 65 mph for the 100-HP calculation.

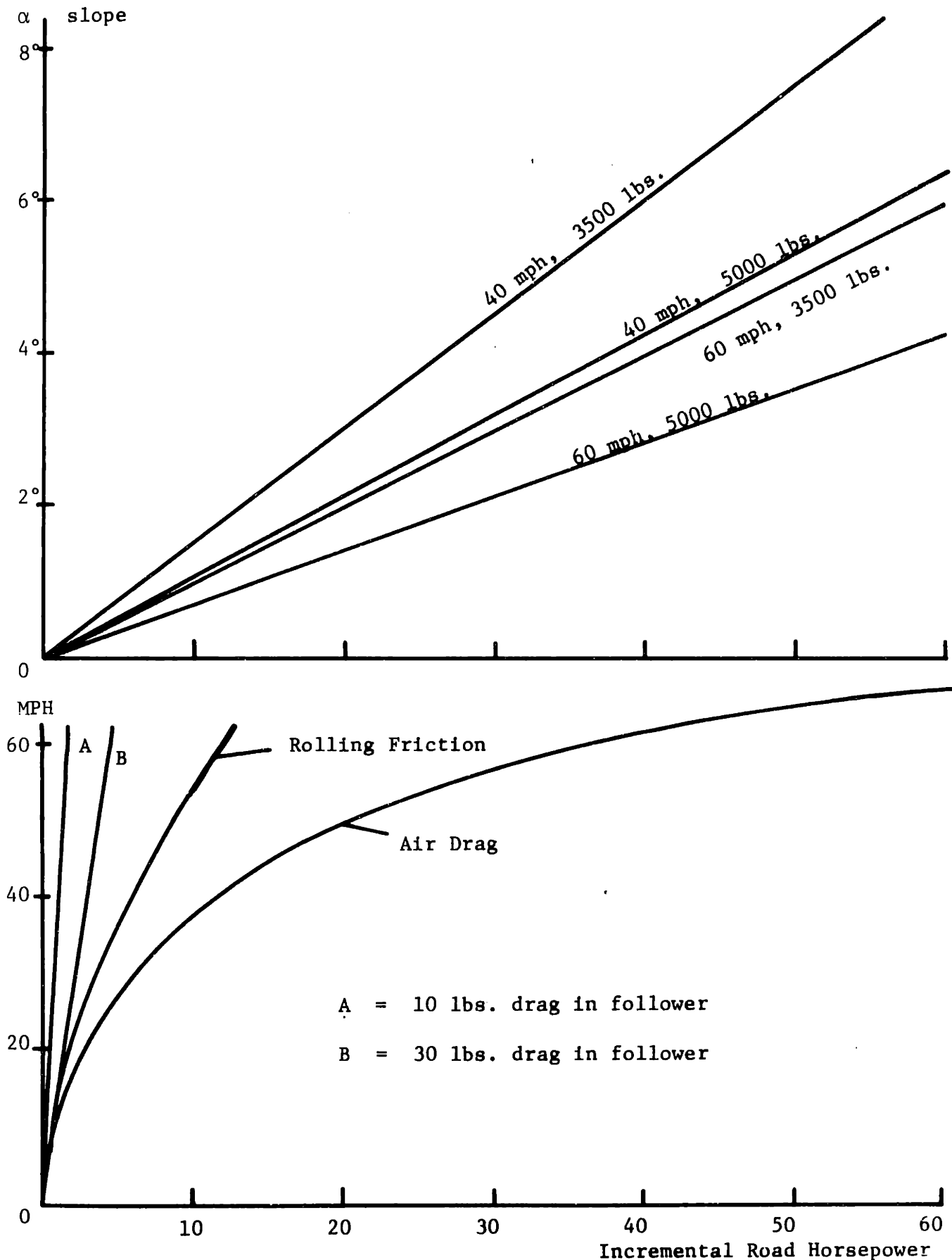


Fig. 5-2. Slope, Arm Friction, Air drag, and Rolling Friction Components of Vehicle Power : 1967 Mustang.

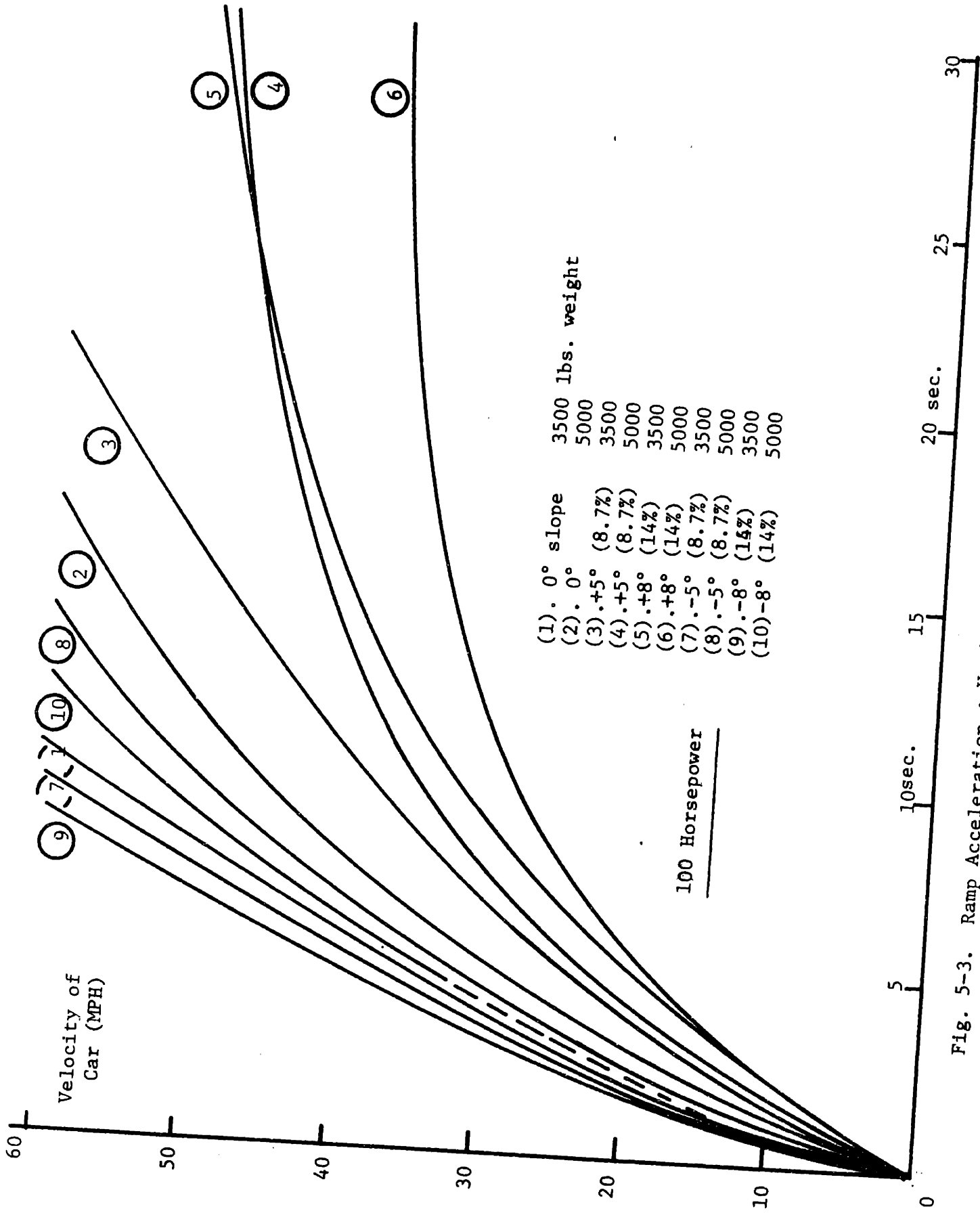


Fig. 5-3. Ramp Acceleration : Various Slopes and Vehicle Loadings : 100 HP Mustang

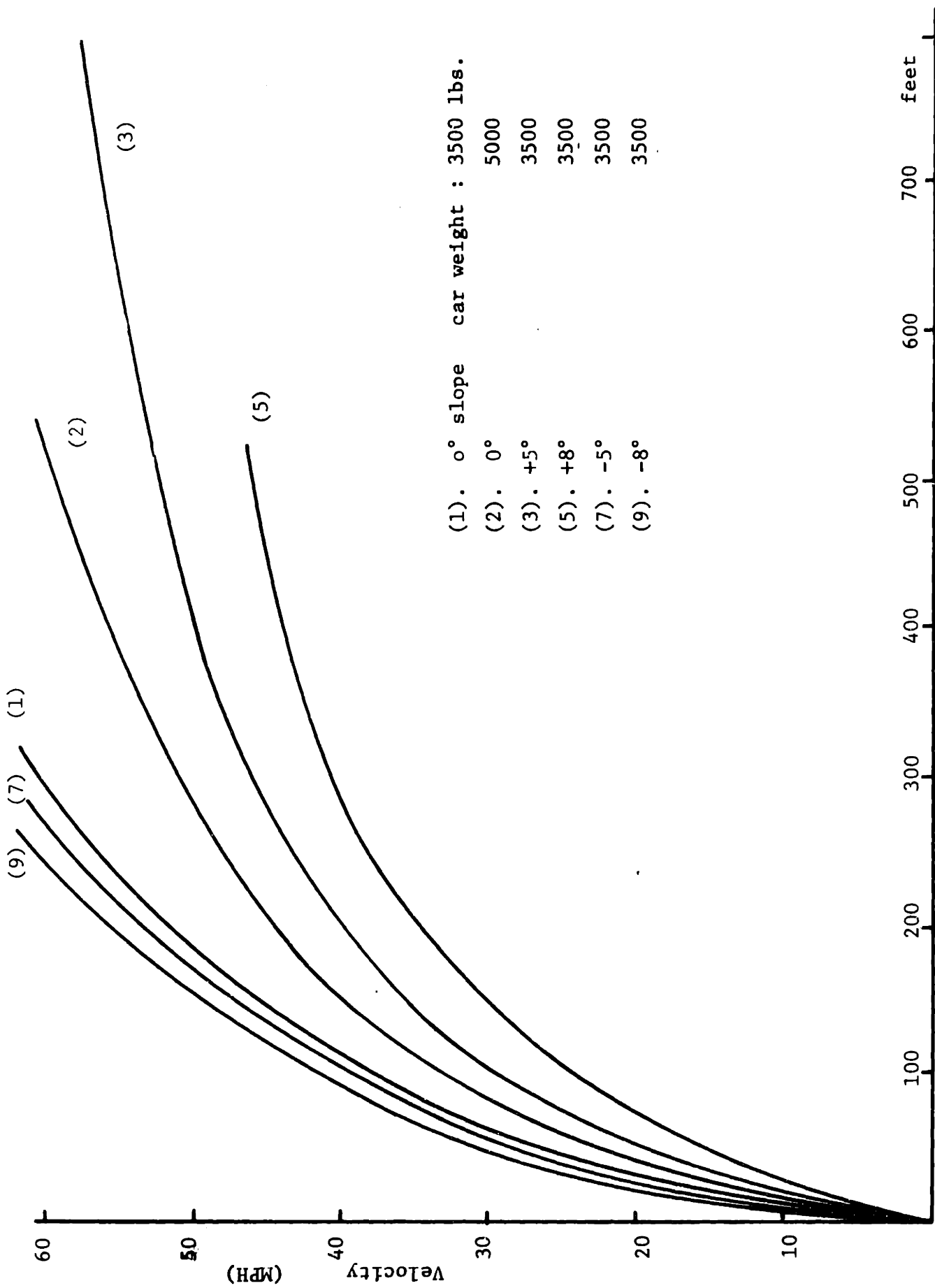
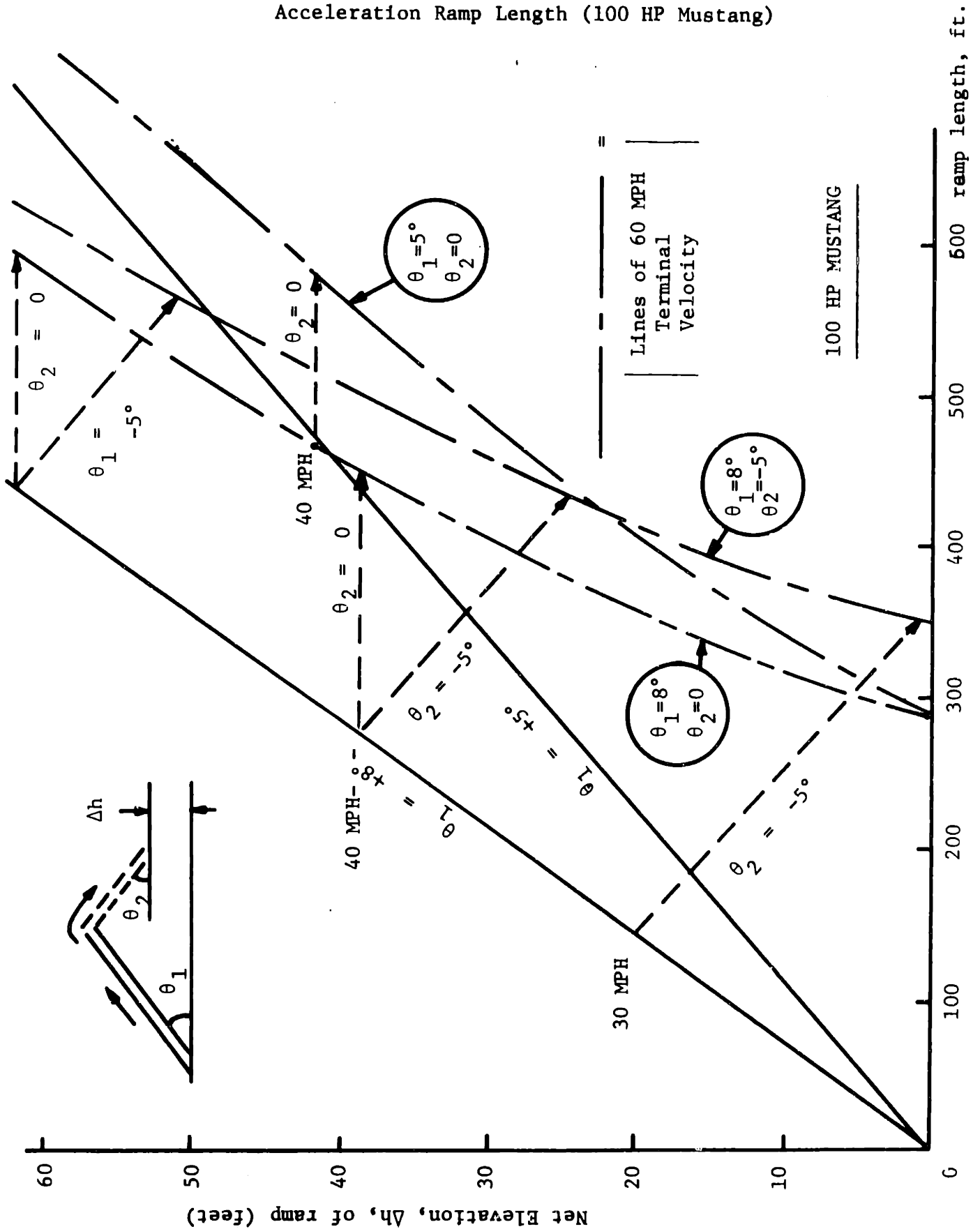


Fig. 5-4. Ramp Length for Acceleration : Various Slopes and Vehicle Loadings

Fig. 5-5. Combination Ramp Segments : Net Elevation vs. Acceleration Ramp Length (100 HP Mustang)



offset motor plus transfer case, and the under-trunk location, with drive to the rear differential.

Wheel motors do not currently exist and are a more exotic future prospect. The driveline location has the advantages of limited vehicle modifications and simplicity, but the motor speeds are restricted to the 3200 rpm range at 60 mph, which is rather low for best utilization of modern, compact high efficiency electric motors. Trunk motors permit single or multi-stage gearing up to higher speeds and motor size and shape becomes more flexible. compared to the tight space requirements of the driveline location (Fig. 5.6).

* * * * *

TABLE 5-2 MOTOR AND DRIVE SHAFT SPEEDS

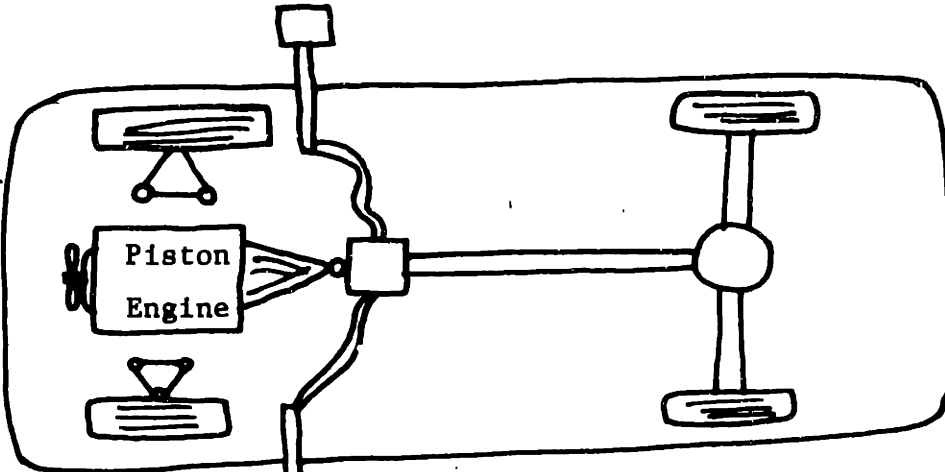
Rear axle speed @ 60 mph (26-in diameter wheel)	=	795 rpm.
Drive shaft speed (for a 4.0 : 1 rear axle ratio)	=	3180 rpm.
Motor speed for 1 : 1 connection to drive shaft	=	3180 rpm.
for 2 : 1 pulley/gear ratio	=	6360 rpm.
for 4 : 1 pulley/gear ratio (2-stage)	=	12720 rpm.

* * * * *

An interesting alternative to the above all-electric considerations, the combination small electric / ICE operation, is shown in Fig. 5-7. The regular ICE and transmission, either manual or automatic, are also controlled by the guideway speed/

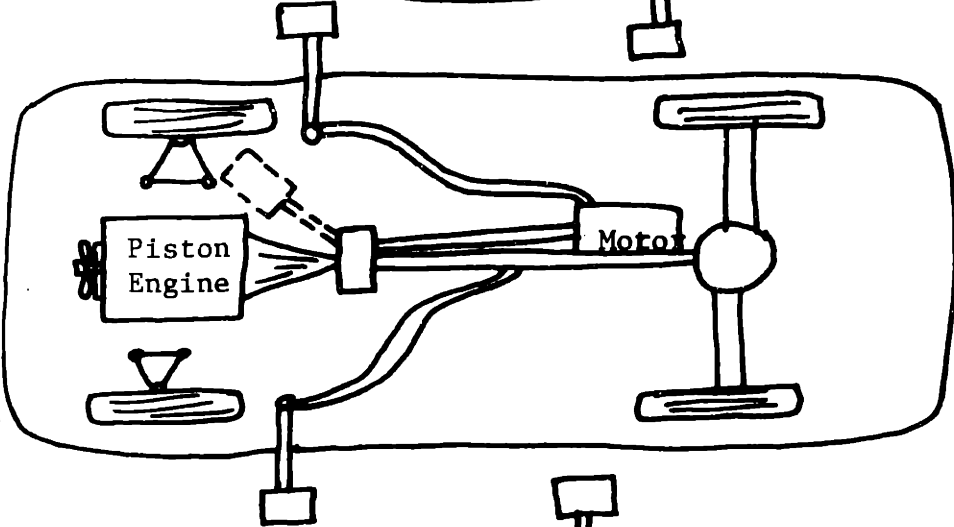
Series-located
Electric Motor
(Driveshaft)

Motor Cruise
Speed :
3200 rpm
@ 60 mph



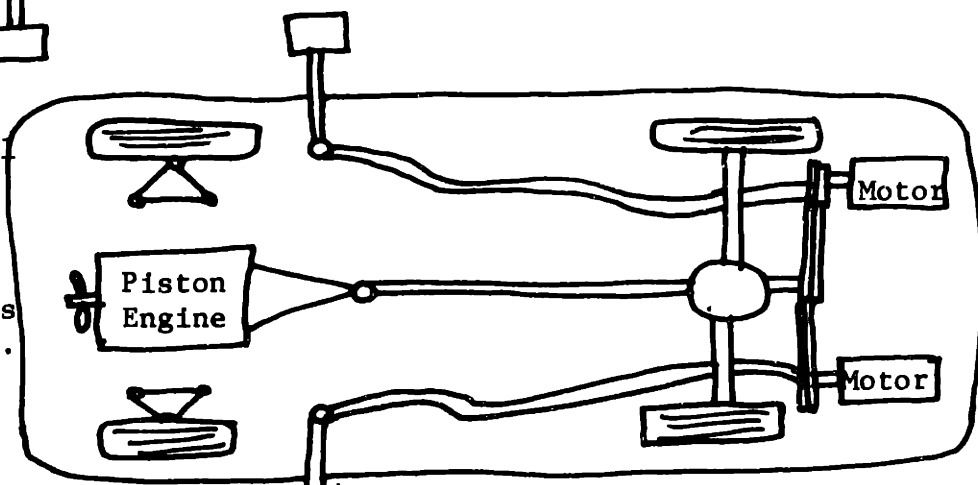
Transfer Case and
Auxiliary Electric Motor

Transfer Case expensive,
but permits gearing up
speed of motor



Differential
Drive from
Trunk
Location

Stub shafts
plus prop.
shaft &
belts or
chain



Motor/Generator/Wheel Motor
Combination

(Future option, to
function like a Diesel-
Electric locomotive)

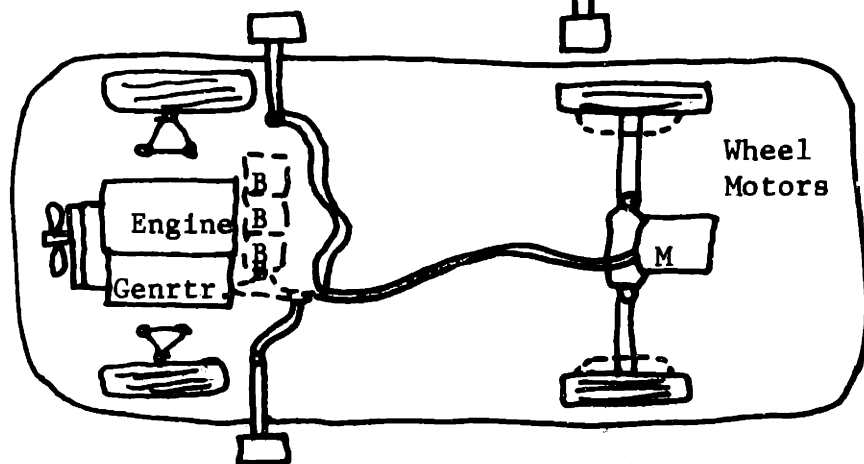


FIG. 5-6. MOTIVE POWER
OPTIONS

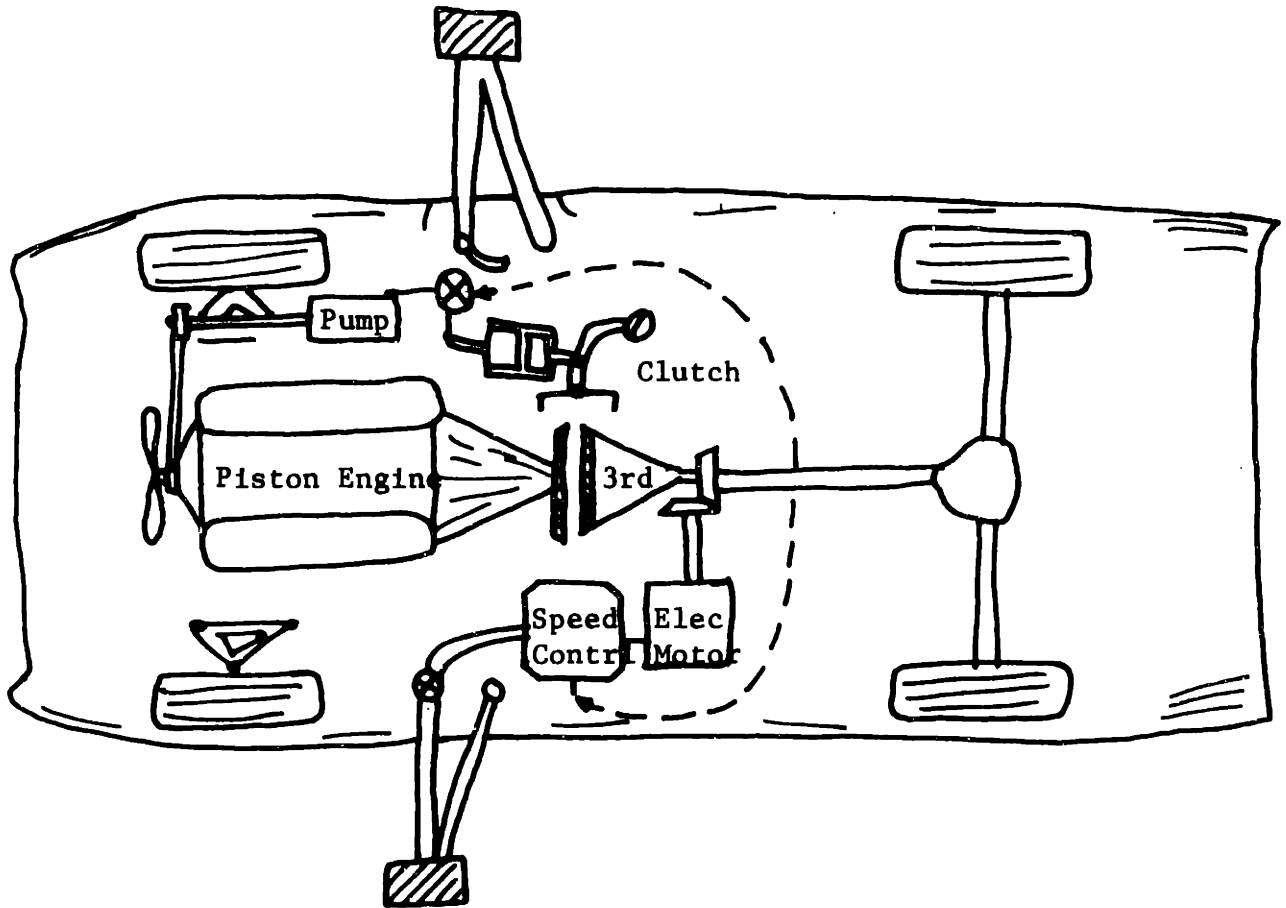


Fig. 5-7. Parallel Operation of Piston Engine & Electric Motor

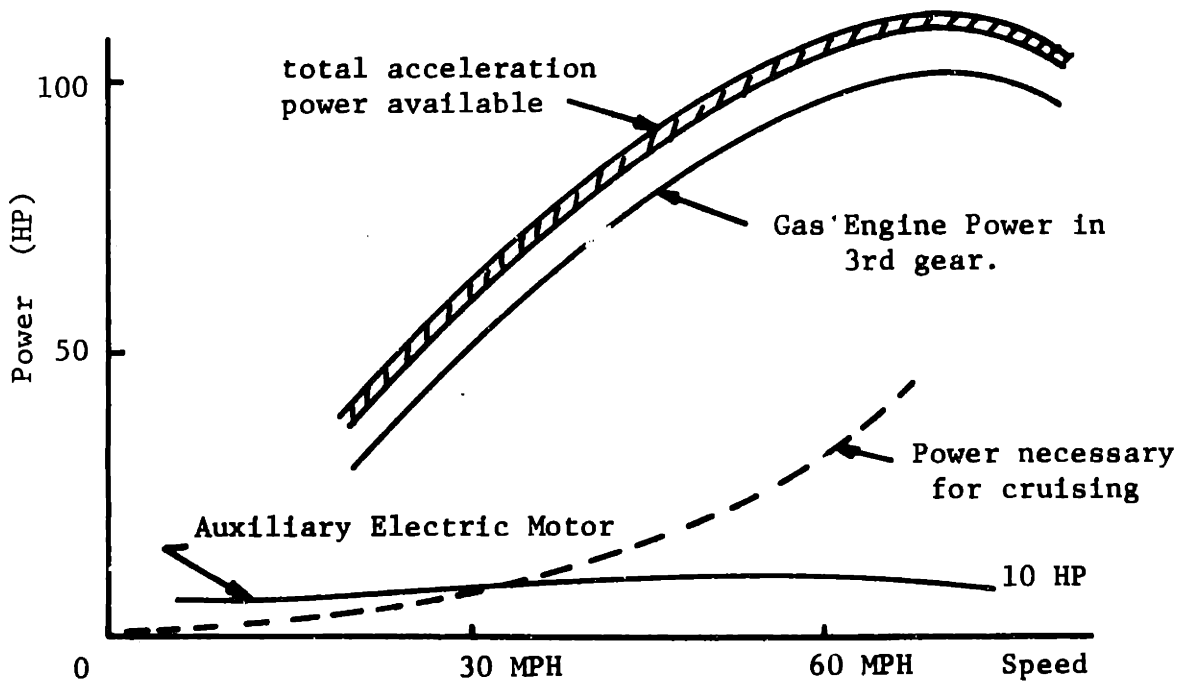


Fig. 5-8. Acceleration Power for Parallel Motor Operation.

power control process. For automatic transmission vehicles, the entering driver would leave the vehicle in "drive" and throttle control would regulate power to the wheels from the engine. With manual transmission cars, the entering driver would leave the car in third gear (cruise) and depress the clutch. Then, after initial acceleration to approx 20 - 25 mph, the automatic control would release the clutch and the ICE power would be available for acceleration. (Fig. 5.8).

An important advantage of the combined-power option goes beyond its simplified add-on power train. One of the severe limitations of any new powerplant -- especially electric and steam engine -- in autos is the need to generate power at rest, the "parasitic" load necessary to run pumps and air conditioners. In some vehicles, the air conditioner may consume more than 15 HP even when the overall vehicle is standing still and using no energy for locomotion. For reasons of this auxiliary power need, the General Motors steam cars have been connected to a torque converter rather than direct drive, in order to use the engine to generate parasitic power at rest. The popularity of air conditioning has increased dramatically since its first factory installation in 1939 Packards. From 7% orders among all cars in 1960, air conditioning is now ordered on more than 55% of 1970 new cars, with accessory stores adding to the percentage. The market has spread to compacts and smaller models, as well

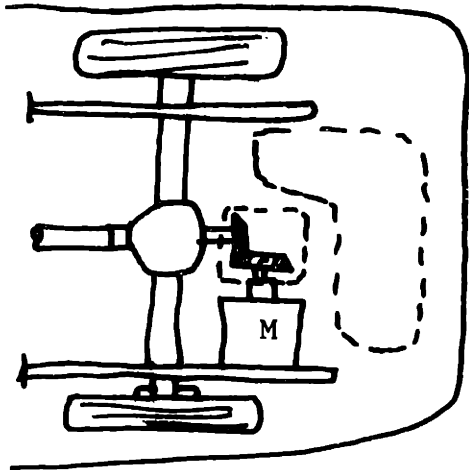
as luxury models. The all-electric guideway power option might work in conjunction with air conditioning *without* an auxiliary electric motor to provide constant duty if a certain degree of cooling intermittency could be tolerated, such as at stations and exits. The lack of bumper-to-bumper traffic jams on the guideway reduces the need for parasitic loads at low speeds.

Whatever may be the optimum type of power arrangement for the individual person or vehicle, the guideway system can accept a mix of vehicles, some with motors under the trunk, others with driveshaft motors, still others with combined power -- as long as the speed control performance of each maintains certain standards.

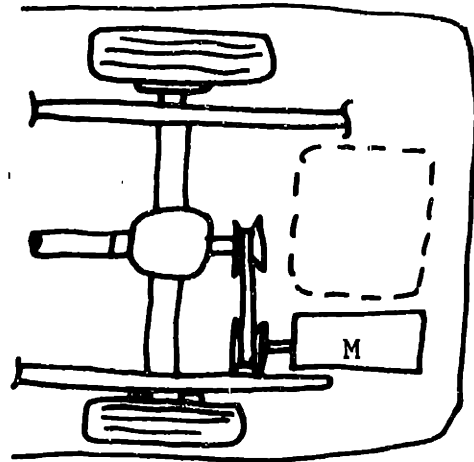
There are several varieties of under-trunk locations, the general class which appears to offer the best initial compromise of space, flexibility and accessibility. Either belts, shafts or chains could be used to transmit the power to a stub shaft extending out the rear of the differential and turning at the same speed as the drive shaft. (Fig. 5.9).

ELECTRIC POWER DISTRIBUTION

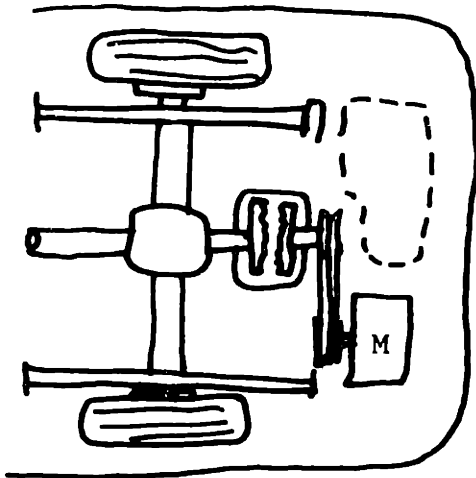
The electric power distribution system includes the guiderail or "third rail" on either side of the guideway, parallel conductor cables as required, periodic power stations (transformers) and power generators if adequate power is not



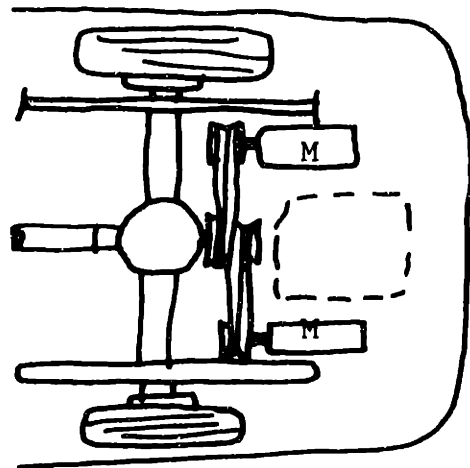
(a). Bevel Gear Drive



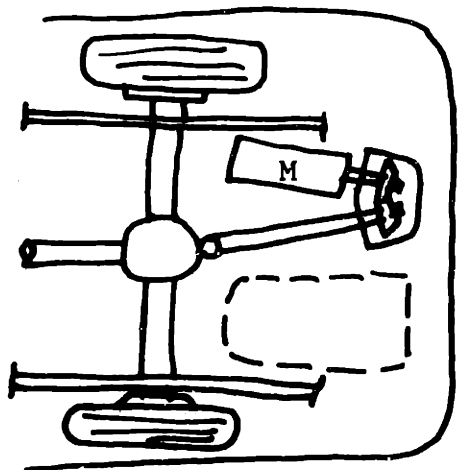
(b). Chain or Belt Drive



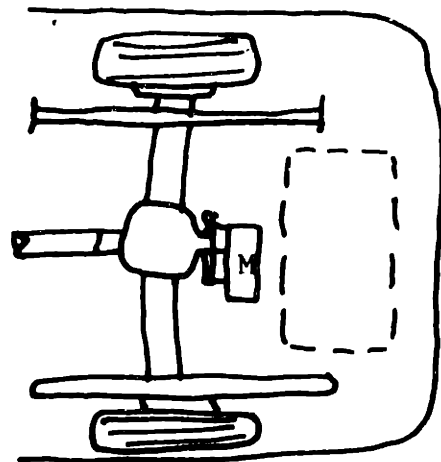
(c). Fluid Coupling & V-Belt



(d). Double-motor & V-Belt



(e). V-Drive Shafting Arrangement



(f). Differential-Mounting

Fig. 5-9. Methods of Delivering Power : Elec. Motor to rear Axle.

available from conventional utility companies. Ideally, system voltages should be kept high to limit I^2R losses but low enough to avoid electrical breakdown and unnecessary hazard to personnel and passengers. Properly shielded design of the conductor guiderail and the insulators should permit operating voltages in the 500 to 1000 volt range and possibly higher.

TABLE 5-3 VOLTAGE LEVELS FOR ACCELERATION AND CRUISE

Voltage	HP	Amps		Voltage	HP	Amps	Slider Area
100	35	262	*	100	100	750	7.5 sq. in.
250	35	105	*	250	100	300	3.0
500	35	52	*	500	100	150	1.5
1000	35	26	*	1000	100	75	0.75
3000	35	8.8	*	3000	100	25	0.25

Note : slider area based on rule of thumb for commutators : 100 amps/in.² max.

Transit has always used the DC traction motor with it quite favorable speed-torque characteristic. Consequently, almost exclusive use is made of DC power collection with voltages related to feasible motor insulation levels of about 600 volts. Most trolley systems operate in the 500 to 600-volt range, although modern developments in electric power systems and insulators have led to numerous advancements in recent years. Contact rail voltages for representative systems are Boston MBTA (500v), Remn Central (600v), Long Island Railroad (660v), Montreal

Metro (720v) and BART (1000v), while for catenary pick-ups the Illinois Central, Erie-Lackawanna and Penn Central use 1500v DC 3000v DC and 11,000v AC respectively. Penn Central cars carry on-board rectifiers to convert to 600v DC for electric traction equipment.²

The DC motor provides high starting torque at low speed, compromised with top speed for overall performance. Starting accelerations of 3 mph per sec and 50-70 mph speeds usually require 110 - 150 HP per car. BART, after extensive analysis and testing, selected a DC system because of its "lower cost, greater reliability, superior maintainability and lower operating cost." Traction control of 1000v DC is by a thyristor or chopper-type power modulation system, and thus avoids the power loss and heating associated with switched resistance equipment. However, because BART was limited to trackside collection and could not use overhead wires, the 4160-v, 3-phase 60cycle option was ruled out.

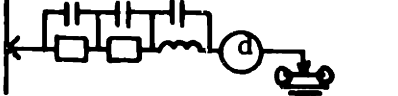


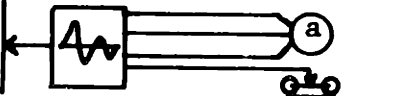
The new proposed TACV (Tracked Air Cushion Vehicle) involves a very complex power modulation system based on a synchronously commutated thyristor inverter. Wayside AC power is picked up and goes through a phase controlled rectifier that converts AC to DC, variable from 0 to 9000v. A DC inductor then acts as a smoothing reactor to remove the wave ripple. Finally, an inverter changes the current to variable frequency AC, which is fed to the Linear Induction Motor.

The alternative to chopper control is the AC induction motor derived from DC distribution via a DC-AC inverter (pulse width modulated) or a DC motor using a polyphase AC source and SCR phase-controlled rectifiers. The latter provides a relatively smooth and continuously adjustable DC current from zero to near peak AC level with high conversion efficiency. However, there are problems of cost and reliability with the SCRs. Westinghouse Air Brake Co. has recently announced the first practical development of AC motors working off a DC source. Using solid state switching, WABCO claims smooth acceleration, lower maintenance costs, regenerative braking, and improved speed/torque control via pulse width modulation.³ (Fig. 5-10)

For dual-mode operations, an extensive analysis has yet to be done on the best overall system characteristics and requirements -- for rectification, speed control, torque-speed relations, efficiency, etc. The most reasonable choices appear to be :

- (a). DC 500 - 1000+ volts supply and motor
- (b). Fixed frequency AC supply and motor
- (c). Variable frequency AC
- (d). Single phase AC, rectified to DC on vehicle
- (e). Three phase AC, rectified to DC
- (f). DC on track, with chopper/inverter on vehicle

500 to 1500 Volt D.C. Systems

⊕	Switched Resistor		Traditional
⊕	Chopper		Modern Systems
	Resistance Shunting Chopper		Variation of Above
	DC-AC Inverter PW Modulated		-

4000+ Volt A.C. Systems


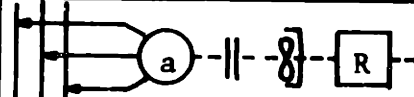
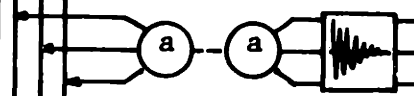

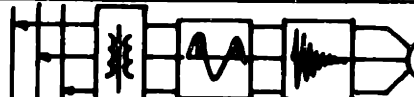
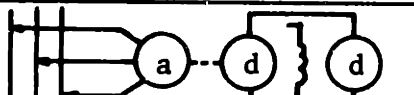
⊕	Phase Contr. Rect.		Highly Developed Solid State Contr.
	Torque Conv & Clutch		Not useful
	Cyclo Converter		-
⊙	Freq. Converter		-
⊕	HighSpeed Freq. Convtr		-
	Ward-Leonard		-
<p style="text-align: center;">⊕</p> <p style="text-align: center;">⊙</p>			

Fig. 5-10. Electric Propulsion Concepts.

Rectified 3-phase and regular DC would have the highest $\int Idt$ per cycle and hence require a lower operating voltage. At higher AC frequencies and high current demand, skin effect and eddy current losses may become very important. DC power on the track will likely have the most serious corrosion problems, while variable frequency AC would be of little value except for acceleration and start-up of a stalled system.

The rectification of the primary AC power supply could theoretically occur either at periodic substations or on the vehicle. Since modifications to the vehicle should be kept at a minimum, rectifiers should be located at substations along the route. The Montreal Metro uses eighteen 36,000 KVA substations to supply its various lines and employs a primary power supply of 12,000v 3-phase 60 cycle AC, with high voltage cables running underground between the distribution centers and the substations. In Europe, new 25,000v AC systems of railroad electrification are being installed in some places, reportedly reducing construction costs of the electric distribution system by 50%, as compared to 1,500v DC lines.⁴ The smaller conductors (1/3 size of DC system type) and less weight permit use of lighter supporting structures. Substations are now spaced at 40-mile intervals rather than the previous 10-mile intervals.

For the initial test sequence, DC power to the guiderail

and simple slider pick-up to DC motors appears to be the simplest and wisest arrangement. Voltages in the 100 to 250 volt range can be used in preliminary stages of demonstration, especially when only public and fleet vehicles are in use. When some degree of power and control feasibility has been demonstrated and public acceptance of the dualmode concept becomes fairly widespread, the voltage levels can be raised, public and fleet vehicles modified and soon the system can be opened for massive public usage, including private cars.

Because the guideway will be grade-separated and the guiderail designed to cover and shield the live power rail from weather and foreign objects, final rail voltages of at least 1000v appear well within reason and practicality. The structural guiderail itself (or part thereof) can serve as a power conductor, while auxiliary cables parallel to the guideway carry the remaining current.

The size of the rail, the line voltage and the spacing of substations are all intimately related. For a typical substation for an AC primary supply and DC guiderail, discretely located substations containing transformers and low-voltage rectifiers (Fig5.11a) would service a line of guideway vehicles, The power drain in the rail (Fig. 5.11b) causes a voltage drop from V_0 to V_1 , depending upon the IR drop along the conductor. Voltage V_1 is determined by the performance flexibility of the motors.

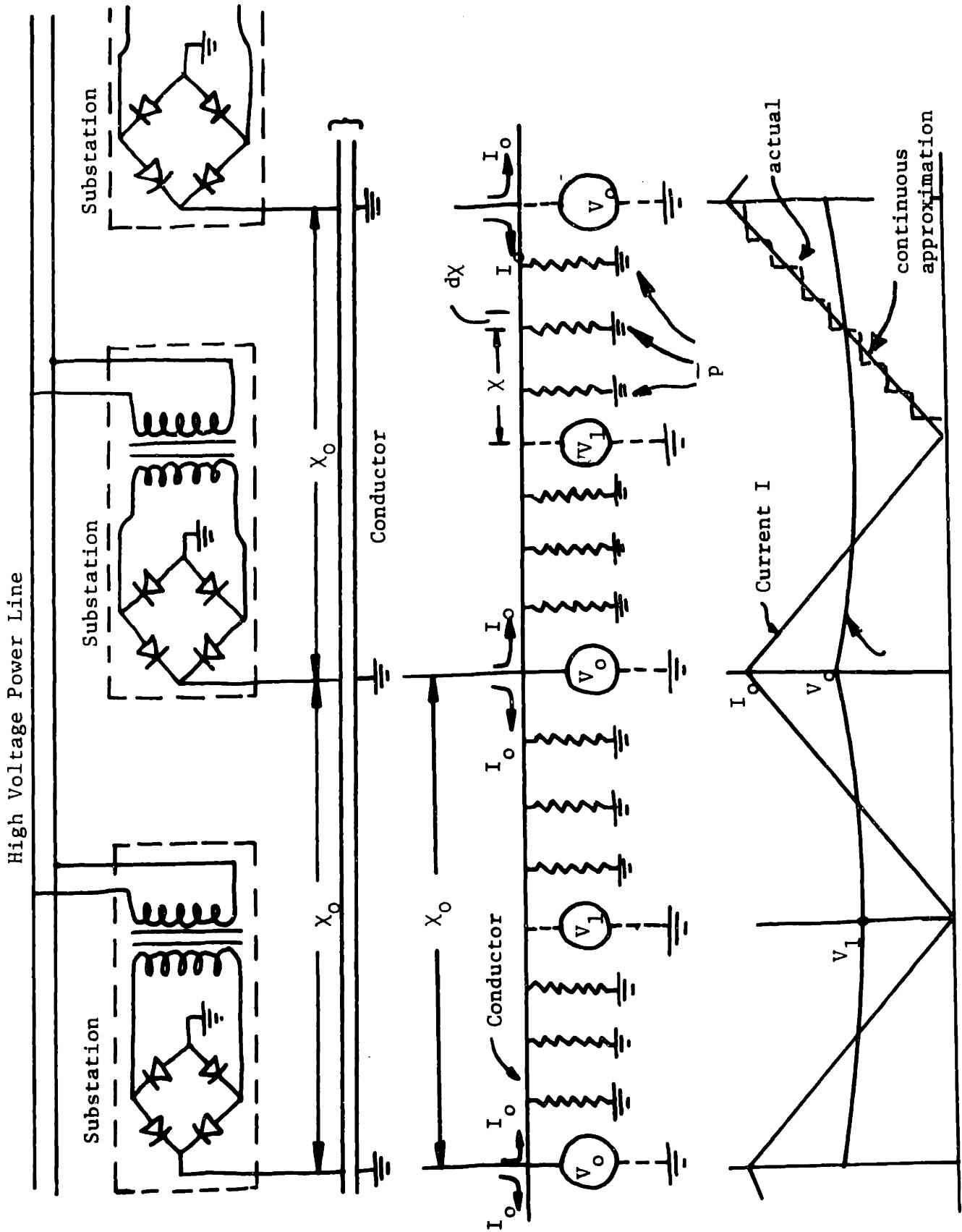


Fig. 5-11. Power System : Current Drain and Voltage Drop.

The rate of maximum voltage drop

$$\bar{R} / \chi_o = \frac{V_o - V_1}{V_o \chi_o} \quad (5.2)$$

is a measure of the regulation of the power system and serves as a useful quantitative measure of power loss and transmission efficiency.

A simple analysis to determine the maximum spacing between substations for a given value of \bar{R} can be used to estimate the best conductor size and station spacing combination.

The following assumptions apply :

- (a). The incremental power loads are symmetrical and balanced. Every vehicle draws the same amount of power \bar{p} from the conductor and vehicles are symmetrically spaced about the center point between adjacent substations, with all slots occupied, or 100% capacity. Thus, by symmetry, the current in the conductor midway between two substations is zero, and reaches its maximum value I_o at the substation terminals (Fig. 5.11c).
- (b). The conductor voltage is substantially constant ($\bar{R} \ll 1$) so that the current drawn per vehicle is constant :

$$i = \bar{p} / V_o \approx \bar{p} / V_o \quad (5.3)$$

and is independent of the position of the vehicle relative to the substation.

Thus the maximum current in the conductor I_o is

$$I_o = \frac{n}{2} i \quad (5.4)$$

where n is the number of vehicles traveling between substations at any given time. This means that

$$\frac{\chi_o}{d} = n_{\max} \quad (5.5)$$

- (c). The number of cars between substations is large, so that the current in the conductor can be approximated by a continuous

(c). The number of cars between substations is large, so that the current in the conductor can be approximated by a continuous function (see Fig. 5-11c). The current between adjacent substations is, at any point χ measured from the midpoint,

$$I = \frac{I_o \chi}{\chi_o/2} \quad 0 \leq \chi \leq \frac{\chi_o}{2} \quad (5.6)$$

From Ohm's Law, the voltage drop dV across an element $d\chi$ is given by

$$dV = \left(\frac{\sigma}{A_c} \right) I d\chi \quad (5.7)$$

where σ = the specific resistance of the conductor

and A_c = the cross sectional area of the conductor

Combining equations (5.3, 5.4, 5.6 and 5.7) and integrating

$$\int_{V_1}^{V_o} dV = \int_0^{\chi_o/2} \left[\frac{2 \sigma I_o \chi}{A_c \chi_o} \right] d\chi \quad (5.8)$$

the relation between substation spacing and conductor size is

$$\frac{\chi_o}{\sqrt{A_c}} = V_o \frac{\sqrt{8 \bar{R} d_s}}{\sqrt{\sigma \bar{p}}} \quad (5.9)$$

where d_s = the slot length (approx. 30 ft.)

To increase the spacing χ_o between substations, the system needs a larger cross-sectional area of total conductor, higher line voltage, greater regulation \bar{R} , less traffic, larger length \bar{p} , or lower \bar{p} (less power per vehicle) or a combination of the above.

voltage, great regulation \bar{R} , less traffic, larger headways, or lower speeds (less power per vehicle) or a combination of the above. The resulting relationship between χ_o and A_c is shown in Fig. 5-12 as a function of line voltage V_o . The maximum current through the substation is also shown.

An elaborate analysis of the guiderail conductor and the cost optimization for steel copper and aluminum has been performed by Zimmerman⁵ with the result that for all voltages, aluminum is the best choice, with steel 40% and copper 20% higher in cost for given conductor performance.

RAIL HEATING EFFECTS

The heating effects in the rail and follower are also functions of the voltage and power distribution and have been analysed by Captain⁶. The rise in temperature of the conductor will be due to the following three factors :

- (a). Resistive heating of conductor material
- (b). Frictional heating due to follower motion
- (c). Contact resistance heating at the follower-rail interface.

Of these three, frictional and contact resistance heating in the rail are basically unsteady state phenomena, and the temperature rise due to them is comparatively less.

In the steady state, heat will be transferred away from the conductor through three methods :

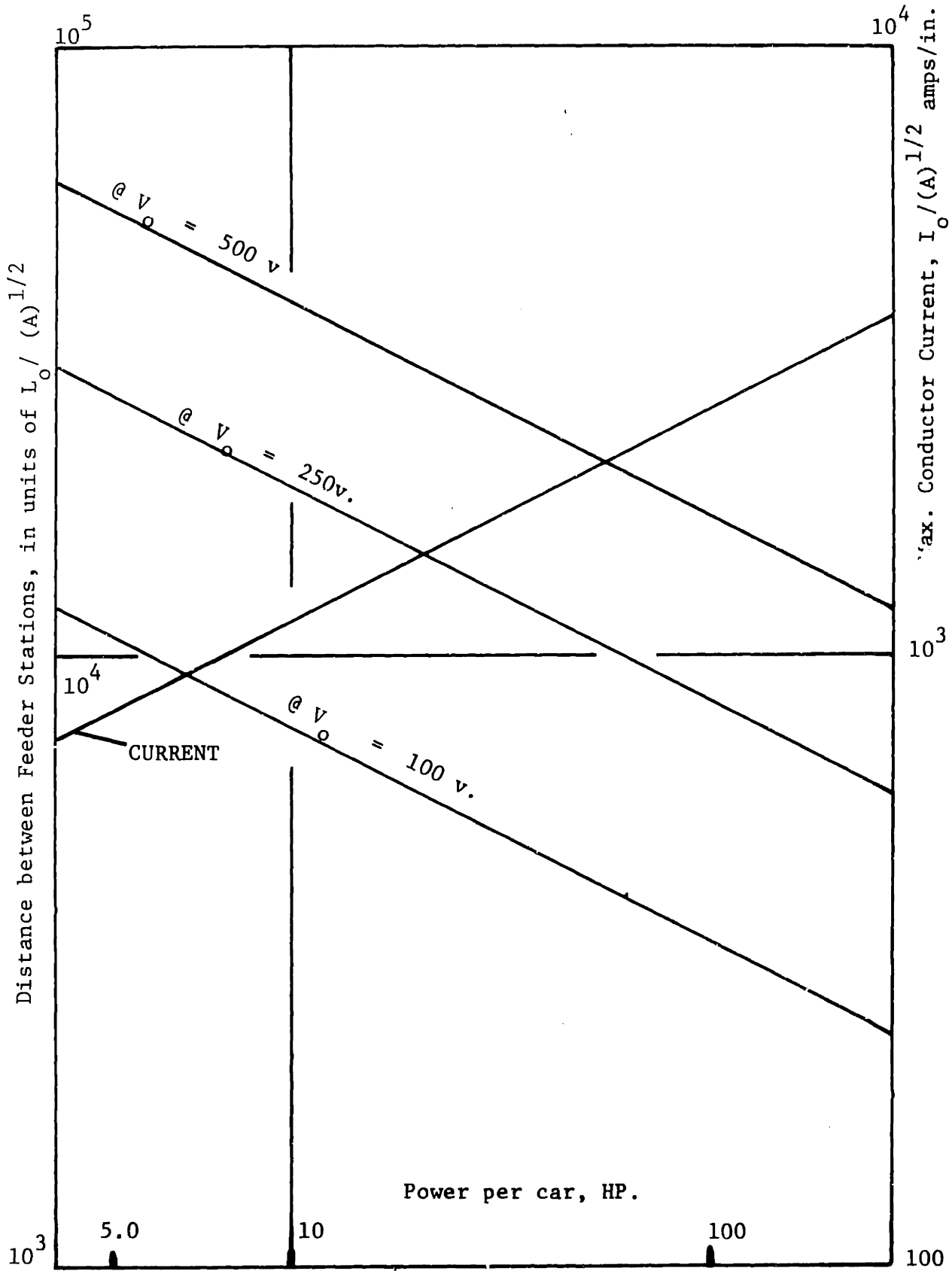


Fig. 5-12. Feeder Spacing and Rail Current

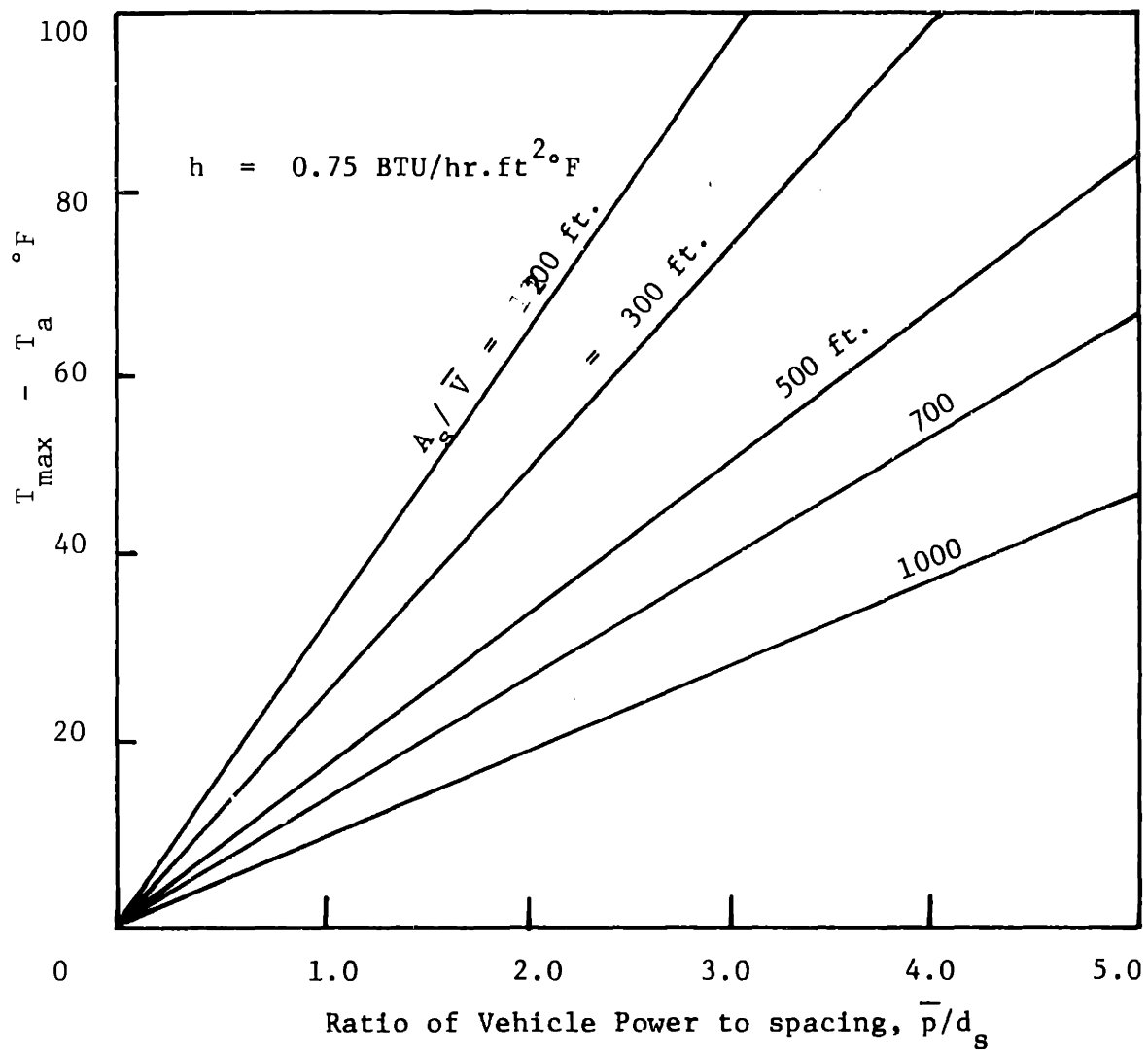


Fig. 5-13. Maximum Temperature Rise in the Conductor

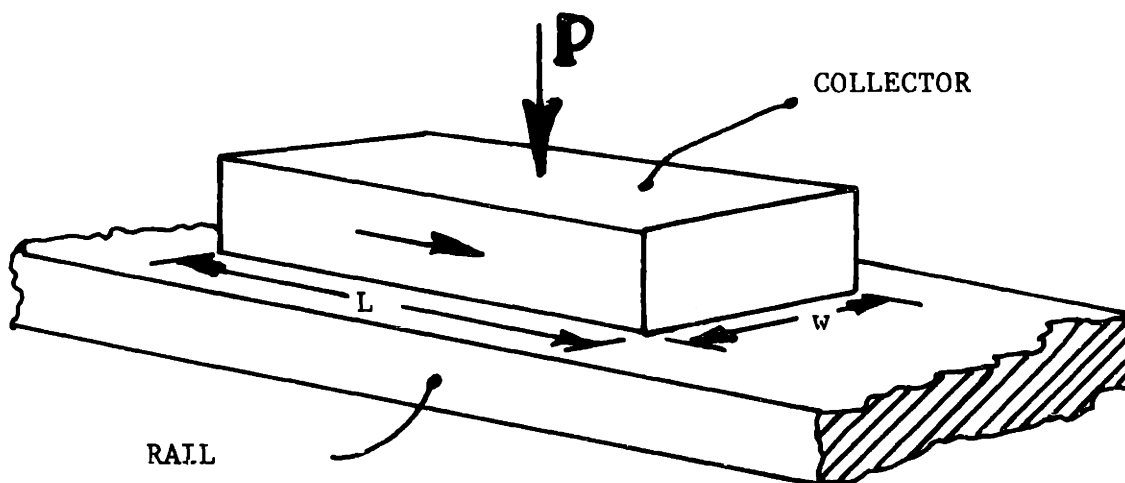


Fig. 5-14. The Sliding Interface

- (a). Natural convection of heat from the rail surface to the atmosphere.
- (b). Conduction of heat to the supporting structure and follower assembly.
- (c). Radiational heat exchange with the environment.

Since the conductor supports will be electrically insulated from the conductor, heat dissipation should be minimal in this direction. Also radiation heat losses should be small because of small absolute temperature differences. The main mode will be natural convection to the atmosphere. Captain concluded that the temperature rise from ambient, T_a , is

$$T_{\max} - T_a = \Delta T_{\max} = 37.3 \left[\frac{\bar{p}}{A_s} \right]^{3/4} \quad (5.10)$$

where $\bar{R} = 0.1$, $d_s = 30$ ft. The maximum temperature rise is shown in Fig. 5-13 as a function of vehicle power-to-spacing ratio, \bar{p}/d . For maximum capacity with $\bar{p}/d = 1$ to 2, the temperature rise will be about 20 to 40°F. In those sections where major accelerations occur, more localized heating develops.

The average temperature increase is calculated to be

$$\Delta T_{\text{mean}} = \frac{\Delta T_{\max}}{3} \quad (5.11)$$

but because of axial heat conduction, the true maximum temperature rise will lie between the calculated maximum and average temperature.

The maximum energy dissipated per foot of conductor is

estimated as 220 watts per foot and the average electrical energy as 73 watts per foot, for maximum capacity flow conditions.

Contact resistance heating may be caused by any voltage drop across the sliding interface, and the heating rate is calculated to be 2.2 watts per foot per volt when $V_o = 250v$ and $d_s = 30$ ft., based on the general relation

$$H_c / \Delta V = 0.073 \bar{p} \text{ watts/ft.volt} \tag{5.12}$$

for \bar{p} in horsepower.

SLIDING CONTACTS AND WEAR

For a constant or average force model of friction force and heating, the frictional heat generated per pad moving at velocity V with normal force F is

$$H_f = \mu F V \tag{5.13}$$

Assuming two pads with $\mu = 0.1$ and half the energy going into the rail, the heat generated per car and transmitted to the rail is

$$H_f = 0.1 F V \tag{5.14}$$

and the average energy absorbed per foot length of rail is

$$H_f' = 0.1 \frac{FV}{d_s} = 10 \text{ watts/ft.} \tag{5.15}$$

for $F = 50$ lbs., $V = 60$ mph and $d_s = 30$ ft.

Past efforts to reduce wear and heating in collectors by using rolling contacts as collectors have been unsuccessful and have actually lead to increased wear. For this reason, sliding contact has been chosen for exclusive consideration.

The required value of the nominal force exerted by the collector, \bar{P} (Fig. 5.14) is determined by the current flow through the collector and the force required to maintain dynamic contact between the collector and the rail. A voltage flash can occur when the real contact area decreases and the constriction in the current flow around the few remaining conducting spots causes excessive localized heating, weakening the material. If there are irregularities in the rail, rough joints, or chatter in the follower, \bar{P} may undergo critical reduction as the collector must undergo rapid acceleration to follow the rail surface and maintain good contact. Whatever is the critical minimum value of \bar{P} , the average value should not be very much higher if wear and frictional losses are to be minimized. Further research needs to be done in this area.

The wear in electrified sliding contacts is caused by mechanical effects, such as abrasion, or by electrolysis & chemical corrosion (oxidation). Although the wear directly due to electric and chemical effects is small, these effects generally increase the surface roughness, thereby increasing the tendency for abrasion to occur. Abrasive wear is produced by protruding

particles on one surface plowing furrows by cutting out chips or grains from the other contact member, and is greatly increased by the presence of abrasive dust particles in the environment. Any metallic wear fragment that remains within the contacting interface will itself serve as an abrading particle -- particularly if it has been strain hardened or oxidized into a hard oxide.

The wear in current carrying sliding contacts can be regarded as the result of four wear processes :

- (a). arcing produces material evaporation from the contact members.
- (b). The arc roughens the surface
- (c). the electrolytic effect of the current further roughens the the surface
- (d). mechanical abrasion and adhesive wear.

The summed effects of the above factors can be summarized in the empirical relationship suggested by Holm⁷ :

$$10^6 W = \mu Qs + S \bar{P} \left[(g \sqrt{Q}) + W_1 \sqrt{0.1 I} + W_0 \right] \quad (5.16)$$

where W = volume of wear at interface (cm³)

Q = quantity of electricity passing through the arc ($\frac{\text{coulombs}}{\text{km}}$)

I = current flowing through the contact interface (amps)

S = distance traveled (km)

and μ , g, W_1 and W_0 are empirical constants that depend on the contacting materials and the type of application.

Very little data is available on the wear behavior of current collectors for trolley cars. For a carbon or graphite-based collector in contact with a hard metallic wire, empirical measurements on MBTA trolley collector wear leads to the following fairly reasonable assumptions : $\mu = 10^{-5}$, $g = 3.7 \times 10^{-5}$, $W_1 = 10^{-5}$, $W_0 = 2 \times 10^{-6}$ and during good weather $Q =$ approx. 10 coulombs per km. Under these conditions, the guideway follower wear is a depth of about 0.1 in. for 10,000 miles of travel, mostly due to current flow and surface roughening due to arcing. For purely mechanical wear situations, Zimmerman calculates the rail wear as 6.7×10^{-4} in. per year for 36×10^6 vehicle passes per year and the depth of follower wear as 13.6×10^{-4} in. per year, given a hardness of 50,000 psi.

Ice and snow can interrupt current collection completely, and on MBTA trolley lines, the carbon inserts are replaced with bronze ice cutters to clear the overhead wires, carrying 500 amps at 500 volts. These cutters greatly increase wear rates on the overhead wires, so their use is limited. On the guideway system, the rail is protected from ice buildup by its inverted channel configuration, and dust/adhesive particles also tend to fall out naturally. The normal life of the MBTA carbon insets is 1000 miles, but under extremely wet conditions, the life may be reduced to only 100 miles. Part of this increased wear is due to arcing and voltage flashes which result from the hydroplaning of the collector

on water accumulations on the power line.

REGIONAL POWER CONSIDERATIONS

The impact of guideway usage on the regional power supply could be considerable. The use of electricity per capita in the U.S. has gone up from about 1500 kwh per year in the late 1940s to above 6600 today, and the figure is expected to double by 1980 according to professional estimates. Today, power shortages can be severe, often occurring on the hottest days when air conditioners are needed most -- and the power companies ask that they be turned off. Subways run at half speed and brown-outs must be instituted. Even now we witness the confusion of the power companies as they mail out advertizing brochures on air conditioners and appliances, and then later must ask for cutbacks in usage.

National power reserves are down from 32% in 1960 to 16% estimated in 1970, although the overall power supply has increased from 162 million KW in 1960 to 336 million KW in 1970. The power industry plans to add 148 KW additional capacity by 1974, but the reserves will not increase as the average customer uses 5% more electricity each year. Utilities commissioners impede power companies from obtaining many rate hikes, while conservation interests and regulatory bodies limit the implementation of present plans.

The slackened reserves are partly due to the failure

of nuclear power to become accepted and operational. Only 19 civilian nuclear plants and one military facility are presently in operating order, and six have been shut down as impractical or unsafe. A few others are operating at only partial power, for safety reasons. There are indications, however, that atomic power is having a resurgence, since utilities have placed orders for 14 nuclear plants this year, twice as many as 1969. The goal for 1980 is 25% of total capacity being nuclear generated, vs. 1% on 1970.⁸

The relative guideway power can be compared to per capita usage of 1500 KWH/yr in 1970. For reasons of environment, politics, and fuel reserves, the growth rate will probably be less than expected, so that by 1990 at least, the usage rate will be 3000 KWH/yr. If 1/4 of the people take 2 trips per day on the guideway of 1/2 hour duration each way in 1990, with 30 HP required for cruise, the guideway component is 5.7 KWH per day or approx 1700 KWH/yr, or an increase of 50% in per capita usage. On a regional scale of 1 million persons, the need is 1.7 billion KWH/yr.

The magnitude of this result is a measure of the tremendous amount of power consumed by self-propelled gasoline vehicles today. The total amount of motor fuel used in 1968 was 81 billion gallons, equivalent to 2.96 trillion KWH, twice the 1968 national total of electric power generated.

The impacts of the overall energy system must be taken into account -- improved pollution control, land-use and service benefits. Comparable to the recent case of mercury poisoning, there may be new trace chemicals associated with gasoline-powered vehicles (such as aldehydes and other additives) which require that automobile usage in cities be curtailed. If the ICE does -- through extensive development -- become better behaved in terms of pollution emissions, the motive power option discussed in Chapter 4 of combined ICE/electric propulsion becomes quite reasonable, and the regional power usage increment due to guideway might be only 1/10 to 1/6 of the all-electric option, or 5 to 8% of the total power requirements.

The possibility also exists to resolve jointly a number of problems afflicting urban areas along the East Coast, and West Coast as well. Since water consumption is also rising rapidly and droughts exaggerate the shortage of water, one can speculate on the combination of a power generating plant and a desalination facility, whereby salt water is boiled off as part of the reactor cooling process and then the steam is condensed. Prior to the boiling process, for conventional power plants, stack effluents could be washed by the sea water.

VEHICLE SPEED CONTROL

The accuracy and reliability of the speed control system is crucial to the success of a dual-mode guideway. Speed must be kept constant for cruising and should be varied only to regulate headways accurately and to provide acceleration and braking. A useful conceptual device for establishing speed control requirements is the "moving slot" model of vehicle flow, characterized by guideway lengths called slots in a moving reference frame traveling at stream speed. Slot occupancy is binary -- there is or is not one vehicle (and no more) per slot. Slot length equals the average vehicle length plus the average headway, although it may be shortened or lengthened for merging and acceleration/braking operations. Slot speed is constant for cruising and varies during acceleration and braking and during transitionals between 30,40 or 60 mph sections of the guideway.

Thus there are two general types of slot flow, constant and variable speed, which must be analysed and described separately. A third conceivable type involves shorteneing or lengthening slots near merges to create or absorb vacant slots or adjust for slot misalignment.

For constant speed slot flow, slots are conserved at constant length and speed. Merges have the interesting character-

istic of absorbing slots, with the outflowing slots numbering half the sum of the inflow branches (Fig. 5-15). Since *vehicle* flow is conserved, a merge doubles the average density of incoming flows and a switch halves the density. Generally, a merge increases lane utilization while switches reduce it.

During variable speed slot flow, the slot *length* will vary also. If vehicles pass through the entrance booth at 3 mph bumper-to-bumper and were each accelerated uniformly as they passed a given location on the ramp, new slots would either have to be formed gradually from zero length to full slot length, or entering vehicles would occupy more than one slot, with slot length increasing from a fraction of a car length at 3 mph to full slot length at 60 mph (Fig. 5-16). The latter case of multiple slots per vehicle defeats the conceptual purpose of slots, since an accelerating car might initially occupy 10 to 20 slots. The idea of a string of slots with *new* slots growing between them as the separating gap between vehicles increases with speed appears to be a more realistic model and more useful for the acceleration process.

Variable slot flow,

$$Q = \frac{V}{L}$$

Where L = average slot length

(5.17)

and V = instantaneous velocity

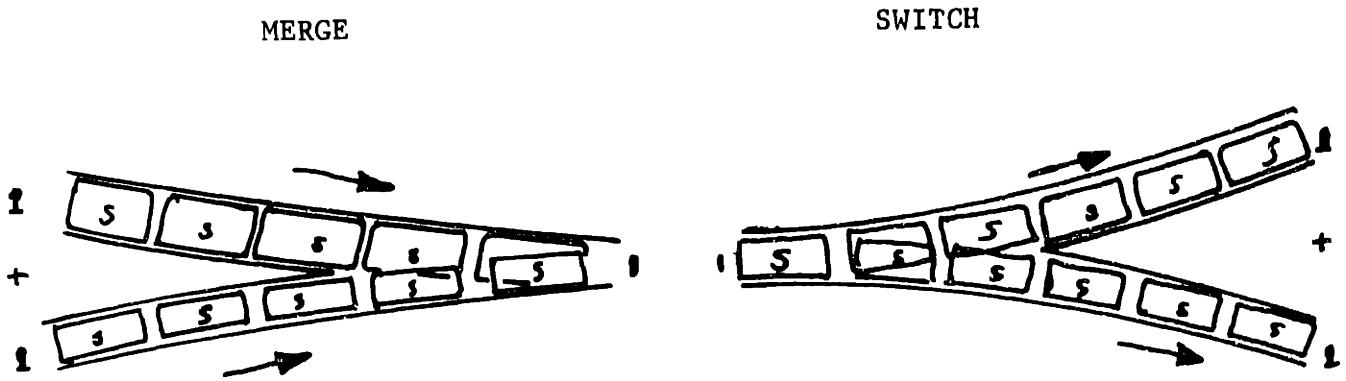


Fig. 5-15. Slot Flow Characteristics of Merges and Switches.

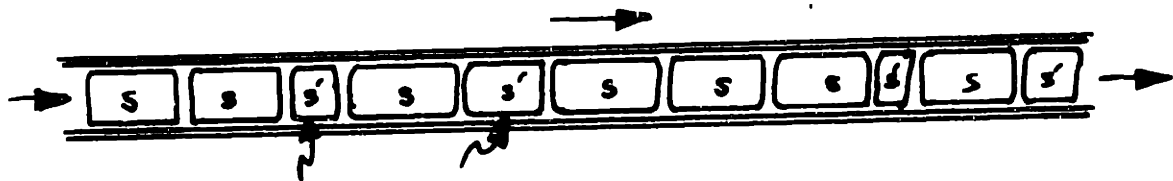


Fig. 5-16. Generation of New Slots at an Entrance.

is completely dependent upon the end points chosen for observation and independent of the variations in slot flow between these end points (Fig. 5-17) :

$$Q = Q_i + Q_I \quad (5.18)$$

or the slot generation rate Q_I is

$$Q_I = \frac{V_o}{L_o} - \frac{V_i}{L_i} \quad (5.19)$$

For the situation of constant slot length,

$$Q_I = \frac{V_o - V_i}{L} \quad (5.20)$$

and a guideway ramp having a 30 mph speed differential between its ends will yield a slot generation rate (30-foot slots)

$$Q_I = 5280 \text{ slots/hr} \quad \text{or} \quad 14.7 \text{ slots/sec.} \quad (5.21)$$

Slots are created or absorbed whenever consecutive vehicles receive unequal or non-simultaneous accelerations (Fig. 5-18). If a slow-moving stream passes point A at $V_i = 30$ mph, and then accelerates at constant 0.2 G, the gap between the original slots opens up as

$$L_a = \frac{at^2}{2} = 3.2 t^2 \quad (\text{for } t < \frac{L_o}{V_o} = 0.68 \text{ sec}) \quad (5.22)$$

and

$$L_a = \frac{aL^2}{2V_i} + \frac{aL}{V_i} \left(t - \frac{L}{V_i} \right) = 1.45 + 4.35 (t - 0.68) \quad (5.23)$$

for $t > 0.68$ sec.

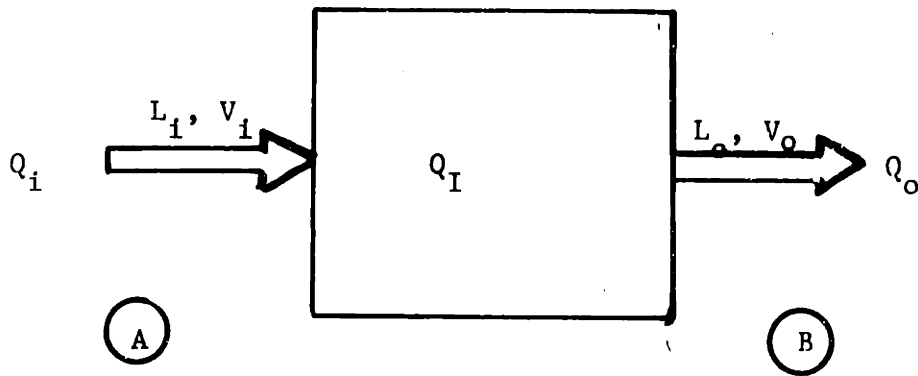


Fig. 5-17. Slot Flow Differential Between A and B

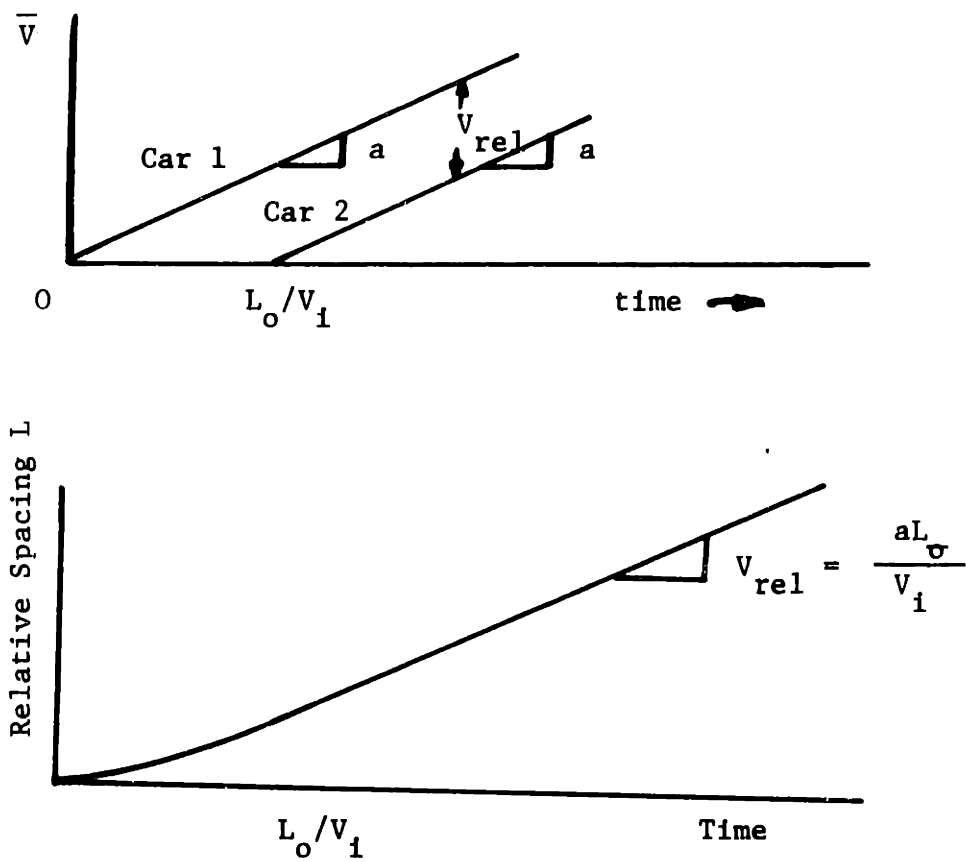


Fig. 5-18. Lengthening of Slot Due to Vehicle Accelerations

A similar process occurs in reverse for deceleration. During braking, a decrease in slots means an increase in flow density ρ . As $\rho \rightarrow 1.0$, a switch must be added to thin out the flow. Thus for large flows, there will be a requirement for fan-out branching ramps -- opening out into many slow-speed ramps similar to the multiple-lane fan-out at a turnpike toll station. (See also Appendix C). The likelihood of extensive use of branching ramps is limited, because of the dangers of local street overloading from excess ramp capacities. The most likely orientation of such ramps is at the radial connection between an expressway and a terminating or beginning guideway, where larger traffic volumes can be considered.

The third type of slot control is that of incremental slot insertion or deletion during cruising. High volume merges would be the most likely normal application of this control technique, although one of the emergency speed control modes could be that of creating a new slot or stretching old ones appropriate to the reduced power and speed capability of a disabled vehicle. Moreover, there may be a slight stretching or contraction of slots due to the physical constraint that where guideway channels laid out over geographical terrain will merge with the slot flow out of synchronization unless there is a flow correction applied prior to the merge. The adjustment will vary from ϵ to $d_s/2$ or 15 ft.

TABLE 5-4 REQUIREMENTS FOR GUIDEWAY SPACING

- (a). Headways not too large (low capacity)
- (b). Headways not too small (frequency/likelihood of collision)
- (c). No disturbance propagation down the stream flow (except in emergencies)
- (d). Limits on maximum acceleration and braking (comfort, braking traction & chance of collision, power limitations)
- (e). Limits on minimum acceleration and braking (short ramps, good performance normally and in reserve; maneuvering)
- (f). Vehicle responds rapidly to any guideway control signal and to any signal generated by the on-board controller
- (g). On-board detectors to detect a slower car ahead or to warn system that a vehicle malfunction is occurring or about to occur.
- (h). Slot control accuracy per vehicle of $\pm 2 - 4$ feet and ± 1 mph or less (BART is ± 0.5 mph)
- (i). Stopping accuracy at stations of ± 1 to 2 feet (BART is ± 1 ft.)
- (j). Ability to move car forward relative to constant flow stream (backwards also) for reasons of merging maneuvers, slot addition or deletion, and slot stretching or contracting for geometric compatibility
- (k). Ability of vehicle to hold spacing accuracy on grades and against moderate headwinds.

To achieve the spacing requirements of Table 5-4, additional preprogrammed information may need to be transmitted to the vehicle, indicating approaching slopes or sudden wind gusts which may require increased motor torque to maintain speed. The motor control inputs

include incremental changes to correct not only for errors in vehicle position but also for controlled merging strategies of moving forward or backward a certain number of slots. Any early information must be relayed to the vehicle within time for it to respond, with the primary lag being high speed acceleration. For a typical intermediate car with a 150 HP engine, to accelerate from 60 to 65 takes an elapsed time of 3 to 4 seconds, or about 300 to 400 ft.

The speed controller could be of the continuous, digital or sampled variety, depending upon the accuracy desired and cost. A bang-bang incremental controller is expected to reduce complexity considerably. Speed control based on velocity measurements or calibrated speedometers is difficult because any small velocity errors would be integrated over time and yield positional errors that violate headway requirements. A better technique is the comparison of position at any given time, so that error is not integrated and instead is nulled, and accurate merging operations are possible. The timer either is an on-board calibrated clock or a reference signal picked up from the signal wire (Fig. 5-19 and 5-20).

A simple arrangement is that of a counter system, with the summation of consecutive/sequential metallic strips, notches, rivet heads or other markings along the control rail. This marking

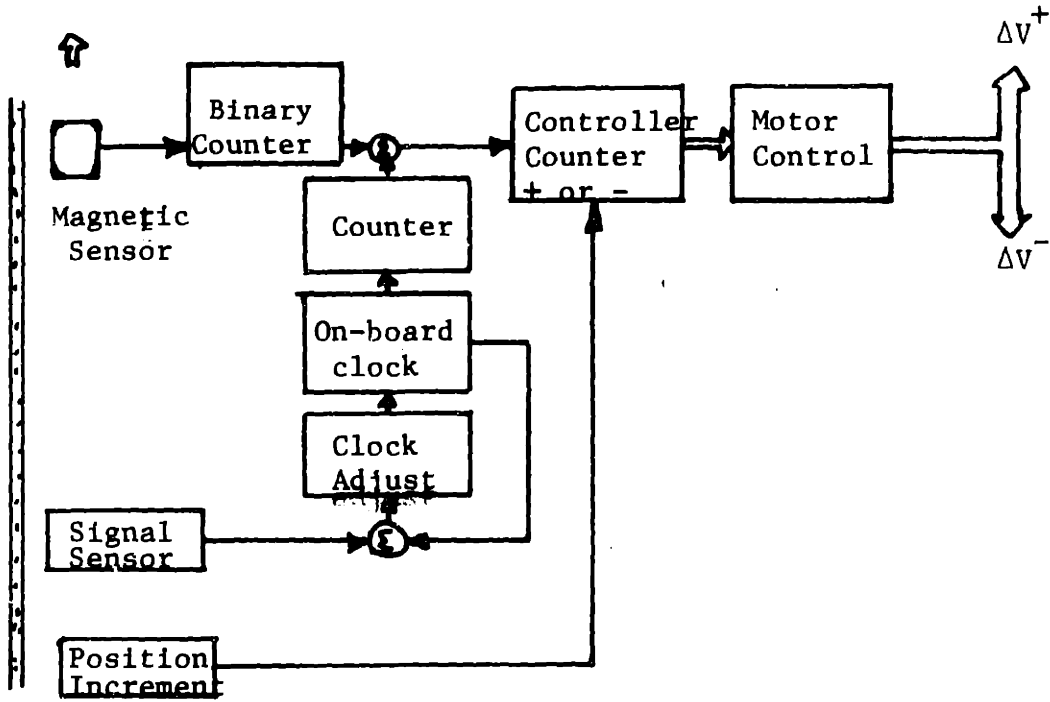


Fig. 5-19. Speed Control System with On-Board Calibrated Clock.

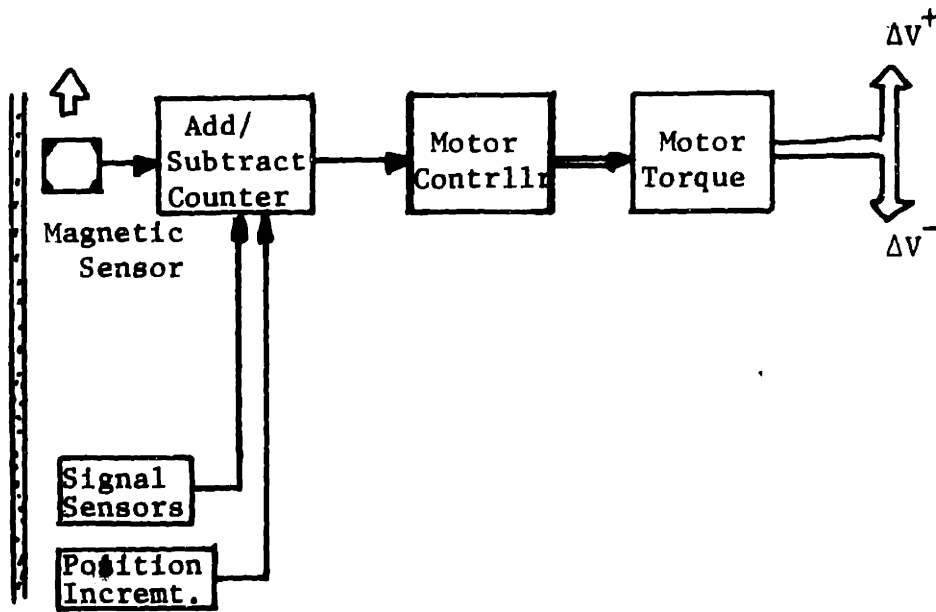


Fig. 5-20. Speed Control System Employing Guideway Reference Signal.

count gives an exact reference of position, which can be compared with the desired position, as determined by the on-board clock or system signal. Vehicle translation relative to the slot flow prior to a merge could be accomplished by artificially incrementing the counter via central system signals. The discrepancy between the clock counter and the marking counter would be nulled by motor signal inputs which would move the vehicle forward or backward, thereby bringing the marking counter in line with the clock counter. Vehicle flow modifications to bring merging slots into geographic synchronization is achieved by locating the rail marking further apart or closer together, until the dislocation distance is nulled and the slot flows merge smoothly.

With metallic strips or rivet heads located every 1 or 2 feet along the guiderail, the counter frequency is 88 and 44 bits per sec. respectively. For a marker separation of 1.47 ft. at 60 mph, a 60 Hz. counting pulse is generated, which compares with a conventional 60 Hz. signal or with the 60-cycle hum in the environment of the guideway. Alternatively, a particular subharmonic of the control channel carrier frequency is an adequate reference signal.

The reference signal could be phase-locked to the actual speed signal, a pulse string developed by an inductive counter passing over the metallic markers. The phase-lock, synchronous detector operates the electric motor control, either continuously

or by bang-bang voltage increments.

If the vehicle control system cannot maintain the required vehicle velocity and position for any reason, an emergency signal would be propagated backwards along the stream flow via the guideway signal wire. The strategies for emergency operations, vehicle rescue and repair, and tow truck movements are discussed more completely in Chapter 7.

A guideway system operating at 60 mph with drop-back and move-up speeds of 55 and 65 mph for pre-merge maneuvering has been investigated by Godfrey⁹ and found to be adequate for safe and efficient merging up to final flow densities of 0.90. A 5 mph speed differential translates into a 7.3 ft/sec movement or 4 seconds to travel one slot length. The length of guideway required to make a slot shift maneuver of N_m slots at 60 mph is

$$L_m = 525 + 360 (N_m - 1) \pm 30 N_m \quad (5.24)$$

where L_m is longer for move-up and less for drop-back.

For a phase-locked system, a main carrier frequency with either two side band frequencies or one sum-and-difference frequency which is added to or subtracted from the main carrier signal. The carrier frequency itself can be pulse code modulated to transmit other control information between the guideway and the vehicles.

Whichever motor control system is selected for the final guideway, the signals must be transmitted to each vehicle either as part of a group of traveling vehicles defined by a static length of guideway (a segment or link between intersections, etits, etc.) or special subgroups or blocks, including blocks of one slot length (Fig. 5-21). The signal relayed to each block is the same for each slot, and giving identical signals to a set of consecutive blocks effectively transmits to the longer segment or link. Single-vehicle blocks would be strategically located before switches and merges in order to provide individual switching and speed adjustment information. For transmissions, a segmented signal bus with interconnecting switches permits useful operating attributes :

- (a). Capability of expanding or limiting the length of the signal block and controlling vehicle movement by sections;
- (b). Improved S/N ratio due to bus isolation;
- (c). Segment failure can be separated from other sections of the guideway control system, with simple maintenance & replacement;
- (d). Central or local computer access is possible, as is direct vehicle-to-vehicle communications (Fig. 5-22).

Slot insertion for merges is the control system equivalent to the provision of an escape road for the one vehicle in 1000 that might not be able to negotiate a high capacity merge. The necessity of its function is derived in response to the results of Godfrey⁹, who found that for virtually all high density merging flows, there

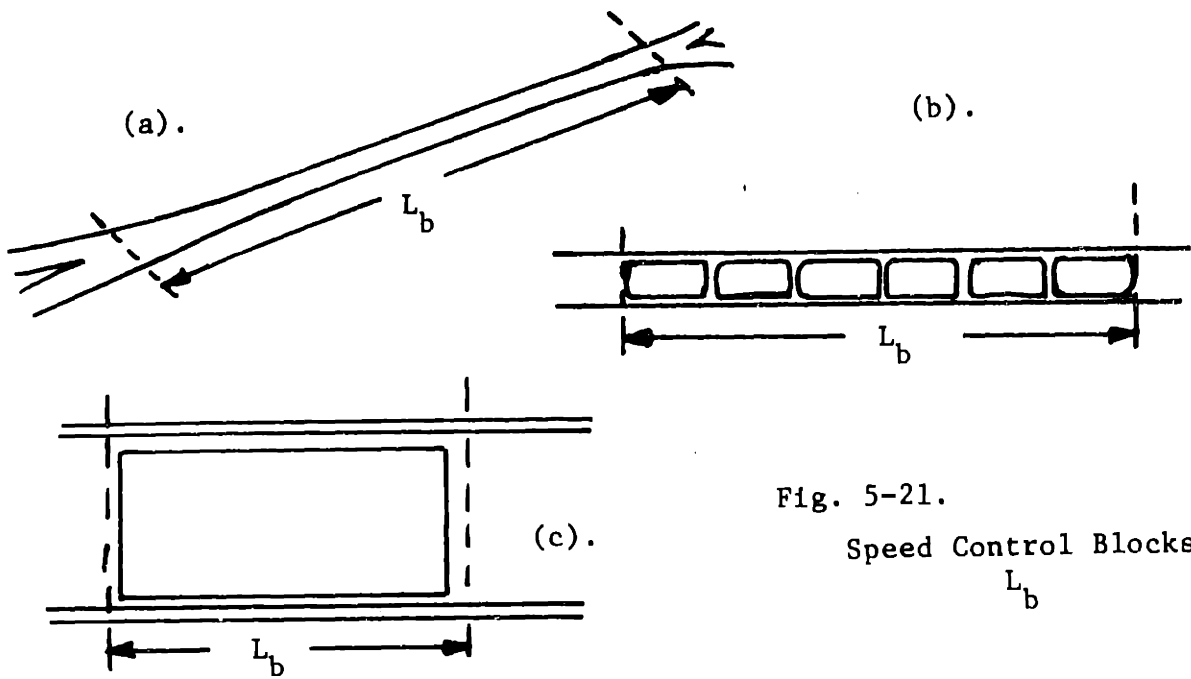


Fig. 5-21.
Speed Control Blocks
 L_b

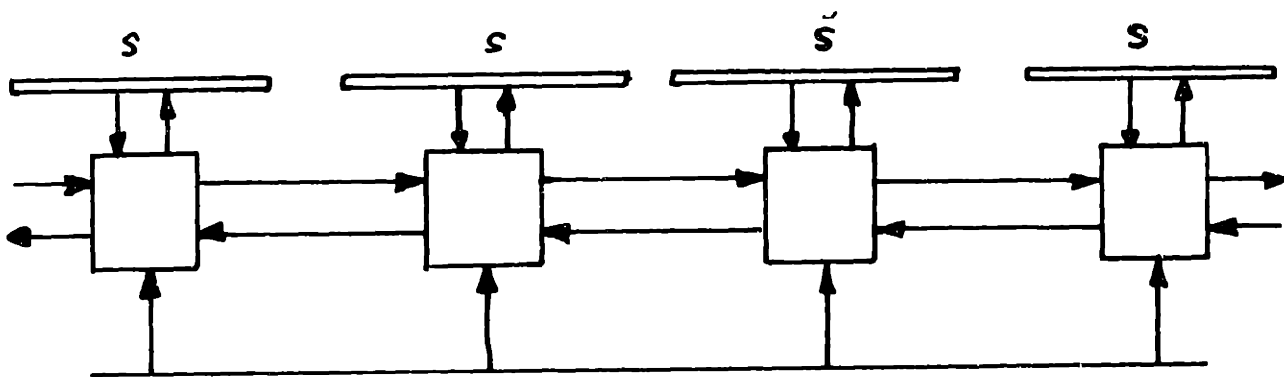


Fig. 5-22. Segmented Signal Bus.

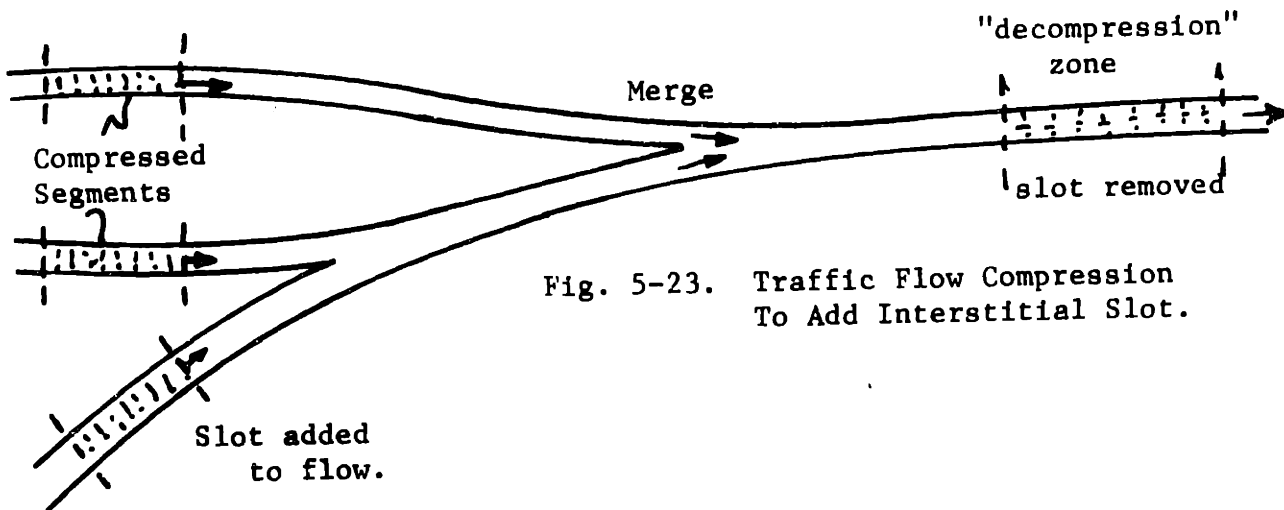


Fig. 5-23. Traffic Flow Compression
To Add Interstitial Slot.

is a finite probability of a collision because of excessive slot-shift requirements on occasional vehicles (in excess of 10 slots), unless considerable look-ahead distance were feasible prior to the merge. The alternatives to slot-shift-plus-insertion are few, primarily focusing on complete system scheduling of all incoming vehicles so that merging conflicts cannot arise, an escape ramp or siding prior to the merge, location of an exit or station prior to the merge to absorb potential conflict vehicles, or some combination of the above. Since station and exit location should not be constricted by merge locations and escape ramps require many wasteful ramps and switching motions, the slot insertion method appears superior.

Slot insertion can be accomplished by setting a maximum limit on the number of permissible slot shifts, beyond which a new slot is formed by the process of shortening or compressing adjacent slots. For instance, each of the following N cars behind a slot insertion point (a "zero length" slot) would drop back a distance

$$L_j = (N - j + 1) \frac{d_s}{N^2} \quad (5.25)$$

where

$j = (1, \dots, N)$ counting back from the lead car, $j = 1$

$d_s =$ slot length

Thus the lead car drops back one slot length relative to the

vehicle preceding it. For $d_s = 30$ ft. and $N = 10$, each slot in the compressed flow segment is cut 3 feet to 27 ft. and the headway is 10 ft. for 17-foot-long vehicles (204 inches).

After the critical merge has been negotiated, the traffic would be traveling with a 11-car section having reduced headway, which should be maintained only until vehicles can be adjusted to fill the nearest open slot (either by shifting vehicles to fill the spot and deleting the specially inserted slot, or simply deleting the open slot in the same manner which the new one was created -- thereby reestablishing original headways. Alternatively, downstream stations, exits or switches could thin out the traffic. In any case, compressed segments prior to a merge must occur on both incoming links at the same distance from the merge in order to provide smooth meshing of slots (Fig. 5-23).

Regular acceleration speed control at on-ramps or station exit ramps leading back to the guideway would require the vehicle to keep pace with an accelerating flow of slots. The basic principle of comparing carrier or clock frequency with guideway marker frequency can be applied to a range of lower speeds, if the inductor pick-up resolution is adequate. For marker separations $\bar{s} = 1$ ft. at 60 mph,

$$\frac{V}{\bar{s}} = \frac{V(t)}{\bar{s}(t)} = 88/\text{sec.} \quad (5.26)$$

and this same carrier frequency could be used at 10 mph if the marker separations were 2 inches. Below the minimum velocity limited by sensor sensitivity and the possibility of stop-and-go queuing at a station, a combination of time-pulsed torque application via chopper control and periodic position checks by the system (at the station or ramp) would become the auxiliary method employed at low speeds. Similarly, this control mode would be initiated for speed control and start-up after an emergency halt to guideway traffic.

Each vehicle normally would use reversed motor polarity and aerodynamic braking to reduce speed, usually at 0.2 to 0.3 G. For emergency stop conditions, the motor could be fully loaded inversely to yield 0.4 to 0.5 G braking. For emergency panic stops the conventional 4-wheel vehicle brakes would be actuated, together with adequate anti-skid provisions and motor speed control to assure rapid, safe and consistent non-skid stops.

For both cruising and acceleration/deceleration movements, the guideway position monitoring and detection system acts to check the accuracy of on-board control. If headways drop below some established minimum d_{\min} (approx. 5 ft.), on-guideway sequence timers would record the gap as less than 0.057 sec., alert the vehicles involved to move apart if possible, and to slow down the following traffic stream if the small gap situation persisted.

Synchronous control systems are unable to provide the necessary forms of headway control prior to merges and on variable speed ramps. Synchronous headways are fixed and not regulated, and -- as the complexity of the network increases -- the merging problems become very difficult, particularly for the geographic slot stretching requirement. For these reasons, regulatory headway control is distinctly preferable to synchronous control.

The information capacity of the system in terms of frequency and complexity of communications and monitoring has yet to be investigated. At entrances, the vehicles will release information on registration number and destination (10-15 bits), while cruising data transmissions will depend upon the switch strategy employed, as discussed in Chapter 4 relative to Fig. 4-4, and the extent of speed monitoring and accuracy of position checks. If each counter pulse corresponds to a one-foot marker spacing, slot-shifts up to 4-slots (120 ft.) could be indicated with a 7-digit binary counter. This counter would also accept inputs to regulate motor torque in the event of ramps, grades and headwinds. The actual numbers on the counter at any one time would be the difference between the actual measured position and the desired or controlled position.

FLOW CONTROL AND SYSTEM SCHEDULING

Part of the overall network system control task is to assure that excessive volumes or small clusters of traffic are not directed at any one merge, and to route flows according to the goal of balancing guideway links as much as possible. Fortunately, the fact that speed control is everywhere system dependent and *controllable* permits rational regulation techniques from a central source to avoid congestion and the anarchic flow that occurs on present expressways.

Compared to conventional freeways, guideways offer new opportunities of distributing vehicle flow, of flattening out the flow peaks and of moving vehicles through the system with maximum efficiency, rather than permit the saturation effect and consequent degraded performance caused by excessive vehicles and exasperated but persistent drivers on congested thoroughfares. At several times of the year, traffic in Boston and other cities totters on the brink of instability, so that the localized factors that combined in the December 28 to 30, 1970 period to tangle Boston traffic were in effect the straw that broke the camel's back -- residual snow inhibiting parking and reducing arterial lane widths, end-of-year motorists seeking their vanity plates from the Registry of Motor Vehicles, a surge in truck operations caused by snow-delays in operations, and the release

of the Ice Capades matinee at Boston Garden just before the evening rush hour. Traffic within the whole Government Center complex and on many of the arterials was at a standstill; at one point, the back-up of inbound traffic on the Mystic Bridge at 5:00 PM was worse than it was during the morning rush hour. The traffic system had lapsed into instability and there was little that could be done except to place all policemen on overtime and send them to street intersections to try to clear up what was beginning to appear to be a stagnant swamp of automobiles. Boston's traffic control apparatus was simply unable to prevent the instability, and could be improved only slightly on a day-to-day basis by concerned press releases by the Department of Public Works Commissioner Edward Ribbs that motorists should leave their cars at home and ride transit -- while construction workers in Somerville and Charlestown continued work on the paralyzing I-93 expressway which would simply make future auto dependence and local street congestion worse. One cannot have a DPW saying at the same time "Become less dependent on the auto" and "Become more dependent on the auto" and have a rationally controlled traffic scheme for Boston.

The guideway system provides the managerial structure to prevent the instability of traffic flow and the chaos of the present day. Congestion delays would be encountered only at

entrance ramps and these delays would be limited because the guideway would function economically more like a turnpike and thus suffer less severe overloads than freeways. Once on the guideway, the rider is assured of a delay-free trip, and any emergency delay which may occur is accompanied by a refund slip, which serves as legitimate explanation for any tardiness the traveler might incur in meeting an appointment or set time. Whatever delays are encountered, especially at entrances, there should be maximum warning to motorists -- radio reports could give a "capacity index" at various times to warn drivers of high usage periods at various sections of the guideway. The overall goal is the maximization of the "certainty constraints" on travel, such as tolls, fees and explicit congestion warning. In contrast, "uncertainty constraints" such as congestion and parking availability lead to risktaking, hunches and a game of commuter Russian Roulette as to whether the traveler can "luckily" get to work on time without a major congestion delay. Hopes will always exceed expectations, and expectations will always exceed the real chances for a congestion free trip, so that "uncertainty constraints" tend to press any system towards instability.

THE SAFETY ASPECTS OF SMALL HEADWAYS

The ordinary observer would expect that small headways present serious safety problems, but beyond a certain point of

proximity, impact energy between vehicles is reduced and the severity of accidents diminishes. Because of the lack of much angularity in any bumping and the lateral constraints of the guidance arms, vehicles might bump and still maintain stable guidance control. There have been several multiple-car crashes on freeways in which dozens of vehicles have been involved, yet injuries have been minor, primarily because of low headways and velocity differentials between vehicles.

The collision energy for cars of differing decelerations and headways has been calculated by Captain¹⁰ (Fig. 5-24). There are two main regions -- one for which no collision occurs because headways are large and another for which collision occurs with either the lead car stopped or both cars moving. Each constant impact energy curve has a maximum for a given relative deceleration and headway, so that system operation should take place distant from the maximum energy locus.

The tradeoff between frequency of collision and severity of collision is a difficult matter which has not been fully probed. The physical compliance and protection of each vehicle is a critical matter, and improved bumpers would be an important step. As a result of insurance company pressure, there may soon be regulations for constant height bumpers and an ability to absorb a 5 mph crash without basic structural deformation, and DOT Secretary Volpe has

Fig. 5-24. Effect of Headway on Collision Energy.
 Initial Velocity = 60 mph
 Lead Car deceleration is 1 G.
 How rapidly must following car brake to avoid collision & what is the energy of the collision.

$E/M = \text{Impact Energy per unit mass.}$

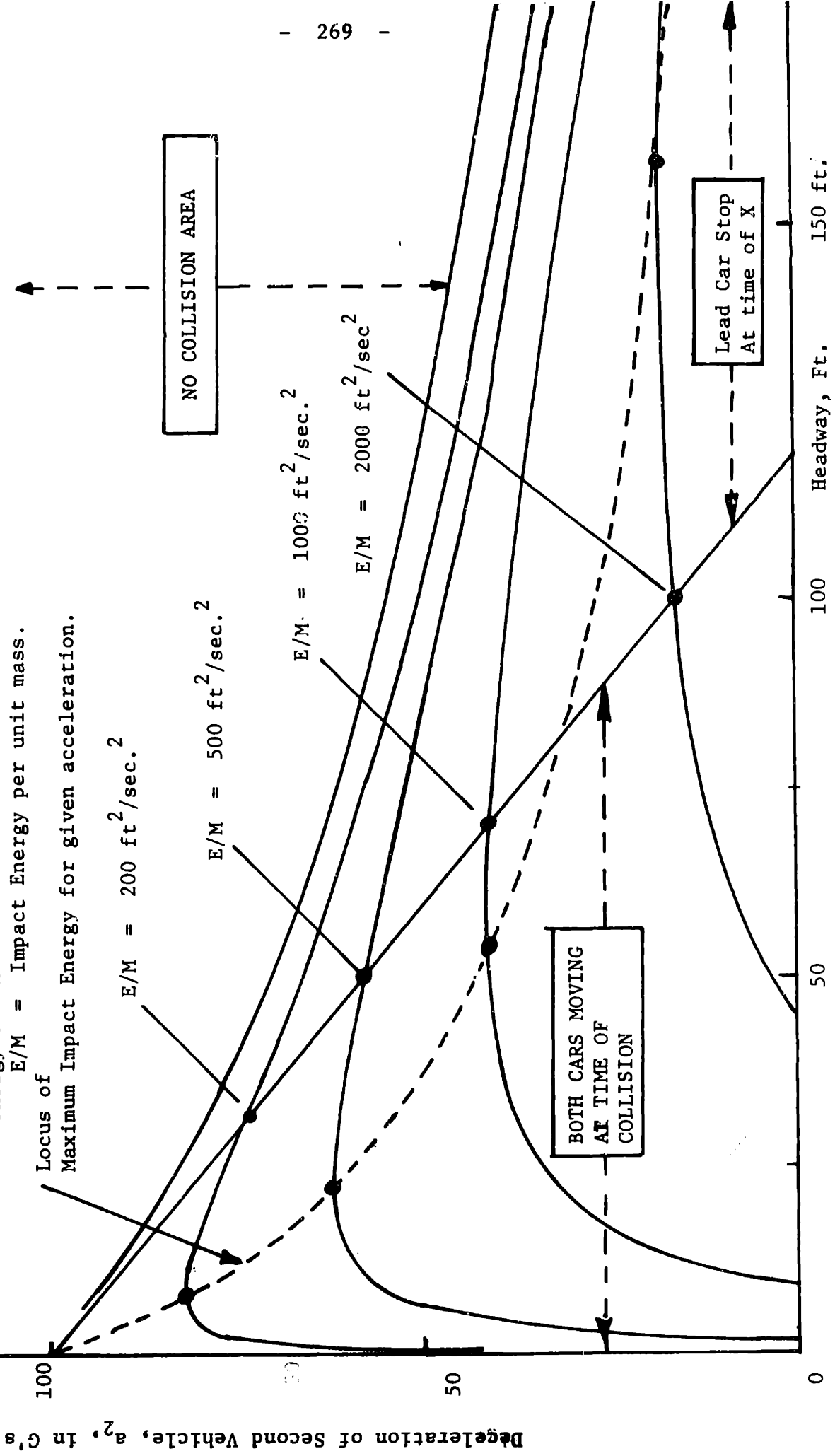
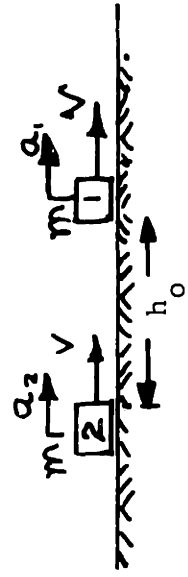
Locus of Maximum Impact Energy for given acceleration.

$E/M = 200 \text{ ft}^2/\text{sec.}^2$

$E/M = 500 \text{ ft}^2/\text{sec.}^2$

$E/M = 1000 \text{ ft}^2/\text{sec.}^2$

$E/M = 2000 \text{ ft}^2/\text{sec.}^2$



BOTH CARS MOVING AT TIME OF COLLISION

NO COLLISION AREA

Lead Car Stop At time of X

indicated that Aug 1, 1972 will be a target date for both of these features.

DESIGN OF SPEED CONTROL HARDWARE

On-board equipment includes the guiderail marker sensor, the counter or phase-locked loop circuit, servo control on the motor, switch-merge logic, arm actuation servos, vehicle identification, and vehicle ID/destination indicators, to supplement the mechanical guidance elements of the guidance arms, actuators, followers, motors, shafts and steering linkage connections. Lane control equipment covers switch-merge indicators, vehicle identification devices, segmented signal bus and interconnected bus switches, destination table look-up, inspection equipment & emergency signal propagation, merging control (calculations and strategy instructions), station and automated garage scheduling, billing records and operations, scheduling maintenance and emergency vehicles, and entrance ramp control to regulate vehicle flows on the system.

The exact form of the hardware for controlling the automated guideway network is not known at this time, but few of these elements must be designed from scratch. Many advances have been made in recent years on automatic transit speed control and signal transmission and certain aspects of aerospace technology might find application. In general, the

design rule should be the utilization of known and tested control components wherever possible, with experienced reliability and simplicity -- as well as low costs -- taking precedence over the design of a completely new and optimum system from the beginning. Provision should be made in the demonstration stages for implementing newer and more optimal concepts, but wherever appropriate, components should be drawn from telephone technology for control and switching strategies because of the ready availability of reliability and maintainability statistics. For the demonstration guideway, the use of already debugged control components will be very valuable in establishing initial guideway reliability and in creating a good climate for common and simple maintenance by newly trained personnel.

Telephone companies have similar problems to those of guideway operation -- detecting underutilized lines, finding optimal routing, monitoring reliability, billing the consumer, and system expansion and updating. Admittedly, there are different requirements and strategies for reliability, since a disconnected telephone line is not as serious as a stalled or disabled car.

The first American transit system to be equipped with automatic train control was the 42nd Street Shuttle in New York City, between Times Square and Grand Central Station. Developed jointly by Wabco and General Railway Signal Company, the system

used an automatic dispatcher and punched tape to regulate train departure. Tape recorded messages were used to warn passengers that the doors were closing, and axle-mounted tachometers served as inputs to the speed governor. A single exclusive track was used, avoiding the possibility of collisions, while a full crew was carried at all times in accordance with union requirements. Public demonstrations began in October 1960 and operations continued until April 21, 1964, when a fire gutted the train and burned out a section of Grand Central Station. The robot shuttle was then replaced with a conventional manual train.

The BART system is completely under automatic control, and the details are still undergoing development and testing. A half-dozen systems were proposed to BART by various consultants, with Westinghouse Electric submitting an interesting system because of its minimization of car-borne and lineside equipment. A track wire is laid between the rails in a square wave pattern, with crossovers 17.5 ft. apart, except where 2.2ft. at stations. The wire was divided into larger loops, and only one train could occupy a particular loop at a time. Each train was equipped with four antennae, two receiving command signals coded by combinations of tones with frequencies of 1575 to 2200 Hz and two emitting constant frequencies of 865 and 1075 Hz. These latter antennae were arranged to produce an oscillating signal each time the train passed a wire crossover. A wayside

controller (a small digital computer) counted and timed the interrupts and from stored reference data of velocity profiles, station locations, loop locations and speed restrictions, it utilizes logical programming to command each train, specifying reference acceleration, train reversal, door operation and speed adjustments.

In the automotive field, limited efforts have been made towards semi-automatic control of autos. The RCA/GM buried cable system has already been discussed in Chapter 3. Ford and GM have been working on systems of automatic headway control to take over the speed control task only for high-speed expressway travel. Ford's system is already operating on a modified Thunderbird and involves four major components, two new and two modifications to existing components :

- (a). Infrared radar set
- (b). Internal computer
- (c). Electrical controller connection to brake pedal or cylinder
- (d). Controller connection to accelerator pedal

In operation, the infrared radar beam from the car's transmitter radiates forward, illuminating the rear of the lead car. A reflector in the lead car's taillights reflects some of the intercepted IR energy back to the following car, whose receiver interprets the phase of the returned beam to determine the headway distance. An on-board analog computer uses position data to determine relative

velocity as well and judge whether a corrective move should be made, either accelerating or braking the car incrementally. After development and miniaturization, Ford estimates that the production version would weigh about 20 lbs. and cost the buyer \$200 to \$300.¹¹ Other controls, such as anti-skid systems could be built in as well, and these will be discussed in the next section.

VEHICLE BRAKING AND TIRE TRACTION

Aerodynamic braking and rolling friction are important constant braking factors, which are not controllable. For controlled speed reduction, the options appear to be :

- (a). Connection to the 4-wheel brake master cylinder
- (b). Reverse motor polarity
- (c). Use of the guidance arms and follower gripper to provide emergency friction braking.

Because of the importance of good system control of speed, even in emergencies, there should be no possibility for extraneous or well-intentioned passenger inputs to the brake pedal. An adequately designed speed control system should be able to detect malfunctions and their effects on headway more quickly than the human observer and decide on the safe and appropriate maneuver, without skidding or locked wheels. In the event of a braking emergency, an audible signal should be given to the passenger compartment, to prepare people for dynamic maneuvers.

Under any form of control, uniform stopping distance will be affected by variations in vehicles and in roadway surface conditions. A variation in tire/road friction coefficient between consecutive vehicles traveling at 60 mph, with $\mu_1 = 1.0$ and $\mu_2 = 0.9$ translates into a difference in panic stop distance of 13 ft. The existence of ice or slick pavement, as well as worn tires and wheel lock-up will tend to increase the braking distance uncertainty.

The goal of the guideway operation is to maintain good traction with adequate safety margin to permit incremental changes in braking sharpness. The automated system does not have the problem of perception lag time of the human driver (0.2 to 0.7 sec) which in dense driving leads often to a propagation build-up in driver panic-braking and eventually collision, whereas the lead car in the freeway pack braked only moderately and proceeds on. Guideway braking would permit simultaneous braking of a line of cars without a delay and build-up in braking severity.

The roadway coefficient of friction is a function of many factors : surface, speed, wheel locked or rolling, tread and tire wear, vehicle weight distribution, weather, oil drips on road, tire pressure, aquaplaning, axle hop and evenness of the brake linings. Oil slicks will be less severe on the guideway because of the regular channelization of vehicles and the tendency for oil drips to fall into the trough between the wheel paths. Bad

tires could be detected at entrances, anti-lock brake systems could reduce skidding, guideway surfaces could be carefully superelevated or crowned to avoid water build-up and consequent aquaplaning. The guideway surface could be composed of materials specially selected for good tractive capabilities, possibly at the expense of wear or cost, since the surface sections could be small and demountable (see Chapter 6). Typical friction coefficients for road materials, for average tires, are

- * Concrete 0.8
- * Blacktop 0.7
- * Wet concrete 0.65
- * Gravel 0.55
- * Wet blacktop 0.35
- * Jennite 0.2

and the effect of tire tread wear can be significant, especially at speed on smooth and slippery surfaces. An SAE paper by Campbell et al¹² gives the following values of μ for new and old tires :

NEW TIRE	0.47 @ 20 mph, 0.26 @ 40 mph, 0.21 @ 60 mph
OLD TIRE	0.28 @ 20 mph, 0.14 @ 40 mph, 0.10 @ 60 mph

Hydroplaning or aquaplaning can be reduced by improved tread design, higher tire pressures and grooved pavement surface. Longitudinal striation has been used on airport runways and some roadways to improve traction, through grooves cut 1/8 in. deep, separated by 1/2 to one inch. Generally, hydroplaning is no problem below 30 mph, but at higher speeds the front wheels begin

to lose good contact. Actual hydroplaning starts at about 50 mph and it is possible for all four tires to lose friction contact with the pavement at 55 mph.

There is an additional problem of maintaining good reliability in the vehicle braking system. After one recent nationwide test which checked brake systems, some 30% of the passenger car brakes were found unsafe, only 6 months after a previous semi-annual city inspection.¹³ Brake linings can last between 10,000 and 40,000 miles depending upon the quality of the brake job -- a good one costing \$60 to \$75.

Part of the guideway entrance process can be regular checks on brake performance, to detect faulty or deteriorating systems. Brakes often give warning of impending trouble, although the motorist often ignores the signs or is unaware of the problem. One new safety requirement for Detroit is a brake warning light that comes on before failure, when the master cylinder fluid level drops too low. Similar detection devices could be used for dual-mode inspections of brakes, motor, arm actuators, hydraulic system, etc.

In addition to improved inspection and good roadway design, use can be made of Calcium Chloride road salt to prevent icing on ramps, although the salt is very corrosive to pavements and also corrosive to the visual environment when sprayed about by tires. In general, road salt use should be kept to a minimum.

Anti-lock braking systems offer many safety advantages on and off the guideway. Chrysler has developed its Sure-Brake system, for which it claims firm steady stops -- even on glare ice, up to 40% shorter stopping distances on slippery surfaces, and end to wheel lock-up and improved vehicle stability during panic stops. There are three main components :

- (a). An electronic control box (small internal analog computer) which monitors the speed of each wheel and is about the size of a cigar box.
- (b). A speed sensor in each wheel -- the sine wave signal created by each sensor is fed into a counter, and a decrease in frequency in excess of 15% means the wheel is starting to skid and that braking must be modulated.
- (c). Brake pressure modulators, which operate between the brake master cylinder and the wheel brakes. The modulators copy the action of an expert driver pumping the brakes to keep the wheels from locking up, only with more optimal control. The modulators trigger the brakes up to 6 times per second, and the three modulators weigh 48 lbs. together.

Sure-Brake has a two-speed modification, to respond to different road conditions. A mercury switch determines whether braking is greater than 0.5 G. If so, Sure-Brake works slower at 2 pulses per second on dry pavement, while for slicker pavements, braking pulses increase up to 6 pulses per second.

Chrysler offers Sure-Brake on Imperials as a \$400+ extra cost option, although mass production could bring the cost down to \$300 or less. Ford and General Motors have anti-skid systems for the rear wheels only, to reduce rear end spin-out and instability, so that the Kelsey-Hayes version on Ford's Continental Mark III costs \$150. Buick has developed an acceleration control system called MaxTrac, whereby engine power is modulated to maintain maximum rear wheel traction, using electromagnetic speed sensors in the wheels and an ignition interrupt system.

In summary, the possibilities are good that a coordinated design package for speed control can be assembled, particularly those relating to regular and emergency braking factors.

QUESTIONS OF CENTRAL VS. REGIONAL CONTROL VS. LOCAL CONTROL

Minimizing information transmission and monitoring complexity can be achieved by not tracing a planned path for individual vehicles for the full duration of their trips. A trade-off must be made between control complexity caused by overcentralization and lack of coordination caused by poor centralized control. The guideway network could be broken up into regional or local segments which would have vehicles inputted from other regions and thereafter would have responsibility for merging and routing them to an exit or station or out a guideway link to an adjacent region. The interface between regions

becomes the critical matter and probably should be the main responsibility of the central system monitor, to assure that regions are not providing unbalanced loading to one another, while the internal routing and control of vehicles within a region is solely the responsibility of the region or some smaller sub-region. All of the information processing, control, and signaling tasks cannot be done by a single centralized computer, nor by a collection of on-board computers. Sub-regional computers and block regions combined with limited speed adjustment capability appear to be the best combination to route vehicles through a network without incurring the immense complexity of a multitude of pre-planned vehicle trips analysed by one central computer.

EXPERIMENTAL RESULTS & THE OVERALL HARDWARE PACKAGE

The motor and control package on the test Mustang consisted of locating a 10 HP, 24v diesel starter motor directly on the back of the differential. The differential pinion was extended by welding a 3/4 in. shaft to the pinion and through the rear face of the differential. A one-way clutch and chain drive made the connection between motor and differential. The motor occupied the area previously taken by the gas tank, and a battery rack was placed at the front end of the trunk behind the rear seat, to simulate guideway power picked up through the rail. Four six-

volt batteries were used with sequential switching to apply stepped voltages to the motor.¹⁴ The assembly on the axle adds at least 40 lbs. to the unsprung weight, but was satisfactory for test purposes. For regular guideway use, a larger motor of 35 HP would be needed (attached to the sprung mass) or the smaller motor could work in series with the ICE, even attached directly to the differential as presently, if weight could be kept down.

The guidance arms on the test vehicle were intended for lateral guidance only, although they had considerable strength in yaw. If the guidance arm pads were connected to the same hydraulic circuit as the pulsating brake line of an anti-skid vehicle, the arm grips could deliver braking pulses which are short and modulated to prevent instabilities of control. If the arms could take 200 lbs. force at the follower (bending forces not excessive), an incremental 0.2 G braking deceleration component is possible, so that with 0.2 G engine braking and 0.07 G aerodynamic braking at 60 mph, the net deceleration is 0.47 G without the necessity of actuating the wheel brakes (or in event of brake failure). By comparison, the conventional panic stop generates 0.8 G.

The above considerations of speed control equipment and weight, as well as earlier discussions and prototype guidance tests now permits a preliminary estimate of the overall additional equipment and weight necessary for dual-mode vehicles :

	<u>Prototype</u>	<u>Later Development</u>
* Motor assembly and drive	50 lbs.	40 lbs.
* Arm Box (two)	30 lbs.	20 lbs.
* Arms and struts (two)	40 lbs.	35 lbs.
* Follower (two)	30 lbs.	25 lbs.
	<hr/>	<hr/>
TOTAL HARDWARE WEIGHT	150 lbs.	120 lbs.
* Braking cylinders	15 lbs.	10 lbs.
* Steering equipment and clamp	15 lbs.	10 lbs.
* Control box & signal equipment	10 lbs.	5 lbs.
* Instrument panel (interior)	10 lbs.	5 lbs.
	<hr/>	<hr/>
TOTAL HARDWARE AND CONTROL WT.	200 lbs.	150 lbs.

SUMMARY

During guideway travel, vehicles could use an auxiliary 35 HP electric motor, or a smaller electric motor in tandem with the regular engine -- either providing overload capacity of 100 to 120 HP for acceleration. Entrance ramps should be steeply banked initially to gain elevation, but in the high speed range a level final ramp or slight downgrade results in the shortest overall ramp length.

The auxiliary motor could be located under the trunk or on the driveshaft, using shaft, chain or belt drive. Up to 1000v supply current can be carried by the protected guiderail, although initial demonstration voltages could be lower for safety. A cost optimization indicates that as a conductor, Aluminum is the best material.

Speed control is achieved by comparing measured distances along the guiderail with a central control signal. Cars would move forward or backward relative to the traffic stream in order to permit smooth merging.

CHAPTER 6 GUIDEWAY GEOMETRY AND STRUCTURES

The configuration and speeds of urban guideways depend critically on the stimulus rate and amplitude, as they relate to passenger tolerances. Travel at speed on the guideway can yield responses from dizziness and overload inputs due to clutter of nearby objects passed, or to an empty barrenness which is dull, tedious and unaesthetic (such as the Southeast Expressway in Boston). Lower speeds in the central city may be necessary because of the busier horizon and environs, and the comfort factor will tend to predominate even though the guideway and vehicle can undergo many intricate moves at speed.

In the off hours, the lower speeds of the CBD guideway can serve shoppers and sight-seers more satisfactorily, with the hectic quality of speed and motion diminished. Since travelers may have a better view of the city, they may feel less separated and insulated from it. Since the average speed of CBD autos ranges from 5 to 12 mph and rail transit from 15-22 mph, a guideway speed of 30 mph becomes quite reasonable and far less frustrating and uncomfortable than stop-and-go. Moreover, a smooth 30 mph flow will carry a vehicle and its passengers 7.5 miles within 15 minutes, which include Cambridge, Somerville, Revere, Brookline, etc. within this range,

Guideway geometry also poses comfort limits, including both banking angle and rate of onset. Excessive banking produces

a bobsledding or roller coaster effect which can leave passengers frightened or ill. Commercial aircraft undergo considerable banking, but the horizon is quite distant and there is no nearby rapidly moving scenery. Needless to say, many man-vehicle psychological tests are needed to determine the degree of significance and interaction between the visual and physiological sensations to movement. Because an element of "sea sickness" is involved, the problem is complicated by additional factors such as stomach digestion, foods and individual resistance to sickness, as well as factors of smell, fatigue and duration of movement.

The human vestibule is primarily involved in the production of motion sickness, since deaf people with vestibular insensitivity do not get sick. Stability of orientation is generally regarded as necessary to feelings of security, and any disturbances to the vestibular system can lead to feelings of insecurity, anxiety, fear or panic.¹ On a rotating chair spinning about a vertical axis, nausea is rare as long as the head stays fixed, like a ballerina's. Usually repeated vertical accelerations (long auto trips, choppy airplane rides or a ship in heavy seas) are the most common cause of motion sickness.

Motion sickness occurs, not as an immediate effect of motion, but only after the stimulation has endured for a period of time. The length of time for onset is a function of the

individual and the other stimuli which facilitate or inhibit motion sickness, such as moving visual objects, visual disorientation, unpleasant odors and uncomfortable warmth, or the general unpleasantness of the task or motion experience. On ships, waves of moderate frequency and acceleration cause sickness quicker than either very gentle or very rough waves -- a most peculiar phenomenon which might be explained by the lack of stimulation of the gentle wave and the excitement associated with very large waves. A seven-foot wave of 22 cycles per minute (maximum acceleration of 0.6 G.) produced sickness in 53% of a group of naval officers within 20 minutes². Yet the sharp head rotations of everyday life and the steady jarring motions of running do not make one sick. Incredibly, the mechanism by which certain waves produce sickness is not yet known. Pilots and drivers, for reasons unknown, rarely become sick; passengers often do, with susceptibility greatest in childhood, decreasing thereafter, and is greater in women than in men. Although trains are noteworthy for the severity of lateral motion (but lack of vertical motion), trains induce the least frequency of motion sickness, followed in order of increasing frequency rate by autos, ships and planes.

Auto researchers are still attempting to evaluate ride comfort, but the multiplicity of variables and individual tastes and moods are so overwhelming that the field remains quite

undeveloped and largely a matter of rather primitive hardware rules of thumb. Even the proven effectiveness of the anti-histaminic drug, trade-named Dramamine as preventative and remedy is unknown. Thus, special comfort criteria and guideway geometry will be developed in this chapter, beginning virtually from fundamentals.

Ideally, the only effects of curves felt by passengers will be an increased acceleration along the "vertical" axis of the vehicle (equivalent to a long gentle hump in the road) and a partial rotation. The controlled speed of guideway vehicles permits tighter radius curves within the city, and for a 25° bank angle, a 125-foot radius turn at 30 mph (or 500-foot radius at 60 mph) can be negotiated with no lateral acceleration sensed by the passenger. Such sharp turns allow the guideway to be routed past existing valuable structures and open space, rather than requiring their demolition, and ramps, interchanges and loops would require much less land area than conventional highway facilities.

The maximum degree of banking on the system will be a function not only of the environment -- visual, aromatic, etc. -- but also of the newness of the system and the response or adaptation of its users. Early demonstration guideways would probably have curves with lesser banking than might be considered optimal, in order to gradually accustom people to the guideway system and allow for possible deep-seated customer resistance

to tighter banking. In addition, the extent of banking at any location cannot have a severely deleterious effect on the other functions of the guideway structure and environment (Table 6-1).

Passenger comfort will be largely dependent upon the combined effects of all forces acting on the vehicles and passengers. The guideway provides several forces at the wheels -- supportive, lateral turning forces and longitudinal tractive forces -- and at the guidance arms -- lateral guidance and frictional drag. The guideway can also create, absorb or reflect noise to and from the vehicle and can reduce vibration in the vehicle. Noise and vibration transmitted to the adjoining environment must also be reduced.

Within the passenger compartment, there are six degrees of freedom and more than a dozen possible magnitude limits on discomfort (Fig. 6-1) :

	LIMITS	
	maximum	minimum
F_N (vertical)	ΔF_N^+	ΔF_N^-
F_{axial} (accel/braking)	ΔF_{ac}^+	ΔF_{br}^-
F_{lat} (lateral)	\pm	$ \Delta F_{lat} _{max}$
ω_{pitch}	\pm	$ \omega_p, \dot{\omega}_p _{max}$
ω_{yaw}	\pm	$ \theta_y, \omega_y, \dot{\omega}_y _{max}$
ω_{roll}	\pm	$ \beta, \dot{\beta}, \ddot{\beta} _{max}$

TABLE 6-1 GUIDEWAY FUNCTIONS

1. Normal support of a range of vehicle sizes : adequate strength statically and dynamically
2. Support the lateral guiderails and conductors, with insulation.
3. Carry electrical power from sub-stations to conductor/guiderail.
4. Support and protect the electrical signal wire, vehicle detection & identification equipment, links to regional and central computers.
5. Provide a firm adhesive surface for rubber tired traction
 - a. Friction coefficient when dry of 1.0 or better
 - b. Friction coefficient when wet of 0.6 or better
 - c. Design so that snow and ice will not accumulate on the guideway running surfaces.
6. Provide lateral restraints in emergencies for skidding or slowed vehicles
 - a. Side rails included in guiderails, acting on guide arms
 - b. Roadway curbs or ridges on curves or at switches to prevent oversteer or spinouts.
7. Aesthetic compatibility with the environment
 - a. Good appearance from outside or street level
 - b. General cleanliness -- lack of sprayed dirt & mud on environs
8. Aesthetic and comfort geometry/visual environment for passengers
9. Flexible routing capability
 - a. Possibility of variable speeds and negotiating sharp curves
 - b. Be lightweight, demountable and adaptable to additions
10. Provision for access to any segment by emergency vehicle --
ambulance, tow truck, guideway repair truck.

There are several types of normal forces, resulting from a combination of :

- (a). Straight-line travel with bumps, with passenger accelerations

$$F_1/m = 1.0 G \pm k_b G \quad (6.1)$$

where k_b is a function of guideway smoothness -- both bumps and roughness -- and vehicle suspension characteristics. Fig. 6-2

- (b). Straight-line travel with long humps or hollows in the guideway (Fig. 6-3), with passenger accelerations

$$F_2/m = 1.0 G \pm k_{vg} \quad (6.2)$$

where k_v is a function of V^2/R_{vert} .

- (c). Curves without bumps or undulations (Fig. 6-4), with optimal banking accelerations

$$F_3/m = g \left[1 + \frac{V^4}{g^2 \rho^2} \right] = \frac{g}{\cos \beta} \quad (6.3)$$

where ρ = curve radius

and β = bank angle

- (d). Forces caused by rotational acceleration of the car (due to changing bank angle) on outside seated passengers (Fig. 6-5).

If the center of gravity travels at constant elevation, banking into a right turn provides a maximum normal force increase on the driver as

$$\Delta F_4/m = \bar{q} \ddot{\beta} \quad (6.4)$$

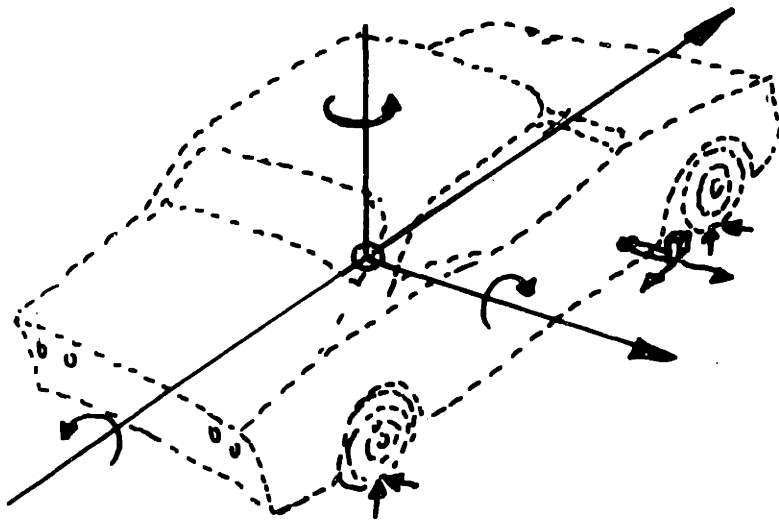


Fig. 6-1. Normal, Axial and Lateral Forces on Vehicle

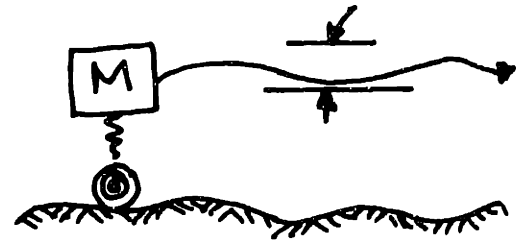


Fig. 6-2. Vertical Undulations of Sprung Vehicle : Guideway Roughness.

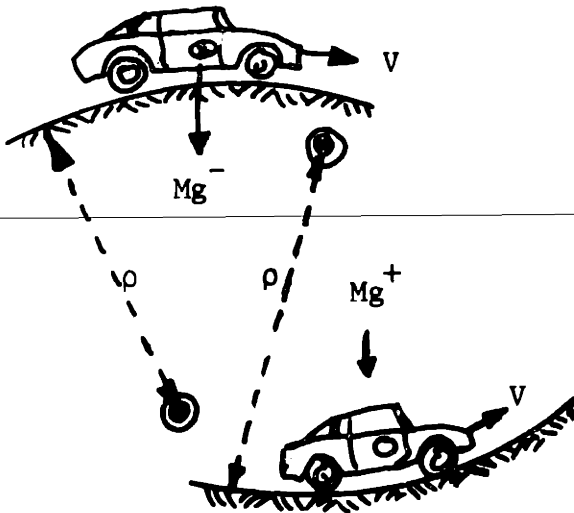


Fig. 6-3. Humps and Hollows in Guideway

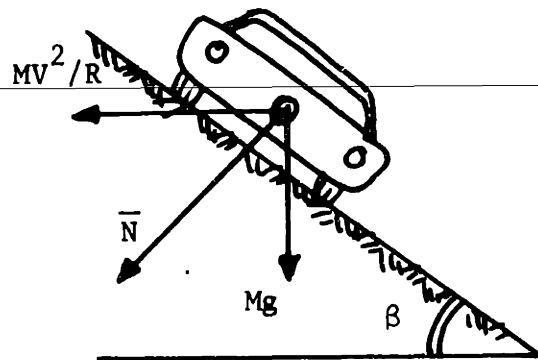


Fig. 6-4. Vehicle on Optimally Banked Curve

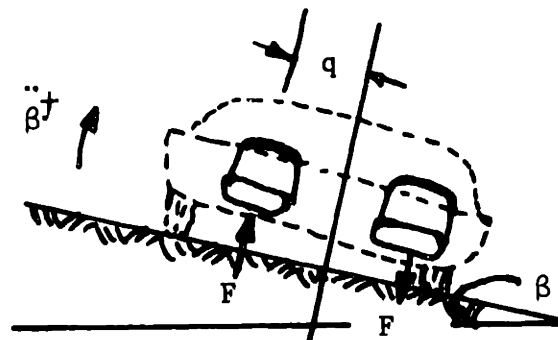


Fig. 6-5. Rotational Acceleration Effects

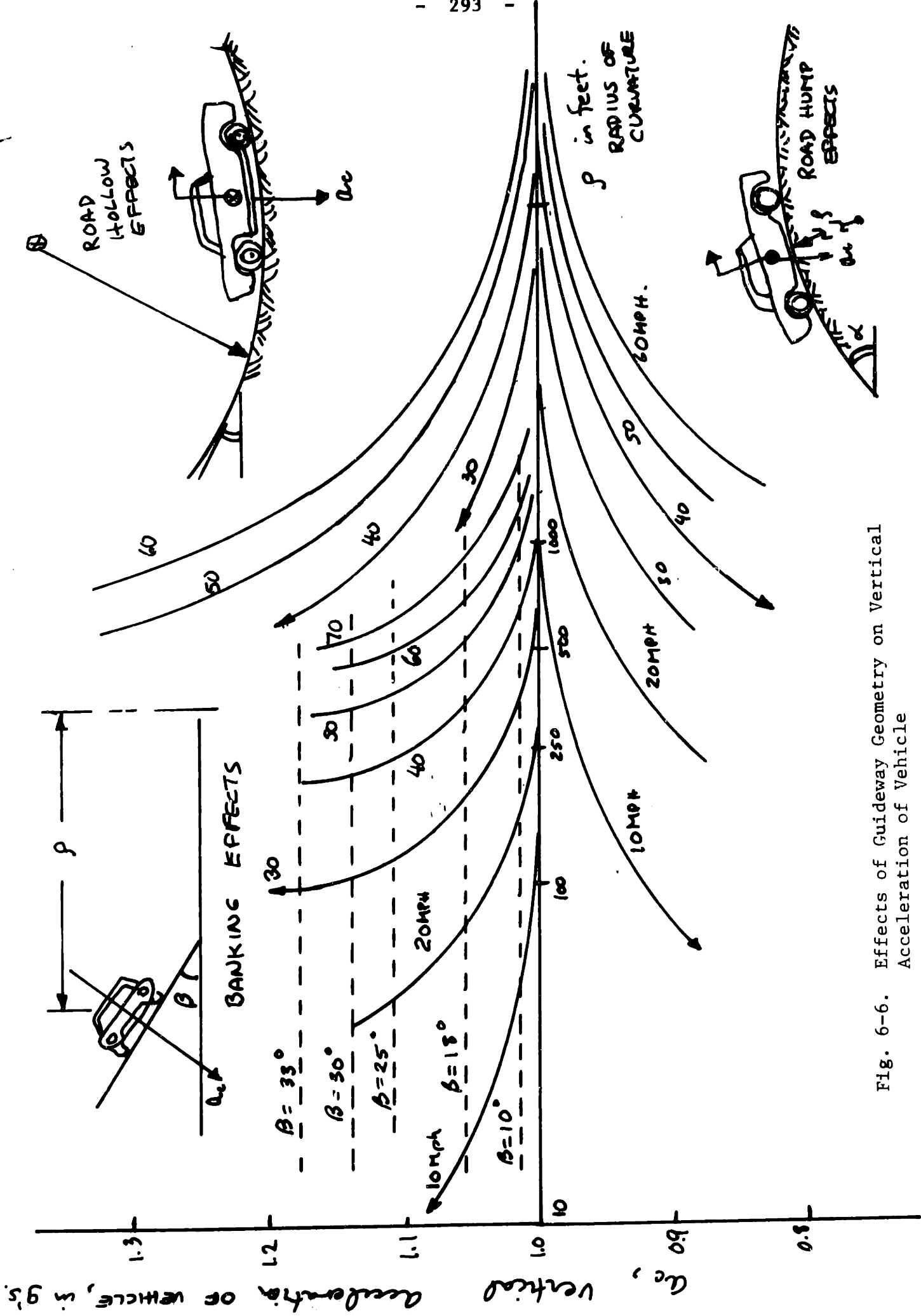


Fig. 6-6. Effects of Guideway Geometry on Vertical Acceleration of Vehicle

nausea associated with oscillating normal forces -- can prevent passengers from relaxing, as many riders of swaying railroad coaches can testify. Even a perfect guideway will not be able to eliminate lateral forces entirely, but good design can limit the disturbances to nominal levels. Contributions to the net lateral force include :

- (a). Switch forces, necessary to nudge the vehicle off the guideway centerline and into the desired left or right branch of the switch (Fig. 6-7). Once lateral motion has begun, the branches would bank off rapidly and optimally to the side, with no further lateral force. This initial switching force is

$$\bar{F}_1 / m = k_{sw} g \quad (6.7)$$

where $k_{sw} = 0.02$ to 0.05 . Whether the car were steered actively or passively, passengers would sense this acceleration.

- (b). Banked curves taken at excessive or insufficient speed, where ΔV may be due to control error, speed variations due to necessary slot-shift maneuvers, or errors in construction or alignment of the guideway.(Fig. 6-8). Since

$$\beta \approx \frac{v^2}{g \rho} \quad (6.8)$$

and the bank angle theoretically appropriate for the actual

speed $V + \Delta V$ is

$$\beta' \approx \frac{(V + \Delta V)^2}{g \rho} \quad (6.9)$$

the lateral force component becomes

$$\begin{aligned} \bar{F}_2 / m &= \frac{g}{\cos \beta} (\sin [\beta' - \beta]) \approx \frac{2 V \beta \Delta V}{(\cos \beta) \rho} \\ &\approx \frac{2 \Delta V g \beta}{V \cos \beta} \quad (6.10) \end{aligned}$$

The lateral acceleration and bank angle for various speed differentials (Fig. 6-8) shows that a 5 mph increment to adjust for a merge would (at 60 mph on a 30° banked curve) produce a lateral acceleration in excess of 0.10 G. Thus high-speed, steeply banked curves are inadvisable prior to high volume merges.

(c). Sudden wind loadings, with a 30 mph gust producing a force of 60 lbs. on the car, or

$$\bar{F}_3 / m = 0.015 \quad (6.11)$$

where $m = 107$ slugs.

(d). Axial rotation forces due to $\dot{\beta}$. Depending upon the abruptness of the curve ($\dot{\beta}_{\max} = 0.3$ rad/sec. [moderate] or 0.6 rad/sec. [sharp]), as in Fig. 6-9 :

$$\bar{F}_4 / m = \frac{V^2}{q} = \frac{V}{q} \dot{\beta}^2 = 0.008 \text{ to } 0.015 \text{ G} \quad (6.12)$$

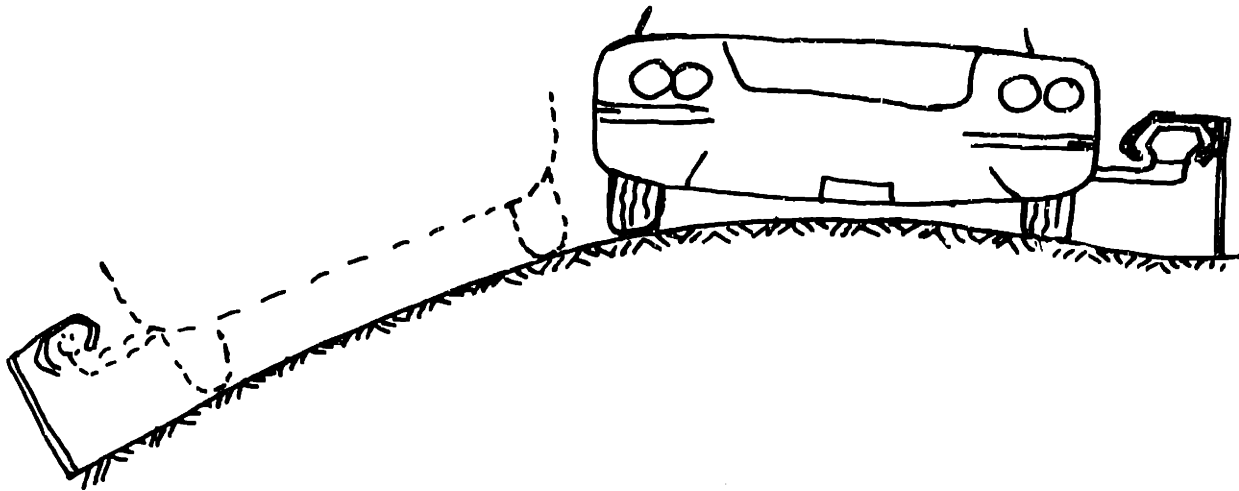


Fig. 6-7. Section of Guideway Switch : Centerline Crown and Banking to Left.

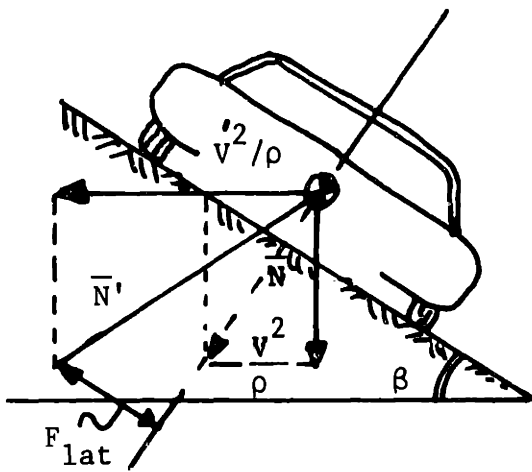


Fig. 6-8. Lateral Forces Caused by Mismatch of Speed and Bank Angle

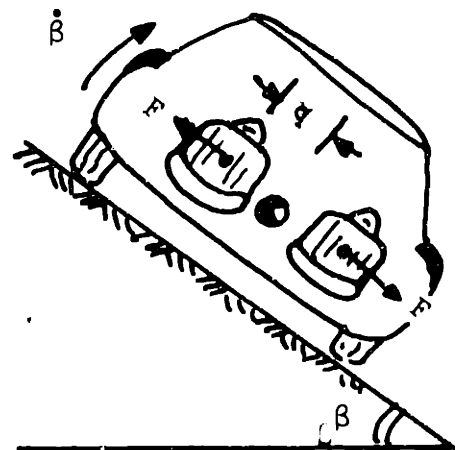


Fig. 6-9. Lateral Forces Caused by Roll Accelerations

(e). Rotational accelerations, relative to the optimal banking centerline (which could be at the C.G. or at road surface level -- see Fig. 6-9) :

$$\bar{F}_5 / m = z \ddot{\beta} = 0.04 \text{ to } 0.08 \text{ G} \quad (6.13)$$

where $z = 2 \text{ ft. max.}$ and $\ddot{\beta} = 0.62/\text{sec.}$ [moderate] and $1.25/\text{sec.}$ [sharp].

The combined equation for lateral forces is maximum at peak bank angles :

$$\bar{F}_{\text{max}} / m = \frac{2 g \Delta V \beta}{V \cos \beta} + 0.015 g + z \ddot{\beta} \quad (6.14)$$

which could approach 0.2 G at worst conditions unless the following precautions and design efforts were made :

- * speed changes kept minimal on highly banked sections.
- * Optimally banked centerline should be about the vehicle C.G. in order to reduce z .

A COMFORT STANDARD

Minimizing the above forces through good design and operation will be necessary to conform with a meaningful comfort standard set for the guideway. Roadway roughness controls will be a structural and empirical process of adjustment and maintenance. The longer duration rotational movements are more adaptable to analysis in terms of guideway geometry.

There have been no methods developed for establishing comfort and geometric standards on automated guideways or in similar banked movements, as a function of optimal speed, bank angle, and roll limits of comfort. More fundamentally, there is no recognized source on acceleration forces, lateral accelerations and jerk, or general passenger comfort. Existing data is very shallow and fragmentary.

Certain limits must be placed on the banking geometry, namely $\ddot{\beta}$, $\dot{\beta}$, $\ddot{\beta}$, and β , and some weighted relationship between them will be developed. It is unlikely that discomfort rises linearly with β and its derivatives, and a better criterion is based on the squared value of the weighted terms. One type of formulation results in an ellipsoidal limit on β and its two derivatives, described by

$$K_1 \ddot{\beta}_{\max}^2 + K_2 \dot{\beta}_{\max}^2 + K_3 \beta_{\max}^2 = 1 \quad (6.15)$$

If a sinusoidal variation of β with distance (and hence time) is assumed, the bank angle takes the general form

$$\beta(t) = \beta_{\max} \sin \omega t = \beta_{\max} \sin \frac{\omega t}{2t_f} \quad (6.16)$$

where t_f is the time from $\beta = 0$ to $\beta = \beta_{\max}$. The constants K_1 , K_2 and K_3 can be calculated from any three known empirical limits (estimated) of comfort. A reasonable initial formulation is to assume that the following are all limiting maneuvers :

(a). Maximum bank angle of 35° (visual and psychological limit)
for one turn

(b). When $\beta_{\max} = 30^\circ$, a total period for the total change from
 $\beta = 0$ to $\beta = \beta_{\max}$ of not less than 8 secs. ($t_f = 2$ sec.)

(c). When $\beta_{\max} = 15^\circ$, total period to maximum banking not less
than 4 secs. ($t_f = 1$ sec.).

Substituting into (6.15) and solving for the constants K, the
empirical comfort relation becomes

$$0.4 \ddot{\beta}_{\max}^2 + 0.8 \dot{\beta}_{\max}^2 + 2.5 \beta_{\max}^2 = 1 \quad (6.17)$$

Other comfort criteria can be developed, including a
square law relation based on only $\ddot{\beta}_{\max}$ and β_{\max} , since both
occur at the steepest banked sections of the curve, where $\dot{\beta} = 0$.
The general equation

$$K_1 \ddot{\beta}_{\max}^2 + K_2 \beta_{\max}^2 = 1 \quad (6.18)$$

combined with the data points (a) and (b) above, and then (b)
and (c) yields two sets of values, $K_1 = 0.60$ and $K_2 = 2.7$, and
 $K_1 = 0.49$ and $K_2 = 2.9$ respectively. Averaging the values of
the coefficients,

$$0.55 \ddot{\beta}_{\max}^2 + 2.8 \beta_{\max}^2 = 1 \quad (6.19)$$

as the limit, while for most curves, this weighted sum will be
less than 1.0. Therefore, any given guideway curve will have
a weighted sum which can be defined as its "discomfort coeffic-
ient" \bar{K} ,

$$0.55 \beta_{\max}^2 + 2.8 \beta_{\max}^2 = \bar{K} \quad (6.20)$$

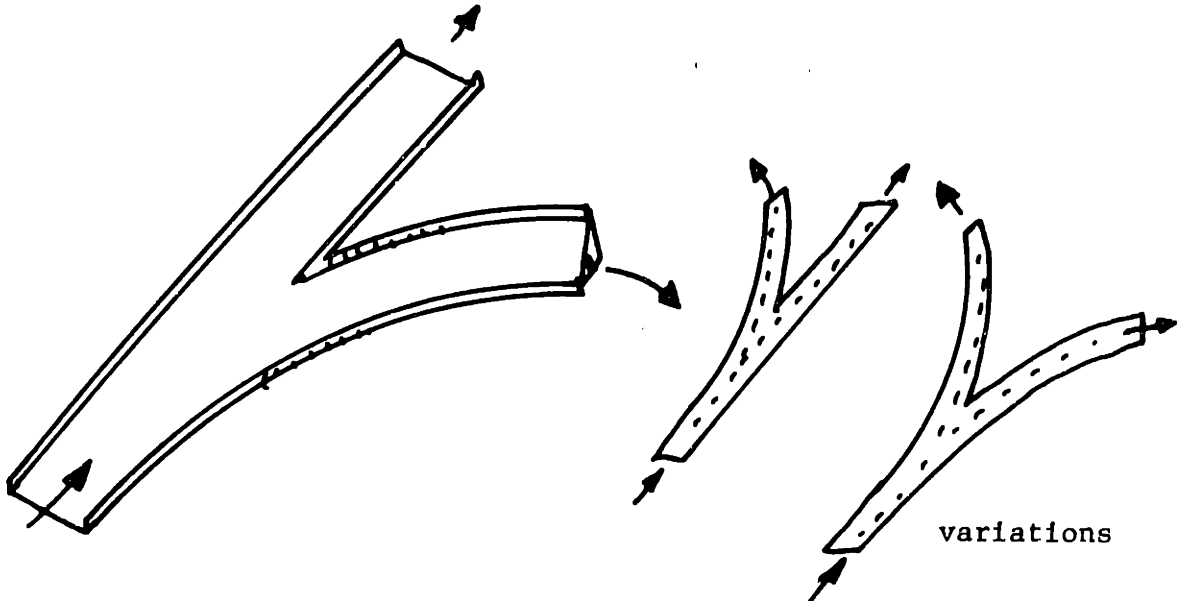
and generally \bar{K} is less than unity, or the curve exceeds comfort limits. Comparison of criteria (6.17) and (6.19) for $\beta_{\max} = 0.3$ and $t_f = 1.5$ sec. yields a difference of only 2% between the two, so for reasons of simplicity, (6.19) and (6.20) will be used hereafter.

SWITCH GEOMETRY

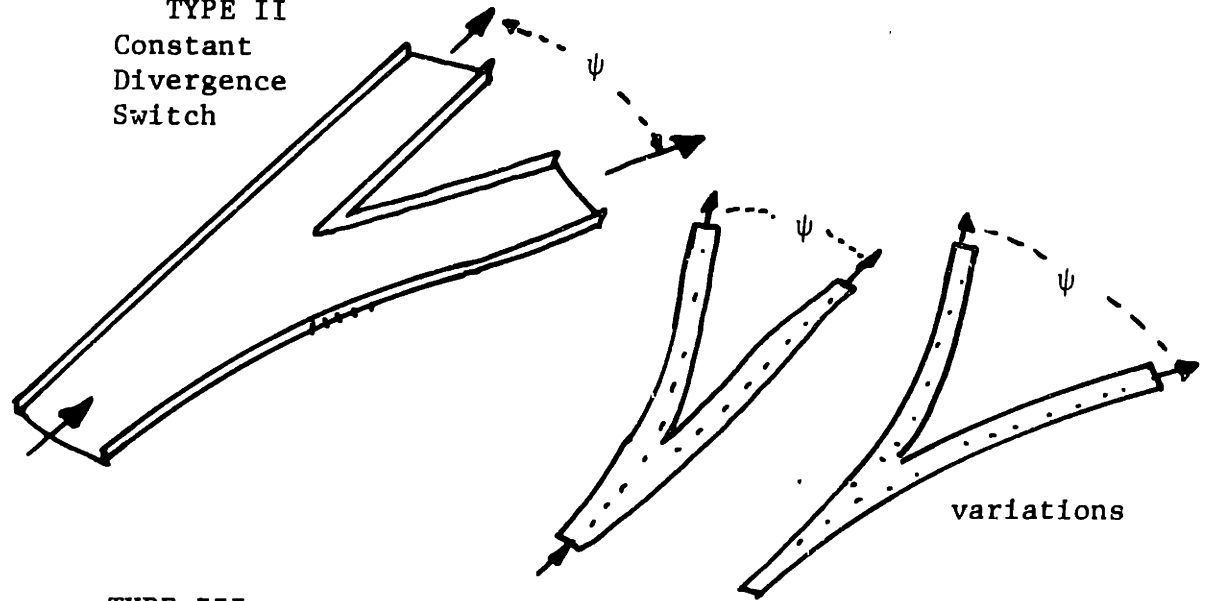
A switch is basically a binary or two-way curve, so that the geometric analysis is similar for both switches (merges) and curves. The switch cross section (Fig. 6-7) illustrates some of the geometric constraints of rapid banking, with a vertical radius of 11 feet being the least possible for good ground clearance. The lateral force $k_{sw}g$ moves the vehicle off the guideway centerline, but thereafter heading is primarily a function of the bank angle relations. The following analysis will assume small angle approximations for both β and ψ , the heading angle.

There are a number of switch and curve maneuvers possible, depending upon the final heading of the branches : zero-diverging, constant-diverging, or increasing-diverging (Fig. 6-10). In the first case, the heading angle change is zero; in the second, a constant ψ ; and in the third, the heading angle would increase with distance from the switch, because one or both of the branches would continue at constant banking & curvature. Steady guideway

TYPE I : Increasing Divergence Switch



TYPE II
Constant
Divergence
Switch



TYPE III
Zero-
Divergence
Switch

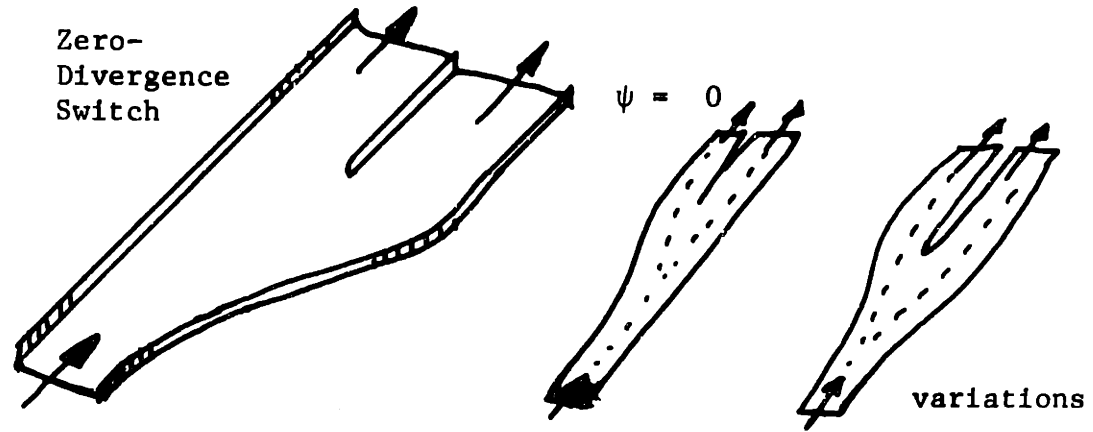


Fig. 6-10. Three Basic Types of Guideway Switches (9 variations)

speeds cause the turning relation

$$\rho \dot{\psi} = V_o \quad (6.21)$$

and

$$\tan \beta \approx \beta \approx \frac{V^2}{g\rho} \quad (6.22)$$

hence

$$\psi = \int \dot{\psi} dt = \frac{g}{V_o} \int \beta dt \quad (6.23)$$

and the lateral displacement from the straight-line position

is (Fig. 6-11)

$$\begin{aligned} \bar{d}_\psi &= \int \dot{d} dt = \int V_o \sin \psi dt \approx \int V_o \psi dt \\ &= g \int \int \beta dt dt \end{aligned} \quad (6.24)$$

which for the small angle approximation used is independent of V_o .

The simplest method of changing direction is a transition curve from level travel to a curve of constant banking β_{max} . Continuous sine curves can be used to represent the bank angle changes (Fig. 6-12) and the consequent integration to yield ψ and \dot{d}_ψ . The comfort requirements are that jerk be small, hence acceleration must be continuous and $\dot{\beta}$ smooth. Thus for the bank angle relations shown in Table 6-2, the total heading angle change at the beginning of the constant curvature section and end of the transition segment can be expressed simply as a function of β_{max} , t_f and V_o :

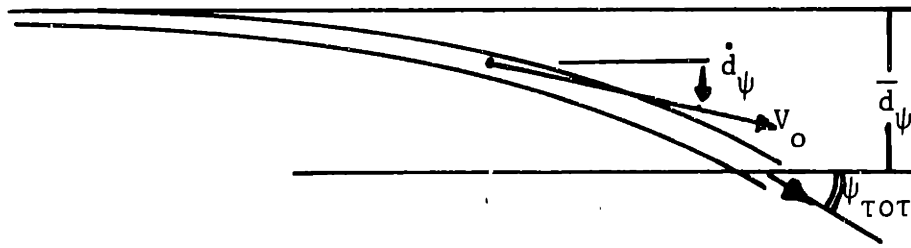


Fig. 6-11. Curve Heading and Displacement Geometry

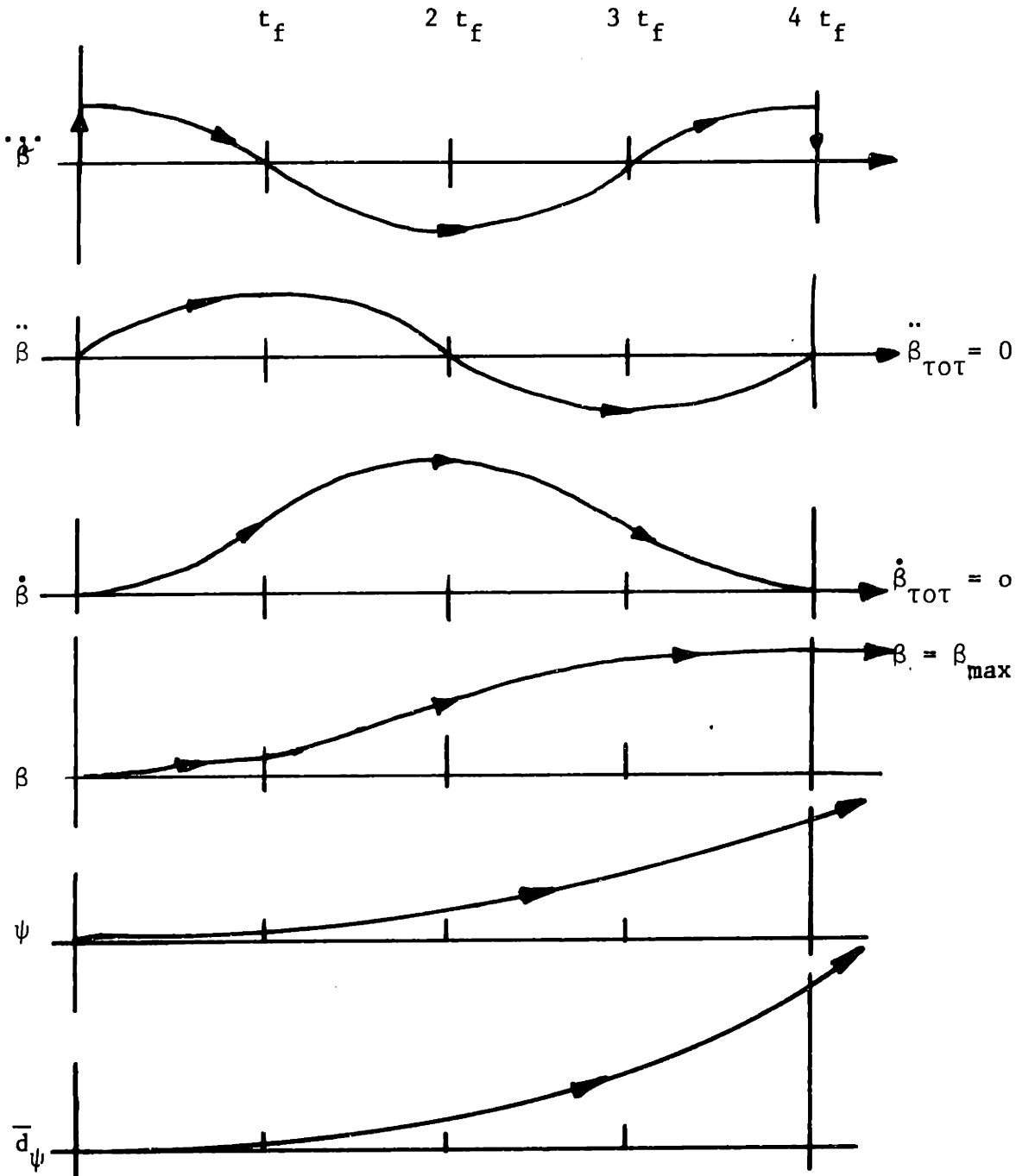


Fig. 6-12. Transition Curve to Constant Banking : Bank Angle and Heading Angle Relations

TABLE 6-2 BANK ANGLE & HEADING CHANGES : SIMPLE CURVE TRANSITION

$$\ddot{\beta} = \frac{\omega^3 \beta_{\max}}{2\pi} \cos \omega t \quad (6.25)$$

$$\dot{\beta} = \frac{\omega^2 \beta_{\max}}{2\pi} \sin \omega t \quad (6.26)$$

$$\dot{\beta} = \frac{\omega \beta_{\max}}{2\pi} (1 - \cos \omega t) \quad (6.27)$$

$$\beta = \frac{\beta_{\max}}{2\pi} (\omega t - \sin \omega t) \quad (6.28)$$

$$\psi = \frac{g \beta_{\max}}{2 V_o \pi} \left[\frac{\omega t^2}{2} - \frac{(1 - \cos \omega t)}{\omega} \right] \quad (6.29)$$

$$\bar{d}_{\psi} = \frac{g \beta_{\max}}{2\pi} \left[\frac{\omega t^3}{6} - \frac{t}{\omega} + \frac{\sin \omega t}{\omega^2} \right] \quad (6.30)$$

$$\psi_{\text{tot}} = \frac{2 g \beta_{\max} t_f}{V_o} \quad (6.31)$$

The distance traveled along the guideway, \bar{s} , during the turning maneuver is $V_o (4t_f)$, and now a dimensionless parameter for the heading angle can be used to describe this constant-diverging switch:

$$\left(\frac{\psi_{\text{tot}} \bar{s}}{g t_f^2} \right) = 8 \beta_{\max} \quad (6.32)$$

Similarly for \bar{d} ,

$$\left(\frac{\bar{d}_\psi}{gt_f^2} \right) = 2.24 \beta_{\max} \quad (6.33)$$

The average radius of curvature (which will be important in preliminary mapping of possible guideway locations, since it can be laid out with an ordinary compass) is obtained from (6.31) and the defining relation

$$\rho_{av} = \frac{\bar{s}}{\psi_{tot}} = \frac{V_o (4t_f)}{\psi_{tot}} \quad (6.34)$$

yielding the desired result for constant-diverging switches,

$$\rho_{av} = 2 \rho_{min} = 2 \rho_{final} \quad (6.35)$$

A constant-diverging switch has a discontinuity in the "jerk" curve $\ddot{\beta}$ (Fig. 6-13) and hence has three regimes of integration. The values of β are

$$\beta = \begin{cases} \frac{\omega \beta_o t}{4} - \frac{\beta_o}{8} \sin 2\omega t & (6.36a) \\ & [0 < t < t_f] \\ \frac{\pi \beta_o}{8} \left(1 - \frac{4}{\pi} \cos \omega t \right) & (6.36b) \\ & [t_f < t < 3t_f] \\ -\frac{\omega \beta_o t}{4} + \frac{\beta_o}{8} (\sin 2\omega t) - \frac{\pi \beta_o}{2} & (6.36c) \end{cases}$$

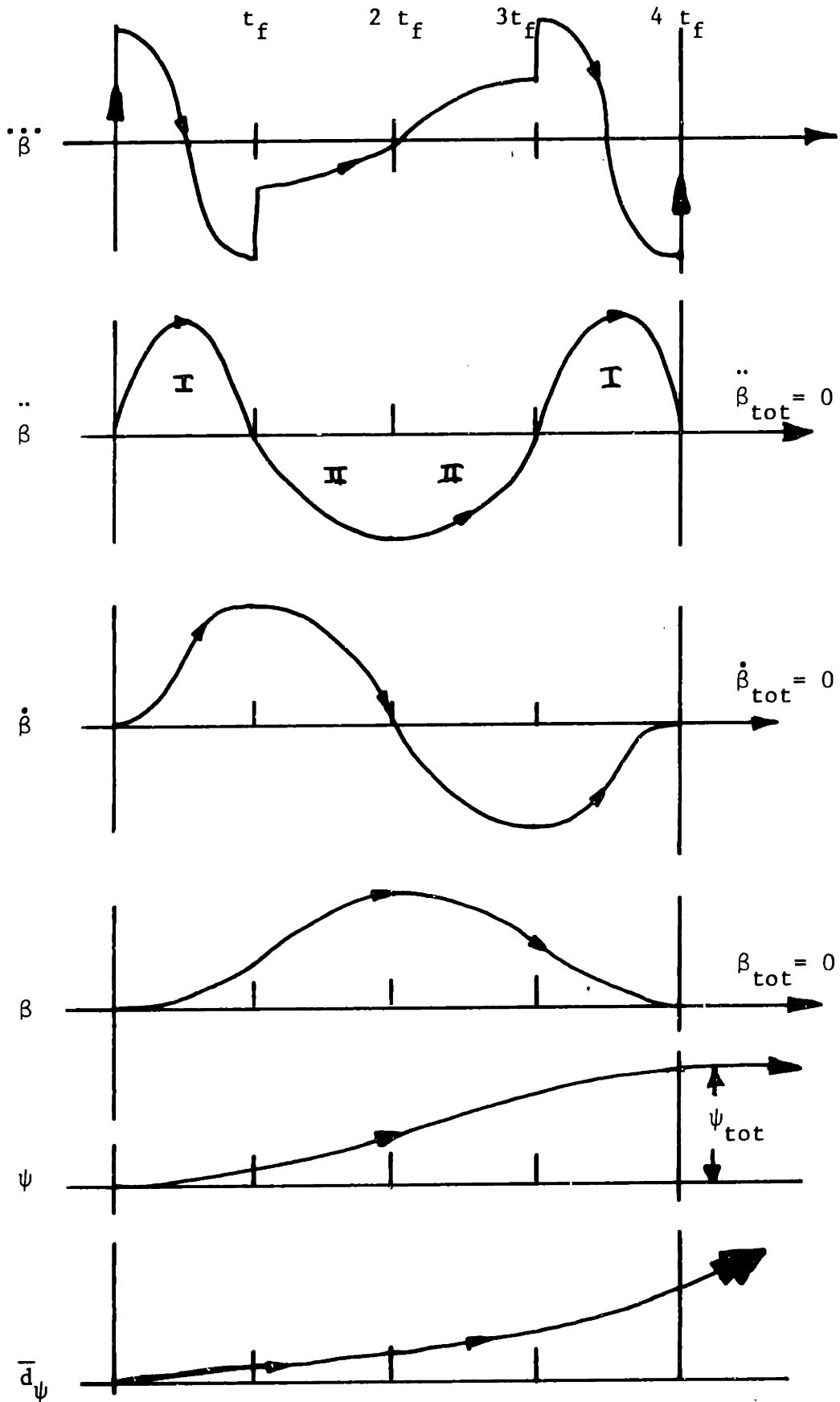


Fig. 6-13. Constant Divergence Switch : Bank Angle and Heading Angle Relations

where the limits of (6.36c) are [$3t_f < t < 4t_f$] and where for convenience β is defined by $0.89 \beta_o = \beta_{max}$. The integration process yields a final heading angle at the end of the switch which thereafter becomes a constant heading angle of

$$\psi_{tot} = \frac{1.65 \beta_o t_f g}{v_o} = \frac{1.85 \beta_{max} t_f g}{v_o} \quad (6.37)$$

or

$$\left(\frac{\psi_{tot} \bar{s}}{g t_f^2} \right) = 6.6 \beta_o = 7.4 \beta_{max} \quad (6.38)$$

A simpler geometric alternative to integration yields by inspection (Fig. 6-14) :

$$\bar{d}_\psi = 2 \rho_{av} \sin^2(\psi/2) = \frac{\rho_{av} \psi^2}{2} \quad (6.39)$$

or

$$\left(\frac{\bar{d}_\psi}{g t_f^2} \right) = 3.4 \beta_o = 3.8 \beta_{max} \quad (6.40)$$

with

$$\rho_{av} = 2.14 \rho_{min} \quad (6.41)$$

The zero-divergence or parallel branch switch is somewhat more complex and is designed so that the integrals of all banking derivatives from β to β integrate to zero. so that the only net effect on the traveling vehicle -- other than moving forward -- is a displacement laterally of \bar{d}_ψ . Thus, as expected,

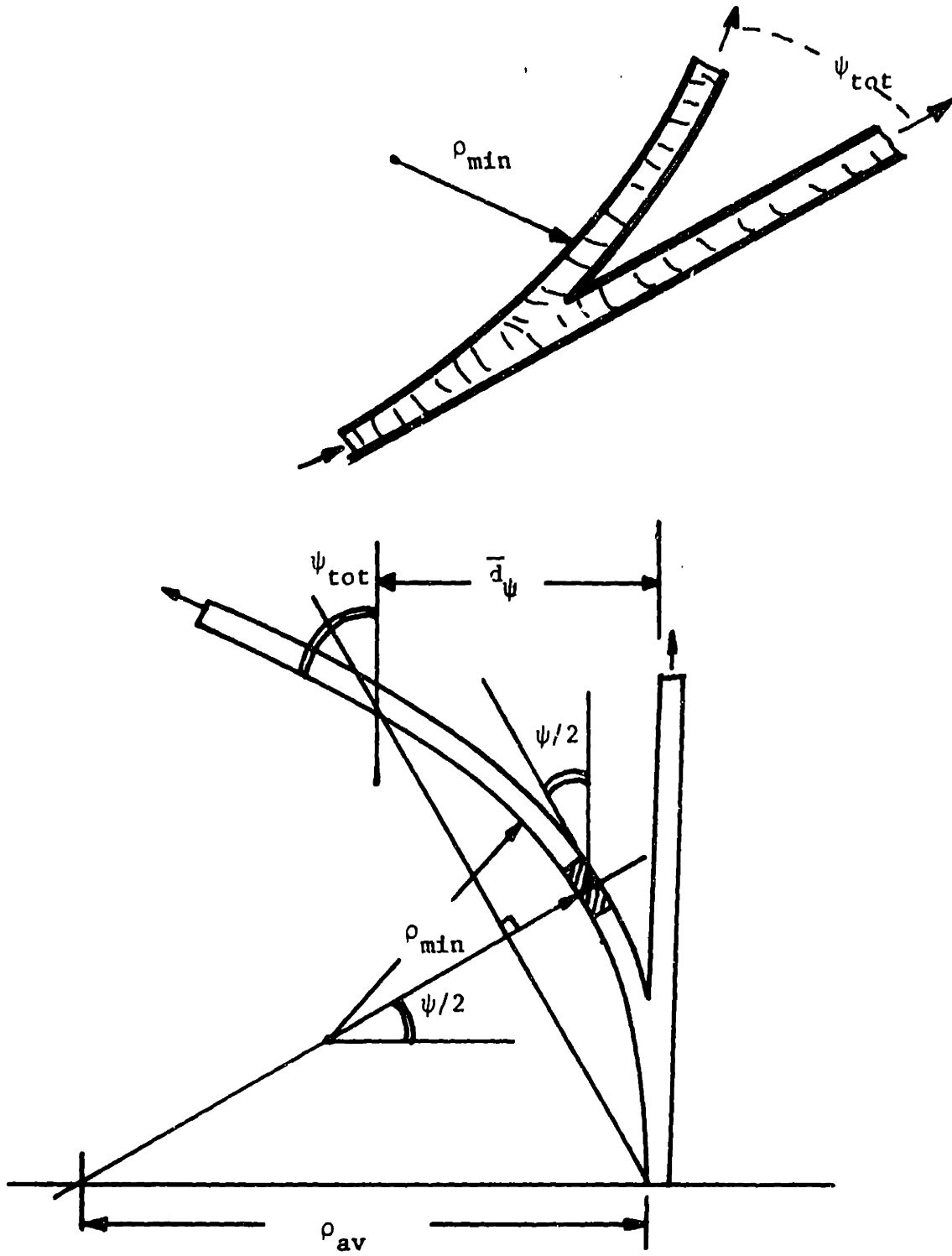


Fig. 6-14. Switch Geometry : Constant Divergence (Type II)

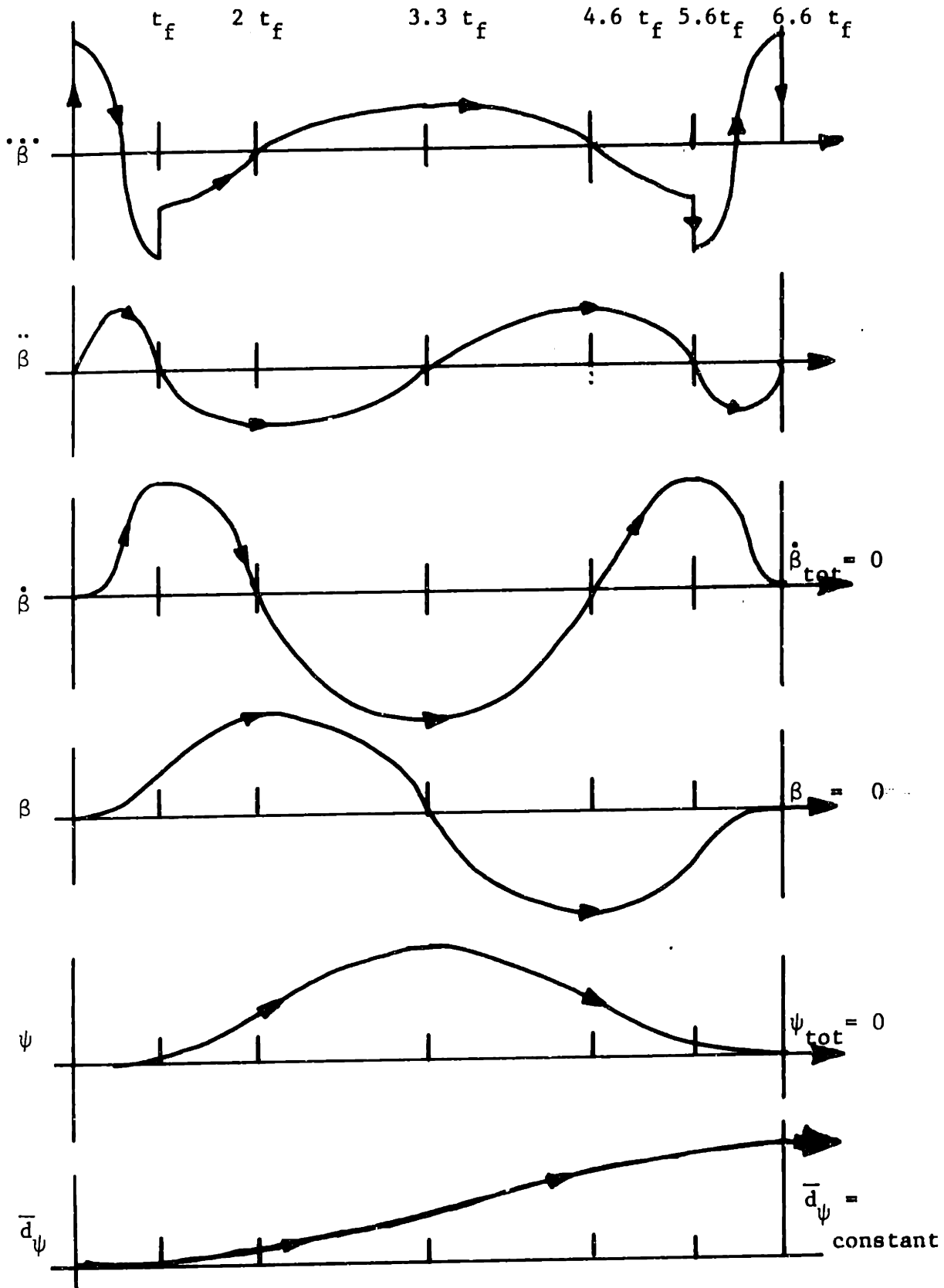


Fig. 6-15. Zero Divergence Switch (Type III) : Bank Angle relations

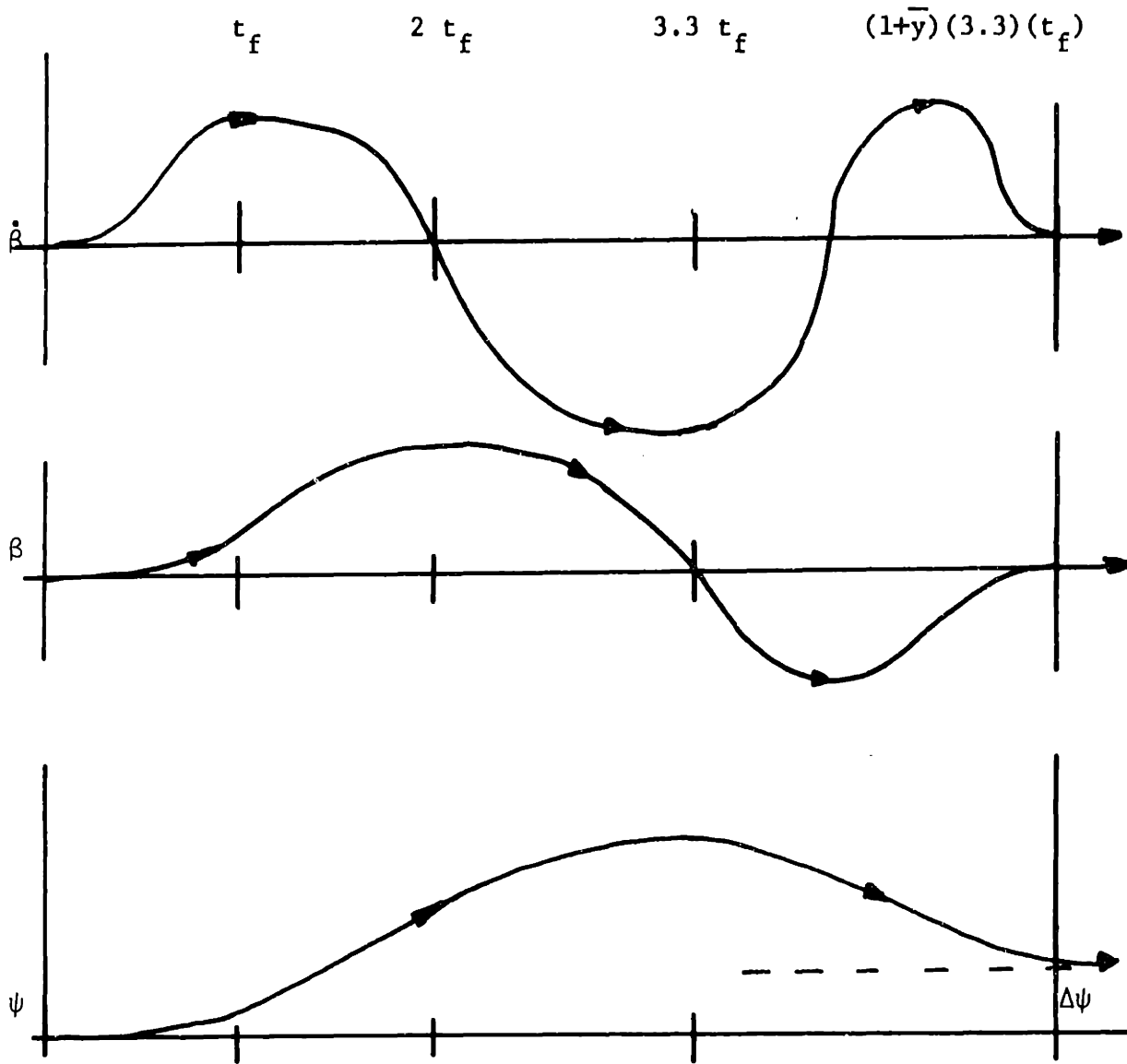
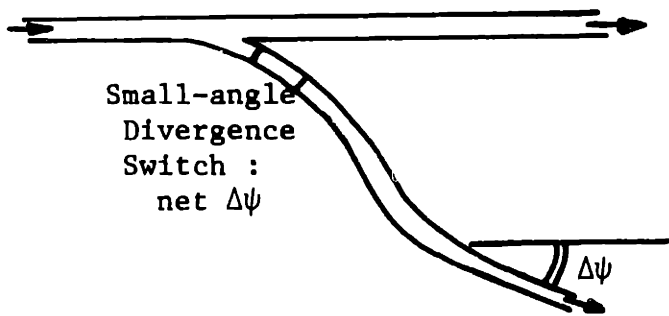


Fig. 6-16. Small Angle Divergence Switch



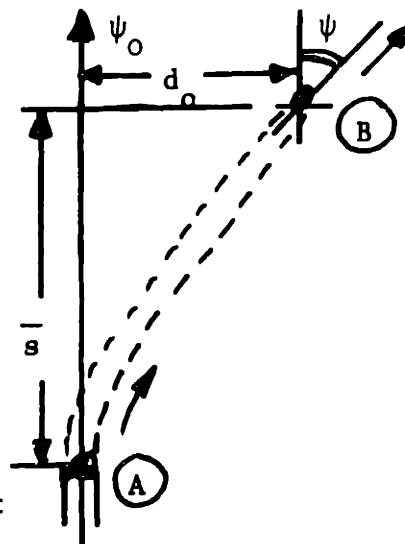


Fig. 6-17. Basic Mapping Problem for Guideway Route Layout

$$\left(\frac{\psi_{\text{tot}} \bar{s}}{g t_f^2} \right) = 0 \quad (6.42)$$

and

$$\left(\frac{\bar{d}\psi}{g t_f^2} \right) = 2.4 \beta_o = 2.7 \beta_{\text{max}} \quad (6.43)$$

In certain cases of difficult geography and the desirability of avoiding long, very gently sloped switches to yield a small ψ_{tot} , a small angle constant divergence switch may be used -- based on the same principle as the zero-divergence switch except that the transitional section is not symmetrical, i.e. the final transition from β_{max} to $\beta = 0$ is accomplished more rapidly than the initial transition from $\beta = 0$ to β_{max} . Thus, the length of the latter section is less than the initial section, the ratio being \bar{y} , and the net heading angle resulting is (Fig. 6-16)

$$\left(\frac{\psi_{\text{tot}} \bar{s}}{g t_f^2} \right) = 4.8 \beta_o (1 - \bar{y}^2) (1 + \bar{y}) \quad (6.44)$$

and

$$\left(\frac{\bar{d}\psi}{g t_f^2} \right) = 4.75 \beta_o \bar{y} + 2.4 \beta_o - 2.35 \beta_o \bar{y}^3 \quad (6.45)$$

The above analysis now permits the synthesis of guideway design geometry and determination of passenger comfort for each

ramp. A separate parallel effort must be made to reduce normal, axial and lateral acceleration and jerk components, while for general motions a discomfort criterion \bar{K}_{\max} is chosen as a function of the newness of the system (e.g., $K_{\max} = 0.5$ for an early demonstration system). Rotational acceleration profiles for banked curves are devised and integrated to yield heading and lateral displacement. The effects of the curve on vehicle dynamics can now be predicted, and preview information for guidance can be accurately specified. Moreover, it is now possible to map out guideway links in physical situations, so that necessary banking and comfort considerations can be checked and become an integral part of the design.

A typical mapping problem is shown in Fig. 6-17, and the general design graphs in Fig. 6-18 and 6-19 can be used for direct analysis. Two points A and B need to be connected by a smooth guideway link. If, for example, A and B are separated by distances $s_{AB} = 500$ ft. and $d_{\psi} = 50$ ft., and if $\psi_{\text{tot}} = 0.1$ radian, with $V_o = 60$ mph (88 fps), one proceeds to use Chart A (Fig. 6-18) in calculating $\psi_{\text{tot}} \times s_{AB} = 50$ ft. Since $d_{\psi} = 50$ ft., the point falls on the line $\bar{y} = 0.62$. Therefore, the second part of the curve is only 0.62 times the length of the first part.

The time traveling from A to B is approximately s_{AB}/V_o and is exactly Nt_f , where N is defined as the total time in the

curve maneuver divided by the parameter t_f . For $\bar{y} = 0.62$, then $N = 5.3$ and $t_f = 1.07$ sec. Furthermore,

$$\left(\frac{\psi_{\text{tot}} s_{AB}}{gt_f^2} \right) = 1.35 \quad (6.46)$$

and

$$\left(\frac{\bar{d}_\psi}{gt_f^2} \right) = 1.35 \quad (6.47)$$

which are equal by coincidence.

The curve for β_o in Chart A intersects $\bar{y} = 0.62$ at the point $(4.7 \beta_o, 4.7 \beta_o)$, so that $4.7 \beta_o = 1.35$ or

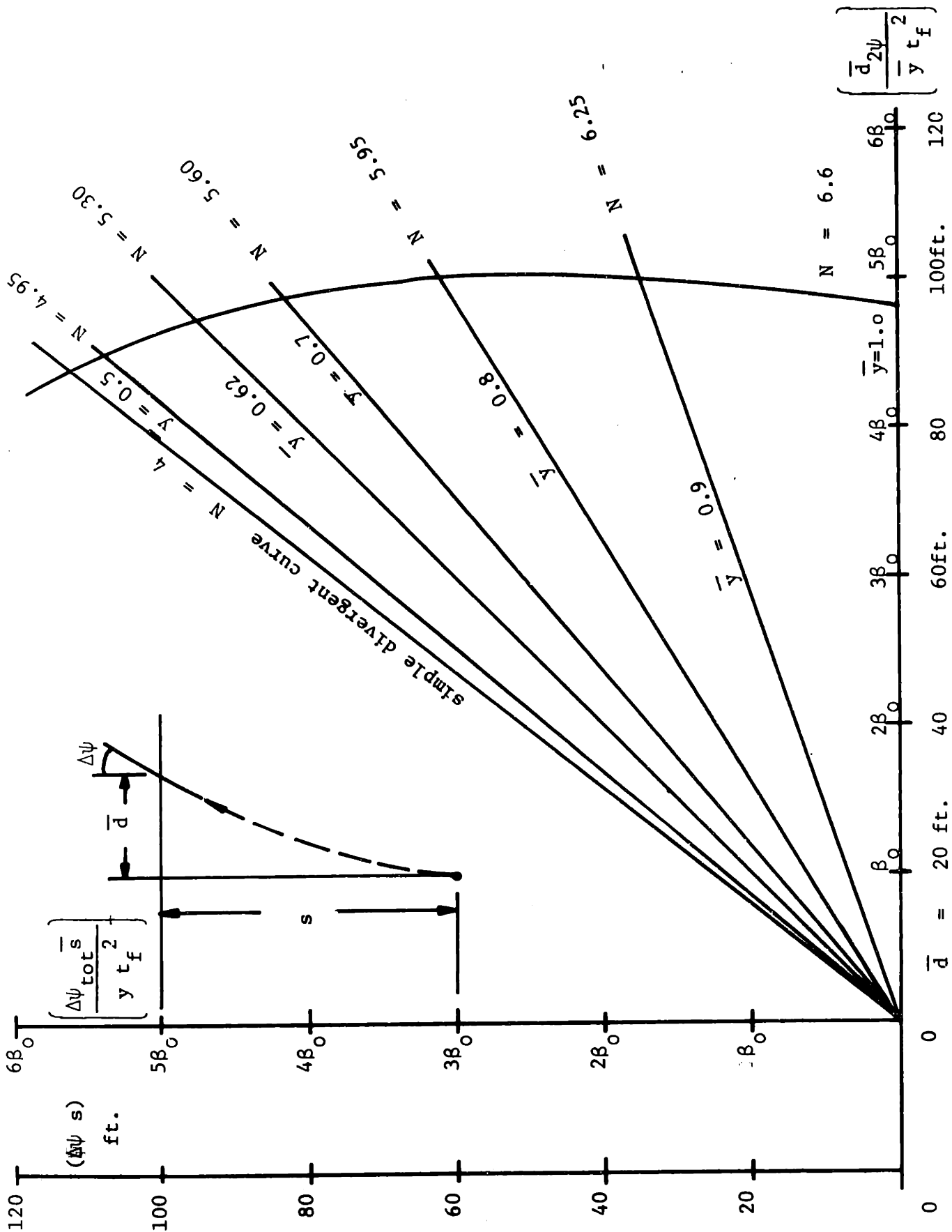
$$\beta_{\text{max}} = 0.89 \beta_{\text{max}} = 0.256 \text{ or } 14.5^\circ \quad (6.48)$$

which is the maximum bank angle.

Chart B (Fig. 6-19) can now be used to determine the discomfort coefficient \bar{K} . For $t_f = 1.07$ and $\beta_{\text{max}} = 0.256$, $\bar{K} = 0.5$ or in other words the curved segment between A and B is feasible and should be quite comfortable at 60 mph.

The choice of sinusoidal banking relations is reasonable and convenient, but arbitrary. A set of first, second and third degree equations for β could also be applied, as well as the traditional spiral transition curves of highway design. Empirical standards have been developed to ensure safe and comfortable rates of change of normal and lateral accelerations. For a length

Fig. 6-18. CHART A for Guideway Mapping



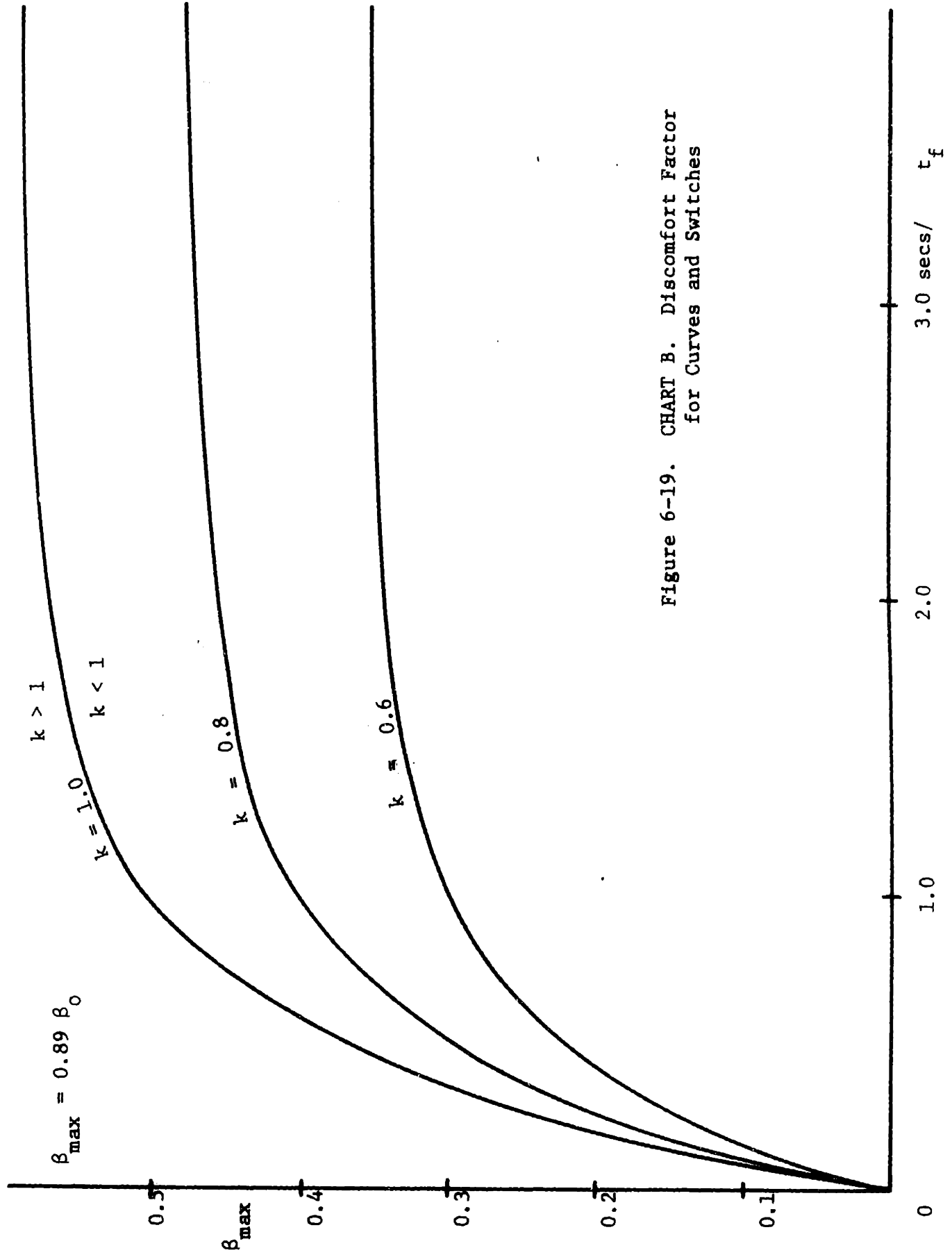


Figure 6-19. CHART B. Discomfort Factor for Curves and Switches

of transition curve L_s and speed V_o (in mph), a common formula is

$$L_s = 1.6 V_o^3 / R \quad (6.49)$$

where R = final curve radius. One suggested formula intended to take account of superelevation \bar{e} is

$$L_s = \frac{3.15 V}{c} (V_o^2 / R - 15 \bar{e}) \quad (6.50)$$

with a recommended value of $c = 1.35$, within the general range of 1.0 to 3.0, depending upon situation and observations of the engineer at the site. Because of speed variations and truck traffic, the degree of banking is necessarily low, so that ramps on expressways and cloverleaves often have uncomfortable lateral forces and the spiral easement concept seems to have little direct application to guideway banking concepts.

PHYSICAL GUIDEWAY DESIGN

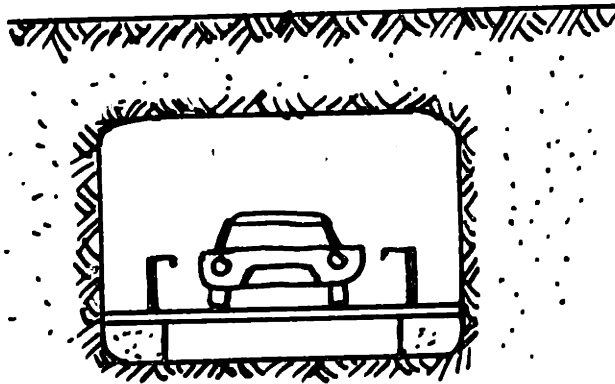
A guideway must do more than support vehicles and connect origins and destinations. It must provide emergency lateral support, carry electric power from substations to vehicles, and provide the electrical signal network for vehicle detection, identification and instruction. An adhesive road surface must be maintained in all weather, and access by emergency vehicles should be rapid and unobstructed. The guideway must demonstrate aesthetic compatibility with the environment, in terms of visual

appeal, noise and cleanliness. Maximum feasible use should be made of routing flexibility in order to conserve the existing urban fabric.

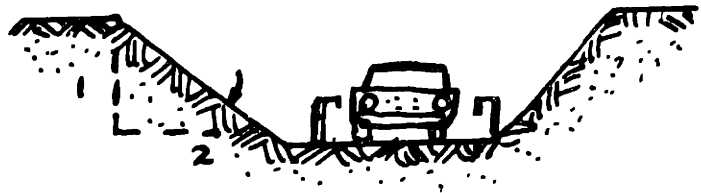
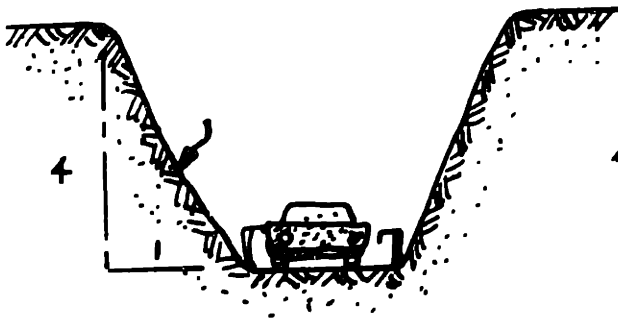
The high ratio of channel capacity to ROW width permits more economical use of land space, an important factor when as much as 40 to 50% of the CBD of larger U.S. cities is consumed by streets and parking. Tunnels, elevated structures and the use of railroad right-of-way without widening become feasible design options (Fig. 6-20). In all cases, ramp and station design can be a problem, because of the increased space consumed and interfaces with local street circulation. In initial guideway systems, entrance ramps could include a spur ramp for emergency reject from the entrance flow stream of any vehicle which could not maintain power or accurate position. Such spur ramps are expensive and consume space, but they would keep defective vehicles on the guideway to a minimum and improve system reliability. An alternative to the reject ramp is an acceleration pre-check at the entrance booth.

Many guideway elements appear readily adaptable for factory production, including straight sections, families of constant β curves and subfamilies of standard transitional segments, bridge structures, columns, station components (platforms, switches, etc.) and switch/merge structures. One should note that from the construction viewpoint, a merge is simply a reversed switch.

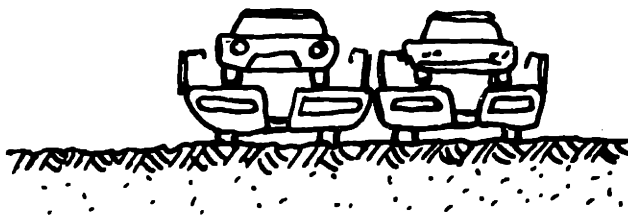
(a). Below Ground.
in a Tunnel
(Shield Driven
or Cut and Cover)



(b). Below Grade : Trench



(c). At-grade Guideway



(d). Elevated above Grade : Columa
Supported
37-70 ft, high

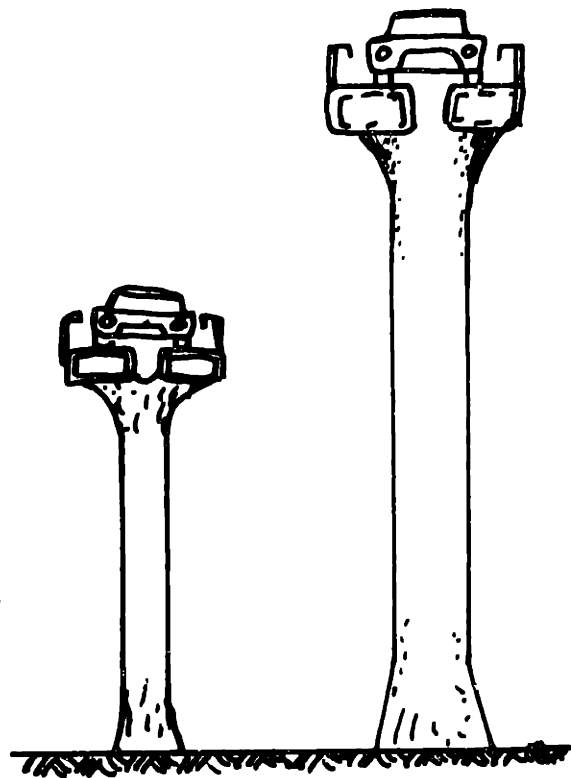


Fig. 6-20. Guideway Elevations

The component elements of a guideway section can be identified (Fig. 6-21) as the structural base, the guiderail and posts, the columns, and the roadway surface, as well as the signal wire, wayside controller and auxiliary conductor to supplement the power guiderail. The roadway consists of two parallel strips of running surface, having sufficient width to accommodate the range of vehicle tracks and tire widths. Maximum width at the outside tire edges for the widest American car is 80 in., while for a Volkswagen, the inside tire width is 46 in. With an allowance for ± 3 in. for steering control variations and crabbing, the roadway strips have an outside width of at least 86 in. and an inside width of 40 in.

The outer and inner **ridges** of the roadway strips are intended to act as raised curbing to reduce excessive oversteer and rear end break-away in an emergency control situation and any tendency of the vehicle to brush against the guiderail (Fig. 6-22). The outer curbing is 4 to 6 in. high, yet would contain periodic drain openings to keep the roadway surface as well drained as possible and reduce vehicle spray during wet situations. The inner curbing height is less, 3 to 4 in., because of ground clearance problems, particularly a vehicle with a flat tire.

The roadway surface must be a hard-wearing, high adhesion material capable of easy maintenance of surface smoothness and alignment. The concentrated use of a relatively small area of

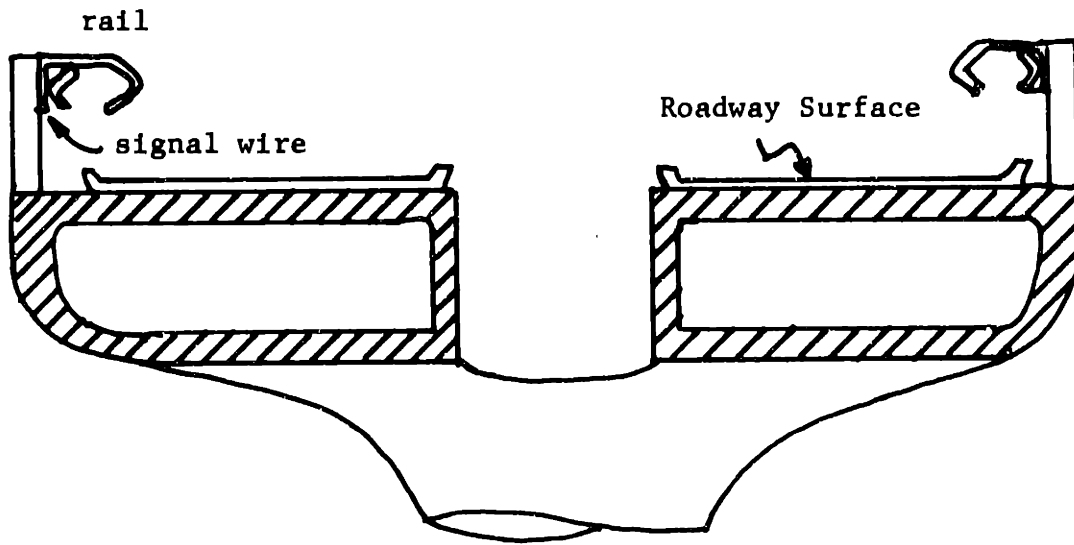


Fig. 6-21. Guideway Components

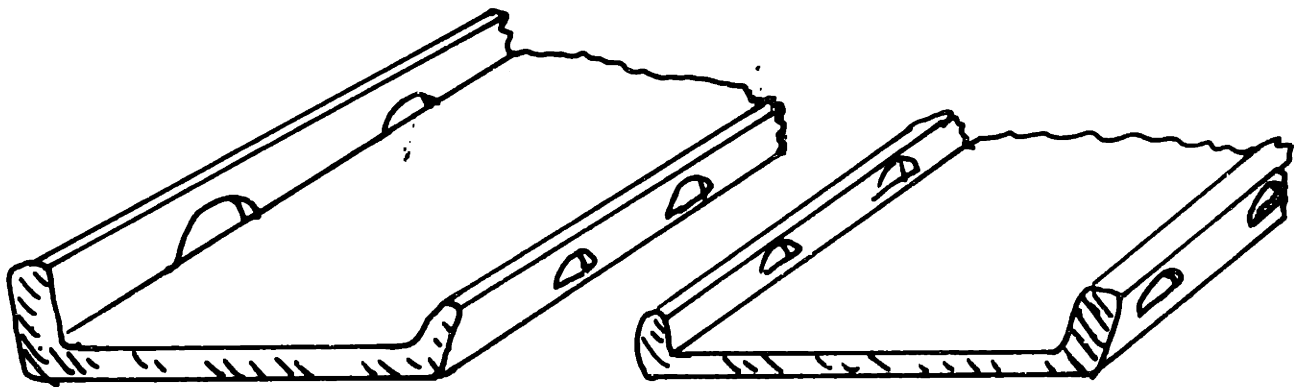


Fig. 6-22. Guideway Curbing Restraints on Rear Wheel Skidding.

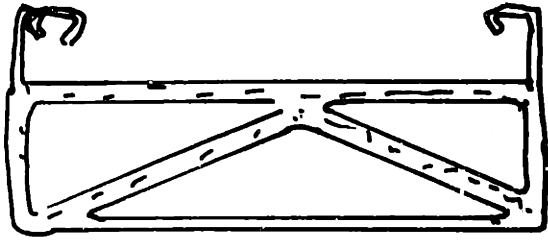
road surface may cause high wear and cracking rates, necessitating special new materials, but because of the limited material volume of the actual roadway surface elements, new and more expensive materials can be used in place of traditional concrete and asphalt. Some form of rubber composite with metallic studs and special synthetic materials are interesting possibilities. Fortunately, the heavy trucks which are so destructive to today's roads would not be using the guideway. The use of baked-on semi-porous plastics may be feasible, particularly if road oil and water drop buildup was reduced. Finally, acceleration and braking ramps might include heating coils within the roadway surface, to prevent icing and induce evaporation and draining of slush and rain.

The structural base could either be full-width or divided. The former is the stronger and lighter of the two, but the latter permits the open space between wheel channels to be used as a drop-through trough for foreign objects that have fallen on the guideway or as a drain/storage cavity for snow and rain. A grating or solid cover located beneath the structural base entraps solid objects and provides a drain pan for water run-off. The lower drainage system is complemented above by partitions 2 to 3 feet high behind the guiderails, which serve to shield the environs from physical impact with guideway byproducts, such as dust, dirt, water and slush spray, and to a certain degree, noise. In any weather, pedestrians should be able to walk in the vicinity of the guideway

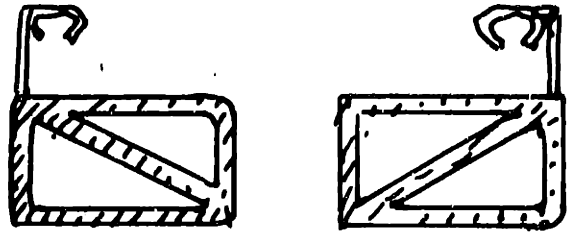
without induced discomfort or fear of getting sprayed with muddy water. The structural base could be a combination of continuous and divided, by periodically having cross-struts across the trough, but extensive engineering analysis remains to be done on the strengths and costs of the several possible designs (Fig. 6-23), as well as aesthetic evaluation by passengers and ground observers.

Because of the electric motive power, the primary vehicle noise comes from tire, running gear, and wind noises, as well as sliding and joint frictions between follower and guiderail. The side and underneath sections of the guideway should be constructed to absorb or reflect upwards most of the running noise, while guiderail joints could be quieted by tapering both joint and the leading edge of the follower pad and employing independent springing in each follower pad.

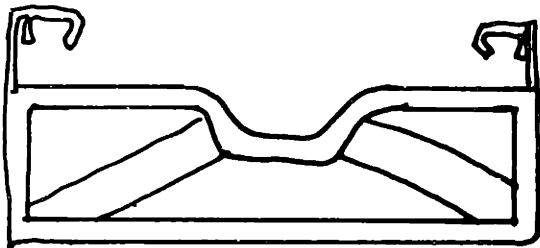
A guiderail post spacing of 10-ft. is reasonable and was used on the prototype system with good results. A 20-ft. spacing is possible for straight line-haul segments, while for low-speed sharp turns at stations the rails may be supported by a continuous structure. The inner rail within the outer guiderail envelope is "hot" electrically ($V = 500$ to $1000v$) and carries the current necessary to power all vehicles between power stations, except when arranged in parallel service with an auxiliary conductor. The guiderail posts would have extensive adjustment capability to position both inner and outer guiderails for accurate and



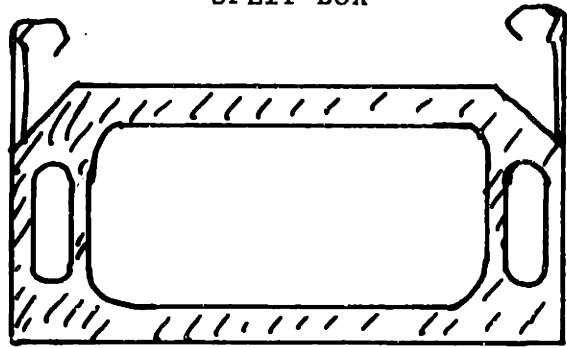
BOX



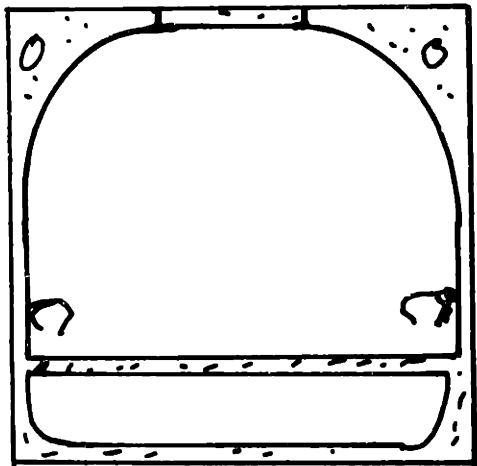
SPLIT BOX



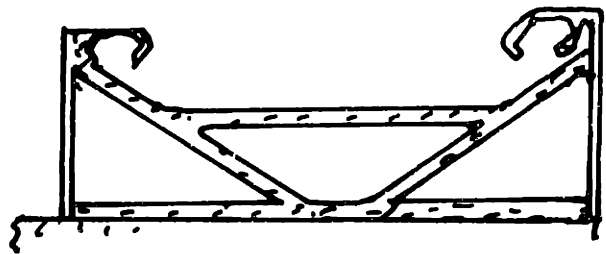
TROUGH



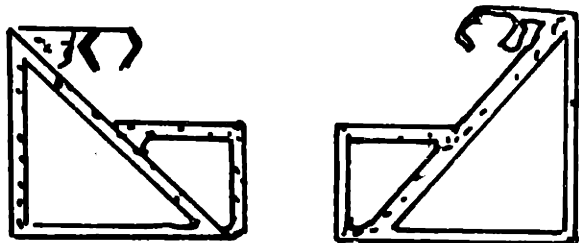
WEB



ENCLOSED BOX



TRIANGULAR



SPLIT TRIANGULAR

Fig. 6-23. Guideway Cross Sections.

well modulated guidance information to moving vehicles.

Guideway supporting columns on elevated sections should be widely spaced in a single line, in preference to double or triple pillars -- which give a railroad trestle/Central Artery appearance to the land area below. The aesthetics problem of the guideway will be discussed in more detail later in this chapter, but suffice it to say that span lengths will probably be in the range of 40 to 50 ft., since a recent Carnegie study³ reported these conclusions after analysing a wide range of vehicles. The superstructure increases approximately linearly with span length, while foundation and supporting structure decreases inversely with length. The Carnegie study found that structures having spans 1.5 to 2.0 times the optimal length cost 25 to 30% more in construction, while span lengths 2.5 to 3 times optimal cost 80 to 90% more.

Design for reasonable adaptability includes the judicious location of columnar structure capable of accepting the addition of another guideway lane or ramp (Fig. 6-24) and a switch/merge to existing structures (Fig. 6-25) with the objective of minimizing downtime of operational segments -- hopefully a day or two on a weekend, during which new guiderail segments and electronics could be plugged in and activated rapidly. Some guideway section could be bolted into place after precasting, so that they effectively would be demountable -- sections could be removed, altered, trans-

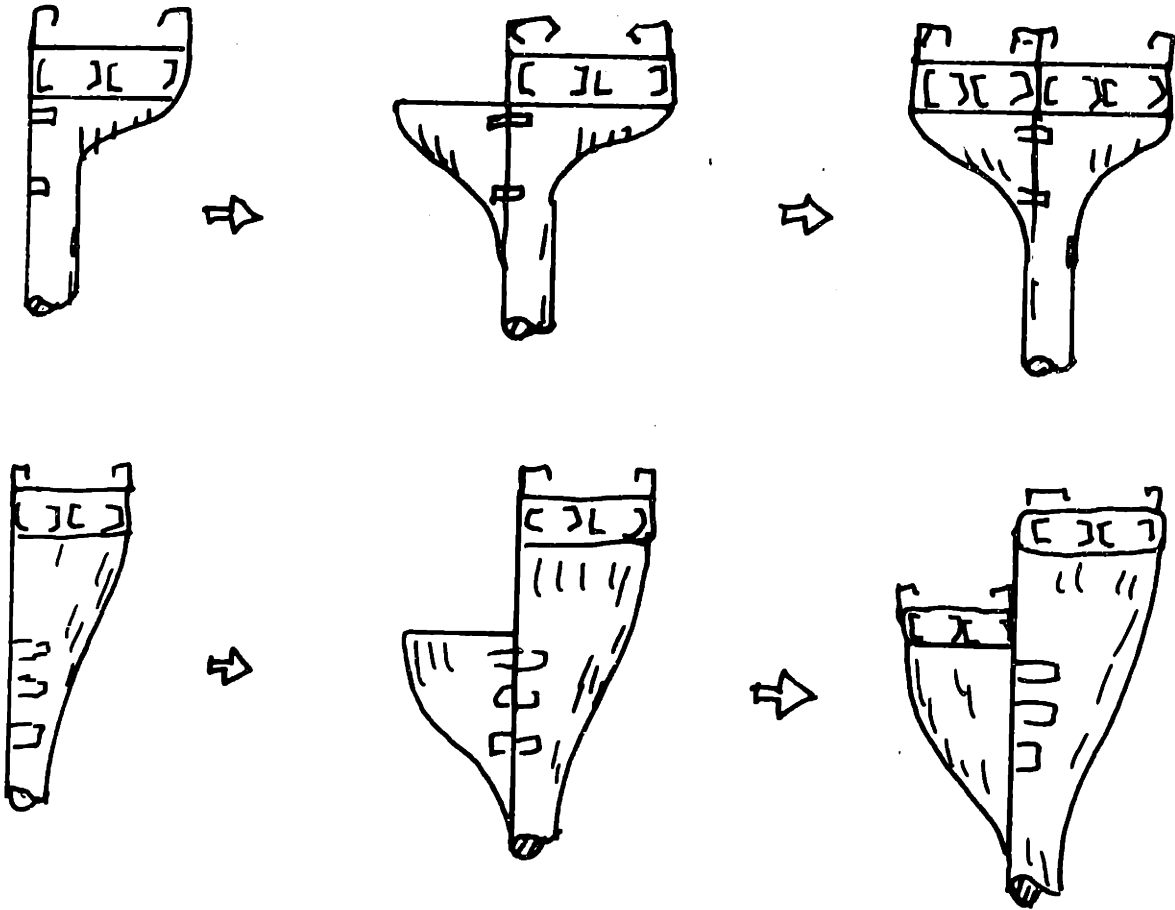


Fig. 6-24. Adaptability Design :
Future Guideway Additions

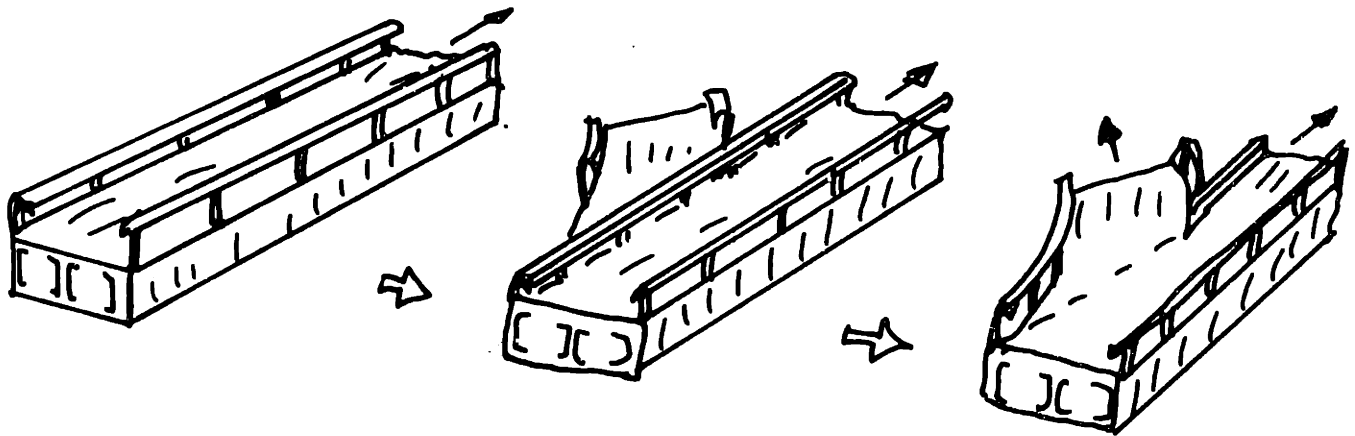


Fig. 6-26. Adaptability Design : Addition of a Switch

ferred or extended where it is conceivable that (at the time of original design) future changes might take place. The range of adaptability includes the addition of a station, switch, merge, spur tracks, ramps and parking facilities, and this flexibility could be shown at the demonstration stage by constructing the prototype guideway feasibility loop so as to be composed of movable segments which -- after preliminary tests and check-out -- could then be moved to the demonstration site by actual system users. Not only would demountability and segment replacement be tested by this strategy, but it is now feasible to request funding for two stages of demonstration at once, using many of the same components for each.

For any modification or demountable change to the guideway, the local streets and environment must not be seriously disrupted or inconvenienced. Most construction operations and companies take an attitude of the-traffic-be-damned while their work is going on. The use of prefab parts and roadway segments which are readily prepared for assembly and avoid lengthy detours and chopped up dirt roads, with consequent dust and delays, is a critical element of system service which is too often overlooked in the present highway construction business and there should be no reason to accept present attitudes by builders that local communities should undergo excruciating suffering by dust, noise or disruption and not complain because "this will only last a year or two."

Some of the new techniques to permit rapid construction compatible with existing community activities and traffic include the extensive use of cranes for construction and the utilization of dirigibles to build and move structural elements. The Soviets have developed an airship capable of lifting five-ton loads of construction materials to various heights, and a second version with 20-ton capability is planned to carry steel beams up to 600 ft. long, with the ultimate goal for the airship concept being 100-ton capability.⁴ At the construction site, the dirigible could be tethered and thereafter would operate as a crane. Winds might prove a problem, but the airship could operate in snow, rain and mud conditions far more successfully than present land-based equipment. The amount of ground level disruption would be minimized.

The design of an emergency vehicle may be heavily dependent on the form and cross-section of the guideway, if a straddling of underslung rescue vehicle design is used. Alternatively, the design of the emergency vehicle can be kept as independent as possible of guideway details, and these issues will be discussed in more depth in Chapter 7 on emergency vehicle design.

GUIDEWAY COSTS

Preliminary cost estimates for guideway construction have been calculated by Clarkeson⁵, assuming a partly elevated, partly at-grade structure installed as a prototype. The at-grade guideway will be slightly elevated in the sense that it is supported 10 to 15 inches above the ground, in order to reduce the effects of moisture and frost -- and thus the costs of maintenance. With this type of design it is easy to conceive of removable and replaceable sections.

Guideway loading is an order of magnitude less than that of transit. For BART, a 100,000 loaded car is 70 ft. long, or a loading of 1400 lbs./ft.; one automated vehicle per guideway slot is 5000 lbs. per 30 ft. or 167 lbs./ft. The guideway loadings are equivalent to H 10 A.A.S.H.O. standards, and the construction costs for a two-way guideway -- not including R.O.W., engineering surveys and supervision, and system controls -- is \$3,250,000 per mile. One-way guideway links would have construction costs in the vicinity of \$2,000,000 per mile. Good soil conditions and factory production of guideway components could result in substantial savings in construction costs (Fig. 6-26).

These costs are for construction only, and thus are ill-suited for direct comparison to comparable highways. Complete costing should reflect the land savings, reduced displacement and disruption of communities and results of better traffic

management and control, especially in congestion and parking.

Interchanges on the guideway are more compact than their expressway counterparts, because low radius curves and merging controls avoid the wasteful weaving phenomenon of multilane interchanges. Switch separation is determined by reliable dynamic response of the guidance arms, rather than driver ability to read and distinguish road signs. The fact that guideway interchanges are by nature many-directional hubs makes them ideal candidates for the location of automated parking garages, particularly if the interchange ramps enclose certain areas of land which ordinarily would be isolated or underutilized. Fortunately, for an automated garage, pedestrian access is not crucial.

Clarkeson has also estimated the comparative size of guideway interchanges : for a straight T, a highway (with 600 ft minimum radii) requires 55 acres of land; a guideway with 250 ft. minimum radii, approximately 10 acres. For a four-direction interchange, the eight-lane highway with the same curve limitations produces a 75-acre interchange; the guideway only about 13 acres. The highway configuration is limited by variable speeds of vehicles, variability among drivers and visibility/decision constraints, and the empirical standards are strictly enforced by Interstate Highway standards. The cost of such large areas in urban regions is staggering and is a severe limitation to location and expansion of highways.

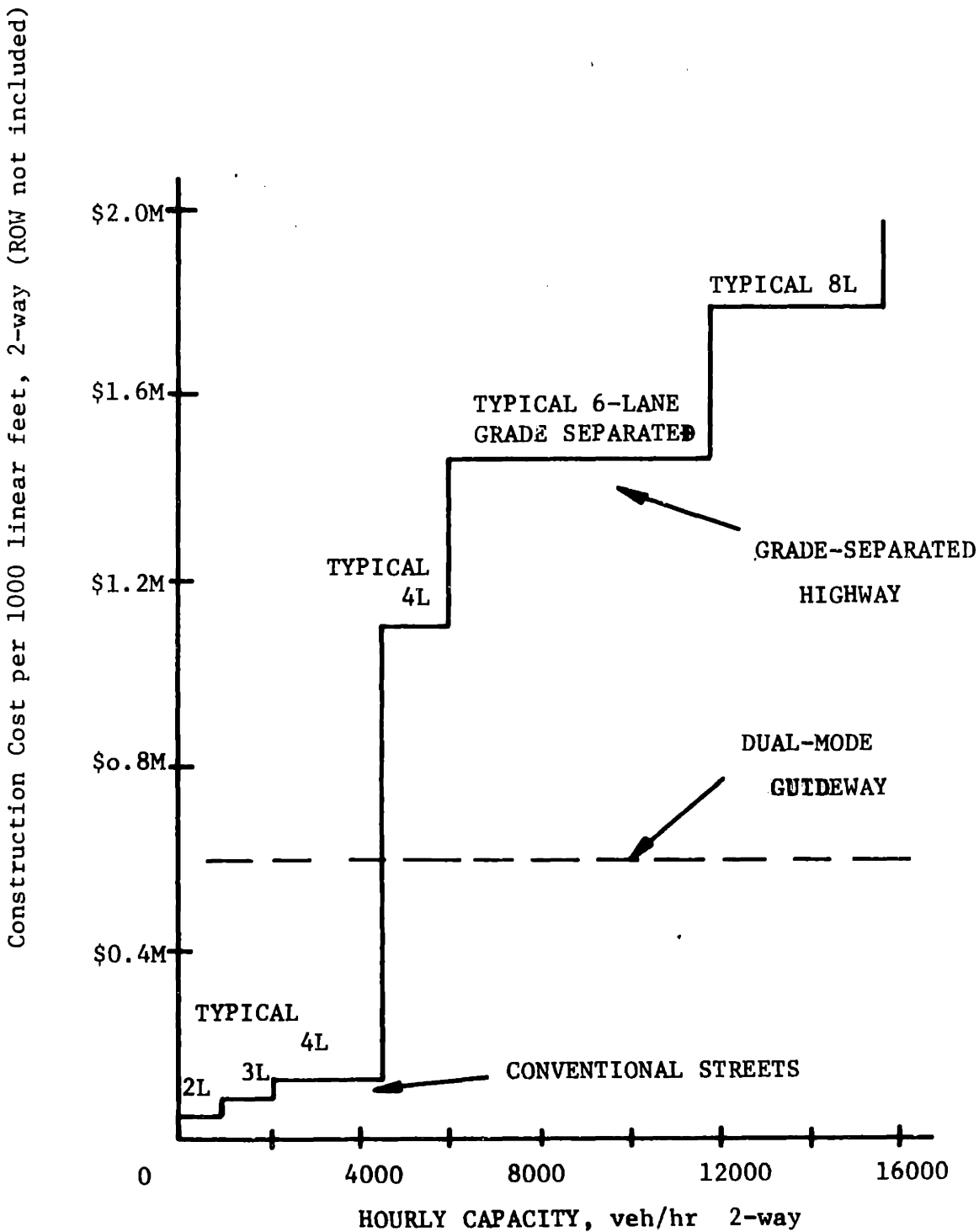


Fig. 6-26. Highway Costs vs. Guideway Costs

(Construction only)

PARKING GARAGES

Primary among the "hidden costs" of highways is the expense the city pays for parking, from lost tax revenues and car-glutted streets to the aesthetic damage of a city dominated by vehicular storage facilities. Cities typically devote 10 to 20% of their downtown area just to parking, and the demands are many and varied :

- (a). Commuters working in the city and requiring half or whole day parking; they arrive first in the morning and have to be kept from occupying spaces intended for short-term parking. Surveys indicate that half of the metered spaces are used illegally.
- (b). Shoppers and visitors seeking short-term parking, with the percentage of all cars that are parked for less than one hour being about 50% for large cities (1 million+ population). Many of these shoppers cannot find legitimate open spaces, and often park illegally or double-park.
- (c). Service and delivery vehicles arrive in the city at all times of the day and usually park very crudely for short periods, reducing arterial capacity.
- (d). Residents' parking is limited and uncertain because of the illegal parking.

Presently, vehicle parking is provided by curbside areas, open lots or multi-level structures. New York City values its curb

parking at approx. \$1700 per space per year, or eight times the average rental cost of elevated garage space located downtown. Offsetting this cost, retail sales of about \$5000 to \$10,000 per year are generated by each parking space. The cost of parking is frequently subsidized by merchants and public authorities or is provided free by the community on the street. Rarely does the consumer pay for parking commensurate with the land value his vehicle occupies, unless his purchases in the city have a sales tax or an income tax which channels funds back to the city.

The automobile dependency and resistance to walking of the American public places a special pressure for parking in the CBD and not at outlying areas of low land value or use -- which are more expendable for parking. Often the best land in the city is consumed by manual parking facilities and localized parking saturation occurs, although there is a net parking surplus in the city because inconvenient lots are underutilized.

As a general rule, excluding political payoffs such as the incredible West End parking lot scandal in Boston, a flat open lot is most economical for land costs below \$200,000 an acre or about \$4.50/ft². However, such a lot is often open to the weather and vandals as well. A conventional ramp garage costs from \$2000 to \$4000 per space, while mechanical garages range from \$3000 to \$5000 per space. Underground facilities require \$4000 to \$6000 per space : the Boston Common uncerground garage has 1565 spaces

and was financed by a \$9.6 million 40-year bond issue on a 3-level, 13 acre site. This cost of \$6100 per space undoubtedly includes some padding as only Boston politics can provide, but inflation may well have made up the difference by now. A \$2.50 per day or \$50 per month rate is charged, which compares with daily rates of \$5, \$6 and \$8 in nearby garages. However, when the garage lets out its late afternoon commuter flow of vehicles, they often become tangled in local street traffic on Charles and Beacon Sts.

The automated parking garages of guideways should avoid many of these parking aggravations. Efficient packing of vehicles within mechanical garages on periferal or underutilized land reduces structures and land costs, while the guideway station serves to provide people access to the CBD and other areas -- a flow-through process rather than a downtown storage device. Cars are stored and recalled on demand, so pedestrian access to them is not required and the pressure for downtown parking is relieved.

A regular garage requires overall about 350 ft² per car, which a mechanical garage permits tighter packing at 300 ft² per car, a 15% saving. The new garage also need have only 5 ft. 3 in. of ceiling height, a saving of 50% over conventional structures. On a volume basis, the automated garage could provide a 65% saving in space, while being located on ~~less~~ expensive land.

Design details of the garage will depend on whether the cars

are self-powered, gravity powered or pallet supported after entering the garage. Self-powered cars require at least one guidance arm in contact with the power rail at all times, hence lateral translation of vehicles into parking slots becomes quite difficult. In recent decades, there have been numerous efforts to built automatic garages and some have enjoyed limited success. The basic methods of vehicle handling are

- (a). Hydraulically raised platforms
- (b). Mobile platforms on fork lift trucks
- (c). Simple lifts,feeding doors
- (d). Elevators combined with pallets (mechanical or manual movement)
- (e). Pallets with horizontal/vertical elevators
- (f). Continuous vertical belt system with platforms (Ferris Wheel)
- (g). Continuous vertical belt combined with pallets.

Within the garage, a three-dimensional filing process occurs, and the movements can be generated either by a conventional ramp and open floor area facility or by elevators and a rectangular grid pattern at each level (X,Y,Z coordinates) or by elevators in combination with a concentric ring model (r, θ, Z cylindrical coordinates). This latter cylinder concept has been adapted successfully by a Swiss firm and is being imported by Otis Elevator Company. Called the Rotopark system, one full-scale model is now operating in Monthey, Switzerland and a second one will be constructed soon in Zurich. Rotopark is basically a one-minute response automatic

parking garage located underground, usually in the basement of an office building. Up to 80% more parking capacity is provided, compared to normal ramp garages. The driver receives a computerized key-punched ticket on entrance and, upon return, turns in the card to have his fee calculated and collected, The car is automatically called and delivered in under 45 secs.

Because the automated garage does not need or allow pedestrian access to the building, better protection can be offered against vandals, thieves and muggers who often frequent parking facilities. There is no ventilation or suffocation problem. If the parking garage location does increase in land value or usage in the future, it is quite feasible to construct offices around the periphery with a high window space to floor area ratio.

GUIDEWAY LAND USE DEVELOPMENT

A design concept prominently in vogue in some highway planning circles is that of Joint Development of highway corridors, the redevelopment of structures and land uses along the right-of-way to make the whole package more compatible with itself. Unfortunately, Joint Development often tends to lead to a form of linear city concept, a glamorized ribbon development that is still incompatible with existing community uses and activities. The scar through the old city too often is simply widened, and Joint Development concepts are effectively just cosmetics seeking

to disguise the scar. The goal of guideway design and location must be to not create the scar in the first place, to use railroad ROW and industrial land where possible and to integrate the structure with pedestrian walkways, crossovers and open space. In most cases, the guideway should maintain a degree of independence, to reduce the effect of transportation on land use, to supplement and reinforce on-going community land uses rather than trying to revolutionize them by the imposition of outsider's values. Ideally, it should be possible to locate a guideway and have no net effect on adjacent land values, either up or down. Guideways should blend into the environment as much as possible, with the only aspect resembling a landmark being a well-designed community station or associated apartment/office complex. There should be no ribbon development or Chinese Wall monument building to architects and engineers' egos.

One can go further and ask whether we should necessarily view the guideway as an intrusion, an instinsically unaesthetic evil. Why not try to conceive of a guideway as an element adding or reinforcing the character, dignity or grace of a community, to enhance the essence of the city and its communities, rather than transforming or destroying its original character. Guideways do not have to make old neighborhoods "the victims of progress," but bad design can make it so. Appropriate precautions and attention to community impacts offer a chance to do otherwise,

to perform a positive function for the community and its expressed needs. What this function is becomes difficult to define and depends upon community participation in defining it -- hence the need for major community roles in planning discussed in Chapter 10.

A different kind of "joint development" or multiple uses of highway corridors can be applied to the guideway as a conduit for numerous service functions, such as power and gas lines, telephone cables, sewers, adjacent street lights and also bicycle and pedestrian paths. As with the BART "linear parks" created by open space under the single-post elevated structures and the separated girders which let sunlight through, a guideway insulated by noise, dirt and slush from the community below can create useful open space below which is neither dirty nor gloomy, and thus provides essential pedestrian crossing vital to breaking down any Chinese Wall effect. Special guideway parks could be created, with miniature cast concrete guideways and coaster cars for tots, so that kids can relate positively to the guideway and not resort to vandalism which strikes Chinese Wall highways and railroads in urban areas.

Guideways located in existing railroad ROW could have air rights stations, with bridges and walkways to both sides of a split community and serving both of them. (In some cases of strong community animosities or where floods of transients and students might result, the old divisions should be maintained). Combination stations and crossovers could be built in an H-pattern

with parallel sidings for stopping vehicles and then a combination of shops and stores on either side of the bridge (Fig. 6-27). Larger complexes could include gymnasiums and community centers. This concept of a "living bridge" goes back centuries, with one of the earliest structures utilizing air rights over a river, the Ponte Vecchio Bridge built in Roman times over the Amo River in Florence, Italy. Since its reconstruction in 1345, it has been lined with goldsmith, jewelry and other shops. The old London Bridge was probably the first English Bridge to carry dwelling houses and even some small gardens and churches. The use of air rights stores on bridges over guideways have the additional advantage of reducing vandalism from thrown objects by persons on a conventional bridge.

An elevated guideway in denser environs could be carried just over buildings, rather than over streets or open space, as in Fig. 6-28. Buildings located under the guideway include stores, public meeting places, offices, guideway stations and parking facilities and the concept has been developed quite successfully in Tokyo, where elevated expressway and underneath shops have been integrated in one design. When an express guideway travels elevated over railroad, industrial or dump lands below and bridges isolated communities, particularly in more suburban locales, the guideway bridge structure could incorporate axial shops under the guideway and pedestrian walkways on either side. By running shuttle buses on the guideway, a form of

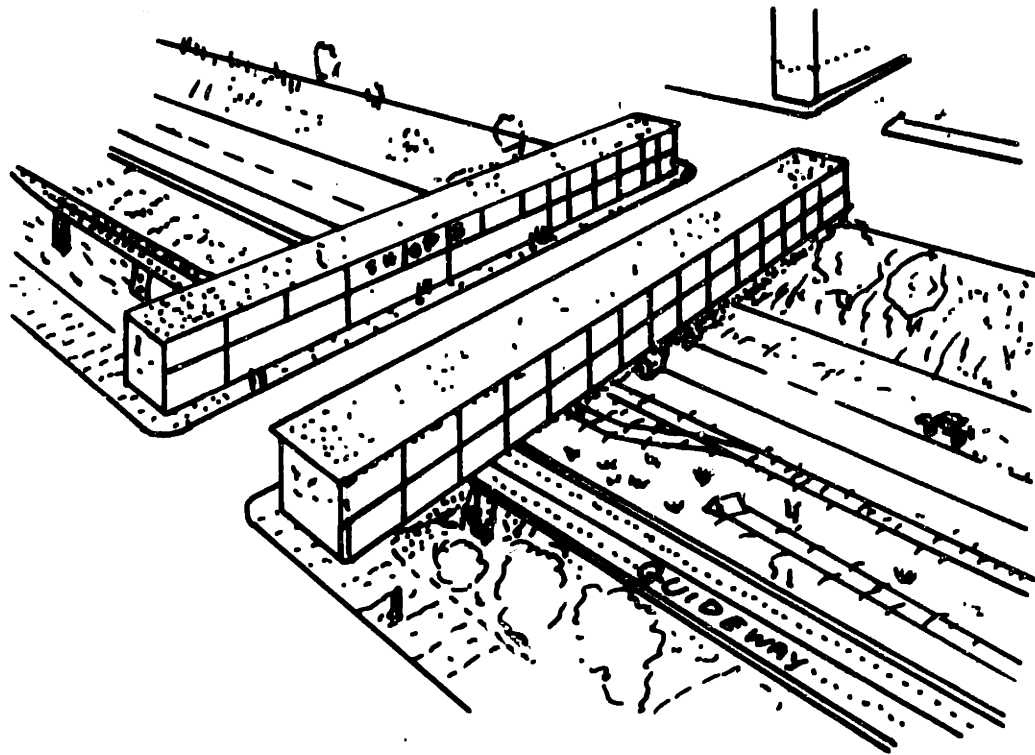


Figure 6-27. Spur Track Station, Shops and Bridge Crossing

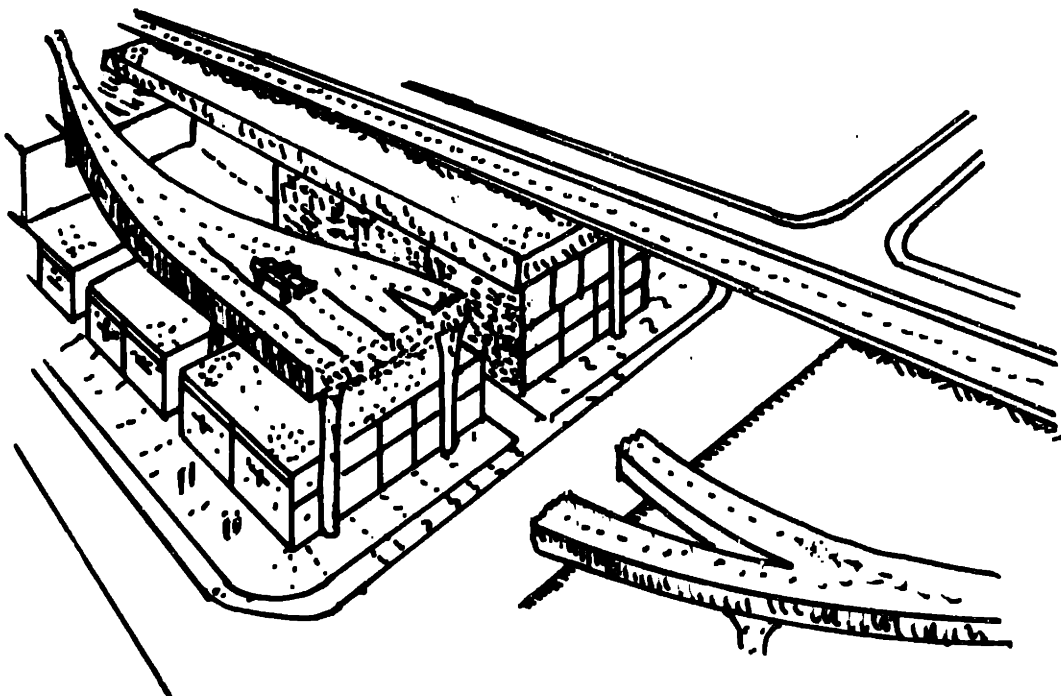


Fig. 6.28. Guideway Elevated Over Stores (Section through Rooftop Station)

linear shopping center could be created, composed both of large and small stores (Fig. 6-29). Elsewhere, guideways -- because of their lightweight structure, small cross-section, light active loading and geometrical flexibility, could be routed through existing or planned buildings. In Chicago, an eight-lane expressway goes through the post office building between the third and fourth floor levels, but the impact of such a major structure is considerable.

GENERAL POLICY ON GUIDEWAY AESTHETICS

The foregoing discussion on the values of good aesthetic design have elements of both reasonableness and motherhood about them. The danger to exemplary design is not a vicious squad of bureaucrats explicitly intent on erecting ugly or damaging structures -- rather the danger is in apathy and expedience, of cost consciousness and a frustration over the complexities and non-quantifiable aspects of aesthetic design, which often become lost in the push and pull of planning and implementation controversy. The same goals for aesthetic highways have been stated over the years, and many pioneering efforts were made, but the last few decades have seen a tragic retrogression in many aspects of highway design. Recall that a 1944 report of the National Interregional Highway Committee appointed by President Roosevelt emphasized an idealistic concept of America's

Fig. 6-29. Elevated Guideway at Rooftop Level, crossing Streets & Railroad Tracks

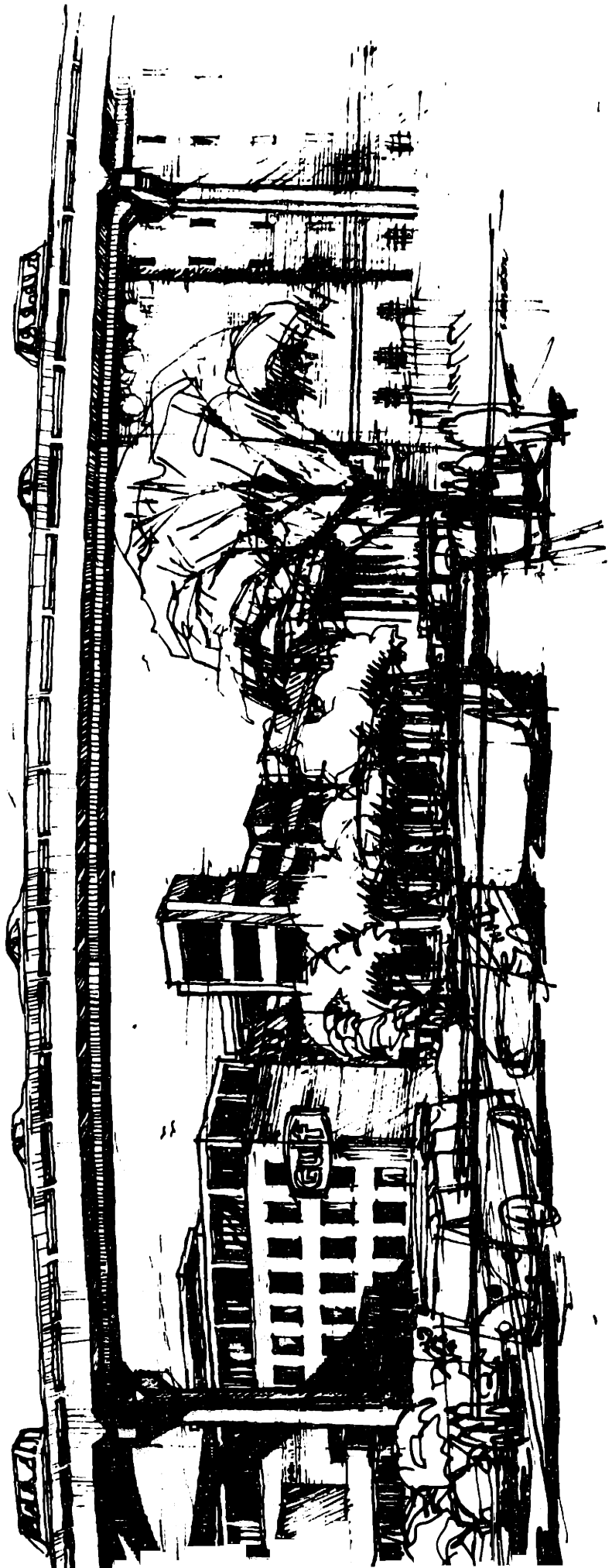
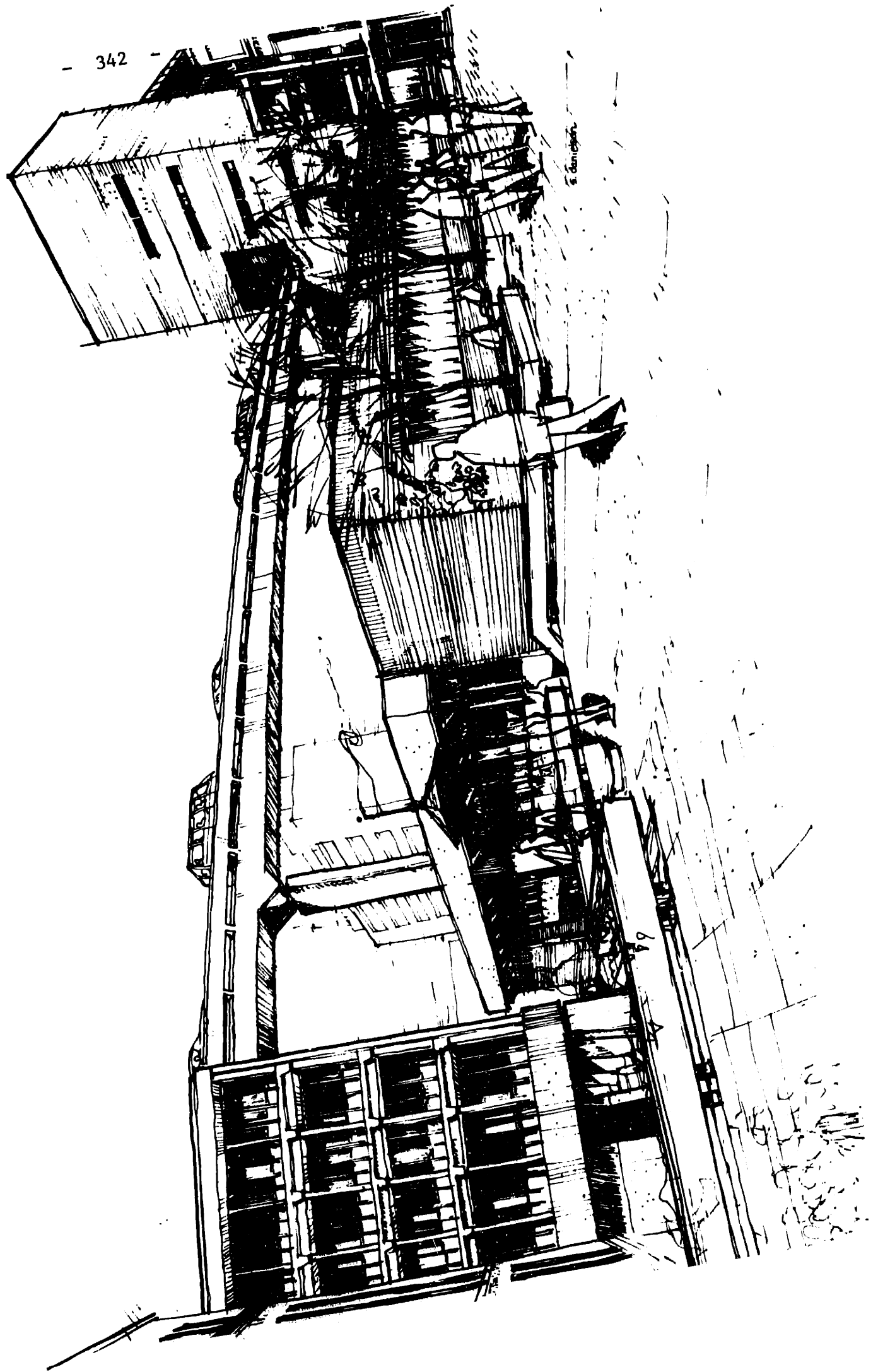


Fig. 6-30. Elevated Guideway Traveling Through a Building

Fig. 6-30.



future highways⁶:

Highway design, in the broadest sense, rests upon landscape principles, as well as upon the more commonly recognized engineering principles of alignment, profile, grade crossing section, roadway and right-of-way width, drainage, and structural strength and durability. A balanced agreement with the two sets of principles characterizes the best design.... All of these things may be done in complete consistency with the utilitarian functions of the expressway. And, so treated, these new arterial ways may be made -- not the unsightly and obstructive gashes feared by some -- but rather elongated parks bringing to the inner city a welcome addition of beauty, grace, and green open space.

A glimpse of the Central Artery or Southeast Expressway in Boston are sufficient to bring home the grim message of how far the above hope is from reality.

The aesthetic goal for guideways cannot be left in a stage of glowing ideals, while unimaginative or insensitive engineers and architects begin setting design specs on structures. The goals must be set, translated into explicit policy and enforced up and down the line, since aesthetics is often the first casualty of an transportation system. If this means a get-tough policy of subjugating the planning role of structures engineers and fanatic architects and city planners with a messianic view of transforming the city to their ideal, then so be it. It is absolutely vital that guideways avoid any hint of the monument complex that pervades so much structural planning, and instead guideway design should consciously seek to be very low-key in concept, form, execution and impact. Its image and

appearance must be as well controlled as its traffic flow, and the focus of this control is always directed towards service with the best community impacts.

In this vein, the view from the community of the guideway should take precedence over the view from the road, although both are important. Today, roads are too often dull, listless affairs, suffering from crude billboards and landscaping; the view to the left is lost in median strip and opposite travel lanes and guardrails. Ideally, guideways should give passengers a good view of the city, without making the guideway too visible to residents, whereas today highways are so disorienting and blatantly visible to the community that the inverse is true.

Along railroad ROW, the aesthetics of the guideway will not be critical, but this does not reduce the possibilities for good design and improvement. Cross sections of the columns can be circular, triangular or hexagonal, since BART's use of hexagonal beams rather than square supports has created a much more pleasing effect. The guideway pillars and footings can be straight or form various terminal shapes, including a formed concrete sitting space.

Thin profile bridges are preferable to truss structures, and the arch design of bridges and spans should be given close attention in the design stages. Concrete or steel arches, cantilever or suspension spans, as well as simple steel beams

can be mounted on masonry or chisel-face concrete piers, with smooth curves and archways predominating over more traditional straight-line, rectangular construction. The sharp curves of the guideway could be located on masonry-sided embankments, to give lateral texture and form and a "winding country bridge" effect similar to that achieved by the Richardson Bridge in the Fenway -- to avoid the spaghetti ramp effect of modern expressways and replace it with parapets and varying curves.

Utmost care should be taken in the design of elevated guideway sections to avoid the tragic mistakes of past such structures. It has been said that, relative to the Sixth Avenue Elevated railroad, the city's two happiest days occurred the day they put it up and the day they took it down. In Boston, the Atlantic Avenue elevated line was taken down in 1942, yet the elevated Central Artery was built in 1954. Lewis Mumford noted⁷ in 1958 that

The destruction of the old elevated railroads in New York was, ironically, hailed as a triumph of progress precisely at the time that a new series of elevated highways was being built, to repeat on a more colossal scale the same errors.

Guideway designers must identify these errors and avoid them; however, the public will still be justifiably cynical about any use of an elevated facility, with complaints about the ugliness, dirtiness, dreariness, darkness and noise commonly associated with elevated railroads and highways. However, the *capabilities* for

good aesthetic ramp design are at hand (Fig. 6-31) and we are no more restricted to duplicating the ugliness of the antiquated "El" than today's cars are limited in their styling by the bulbous creations of the 1940s.

Sections of the guideway must be under flexible aesthetic standards to adapt to local needs, so that the rigid pattern of Interstate Standard sameness is not repeated to the detriment of the environment. Guideways can be designed to harmonize specifically with the immediate locale, with anodized aluminum sheet inserts attached to the flanks of the guideway to give texture and color that matches nearby buildings and land uses -- and be changed to suit community desires. Relocation of regular electric and telephone cables from adjacent streets would reduce a recognized eyesore. Guideway columns and spans could be adorned with plantings such as shrubs and ivy, at the risk of increased upkeep, of course. As bad as it sounds, plastic imitation plantings might have a salutary visual effect. The initial low-pollution qualities of the guideway make it more meaningful to consider healthy plantings in the corridor, with the best deciduous shrubs for hardiness and general pollution resistance being Forsythia, Privet and Spirea. Japanese Yew and Juniper are the best evergreens, and the most suitable trees include Norway Maple, Sycamore Maple and Pin Oak.

A well designed guideway, in coordination with planned concepts for local street traffic control, can aid in bypassing



through traffic and reducing traffic on local streets. By providing good pedestrian and local street cross movements, the guideway can actually reduce the Chinese Wall effect in the area, including that caused by existing jet streams of traffic on local streets. The ground level can become less congested and hazardous for pedestrians and bicyclists and would open up community movements for shoppers, children and elderly which long have been suppressed by the presence of autos dominating local streets.

Automation of the guideway offers an unexpected aesthetic advantage -- the removal of all road signs except informational ones, declaring that "You Are Entering Cambridge..." etc. This removal of roadside clutter will improve guideway appearance from the community and provide a better view from the road. However, strict regulations will have to be enforced against the excessive use of billboards, such as a prohibition of any billboard within 500-ft. aimed specifically at the guideway. Despite the best aesthetic goals of the guideway planners, the general rule that applies is that if a buck can be made, a good idea will often be corrupted -- and guideways could become a linear litter basket of billboards. Although the Highway Beautification Act of 1965 has long been passed, not one sign has come down. Of the \$42 million authorized for the program, less than \$3 million has been appropriated, and only \$1.9 million expended, mostly for a survey to count the billboards. The strength of the Billboard

Lobby is clearly in evidence here.

To guard against the tendency to ignore or subvert the intent of aesthetic concerns, guideway design must have an explicit checklist of environmental factors which planners must consult literally at every turn -- and straightaway. Nor is there any confining need to consider environmental needs as a restraint or negative effect on guideway design. The innovative spirit of the guideway must be combined with innovative means of developing and preserving the environment, sometimes in a very assertive way, rather than defensively, in the same way that New York's Central Park and Boston's Fenway sections were remarkable innovations in their day. Elements in the environmental checklist include :

- (a). Safety
 - 1. Full separation of pedestrians & vehicles
 - 2. No intrusion of through traffic or traffic of unsuitable character.
 - 3. No major conflict points; no excessive speeds
- (b). Comfort
 - 1. No undue proximity of pedestrian areas or buildings to medium-heavy vehicle flows
 - 2. Same concern applied to grouped car parks & structures, incl. overpasses.
 - 3. No overpowering scale effect of structures
- (c). Convenience
 - 1. No severance of distributional traffic routes
 - 2. Adequacy of pedestrian access system
 - 3. Adequacy of pedestrian access to public transit
- (d). Appearance
 - * No dominance by moving or parked vehicles, structures or other fixed facilities.

SUMMARY

The components of normal, axial and lateral forces, as well as rotational accelerations must be understood in order to ensure a comfortable, acceptable ride for guideway passengers. Empirical limits can be placed on these forces and a weighted-sum comfort factor can be calculated and evaluated, given various guideway geometries.

If the bank angle relations are known, the heading angle and lateral displacement at any time can be calculated and a discomfort value associated with the maneuver. Concepts of zero-divergent, constant-divergent, and increasing-divergence switches are useful in describing methods of mapping guideway segments between various locations. The average and maximum values of the radius of curvature result in further aids to mapping. Summary charts simplify the design process considerably.

Various elevations and ramp orientations are possible for guideway travel. The guideway must be designed so that a minimum of dirt, noise and rain/snow runoff impacts the immediate environment. The overall structure should not be imposing or monumental. Construction costs are estimated to range from \$2 to \$3.5 million a mile, although prefabricated construction would help to reduce these costs appreciably.

CHAPTER 7 MANUAL/AUTOMATED CONTROL TRANSFER AND EMERGENCY OPERATIONS

A transfer of control from manual to automatic occurs at entrances, while the reverse takes place at exits. Entrance configurations depend upon locale, building density, access and entrance capacity, and the necessary functions can be specified as :

- (a). Provide adequate access from conventional roads and streets covering a number of directions and a wide area;
- (b). Avoid excessive congestion and queuing of traffic on approach roads;
- (c). Facile alignment procedures & minimal training for manual drivers;
- (d). Reliable changeover to automatic guidance and speed control;
- (e). Pre-entrance inspection of vehicle guidance, power and speed control equipment;
- (f). Vehicle identification and processing of destination request;
- (g). Acceleration lane and merge with stream guideway flow;
- (h). Permit convenience rejection of vehicles which fail inspection.

Access is provided by special approach roads or ramps, by use of existing parking lots, or by suitable orientation to existing arterial streets. Queuing takes place on these access links or in the parking lots, and the remaining sequence of entrance operations continues as in Fig. 7-1.

The instructions to entering drivers must be quite simple

and concise :

- * *Drive to entrance booth and enter on green light.*
- * *Relax all control when "automatic control" light comes on.*
- * *insert credit card and select destination.*

At one section of the entrance, an information booth will be available to dispense maps of guideway routes and exit numbers to new users and visitors.

Entering vehicles pass over two loop cables buried in the roadway, with loop A identifying any vehicle which is unmodified. Entrance loop B identifies the vehicle by its underchassis number and signals the guidance arms to swing out from the body and assume a horizontal position. At this point the auto is still under manual guidance and speed control. (Fig. 7-2).

The vehicle with its extended arms is now driven into a guideway channel or curbing funnel which positions the car laterally so that the arms can properly grip the guiderail. Drivers are expected to position their vehicles within certain limits (± 1 foot laterally), so that either a gently sloped trough, a single wheel guidance groove, or by pressure loaded movable curbs (Fig. 7-3). Excessive entrance speed is reduced by a swing-up bumper damper (Fig. 7-4) or similar device which slows vehicles down and then quickly retracts.

When the arms have been properly channeled into the lateral guiderails, the manual-to-automatic changeover can occur abruptly or by a sequenced transfer of control, beginning with guidance and

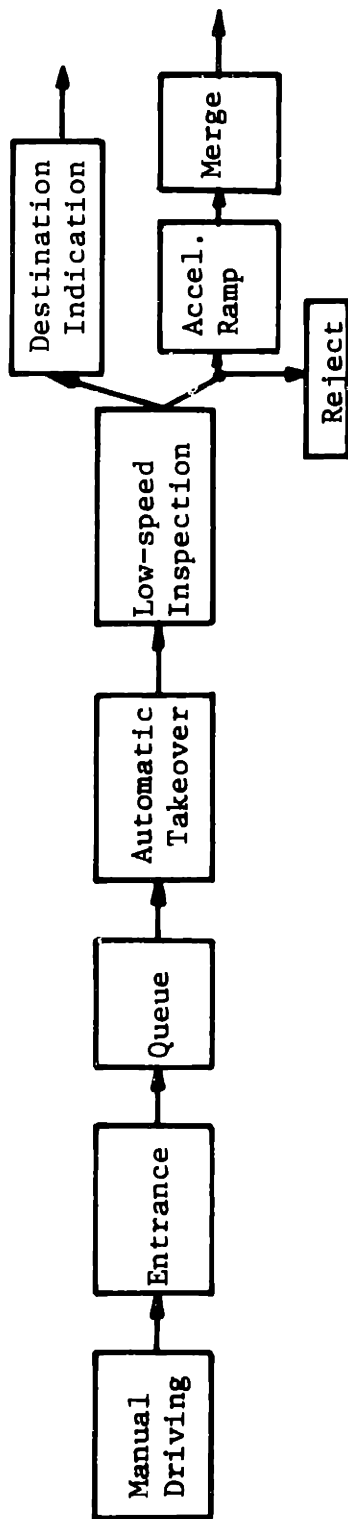


Fig. 7-1. Sequence of Operations at Guideway Entrance

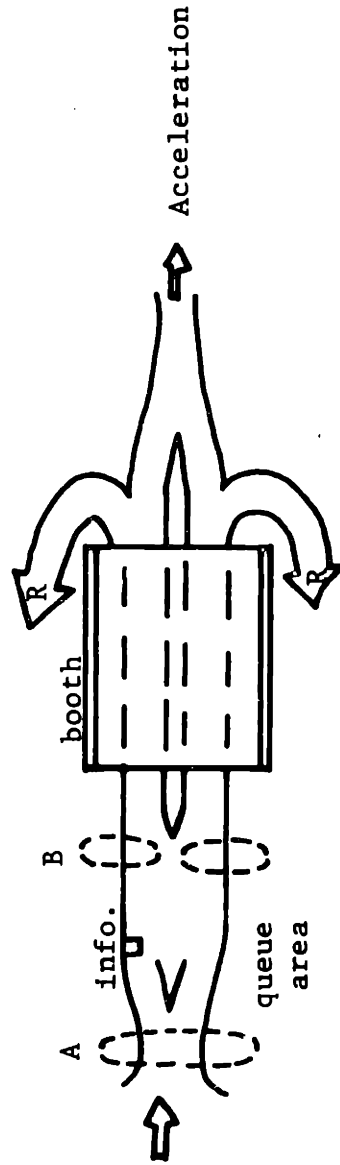
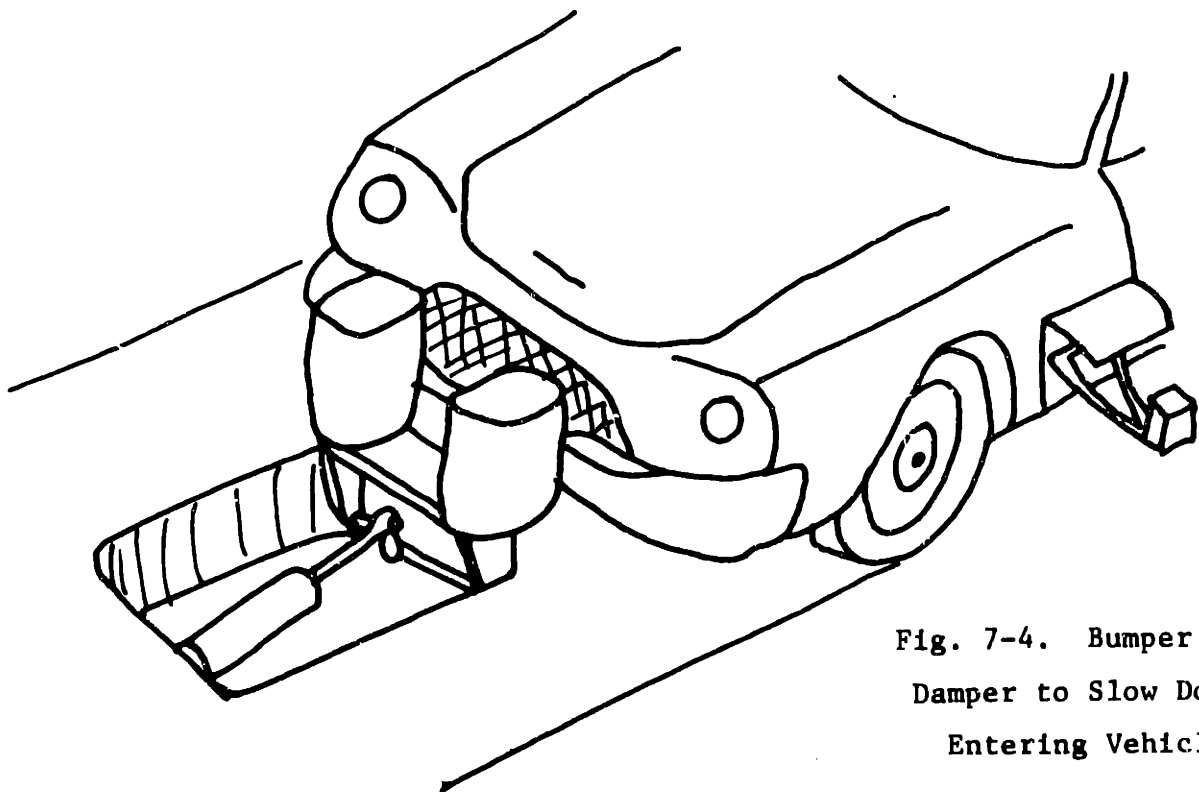
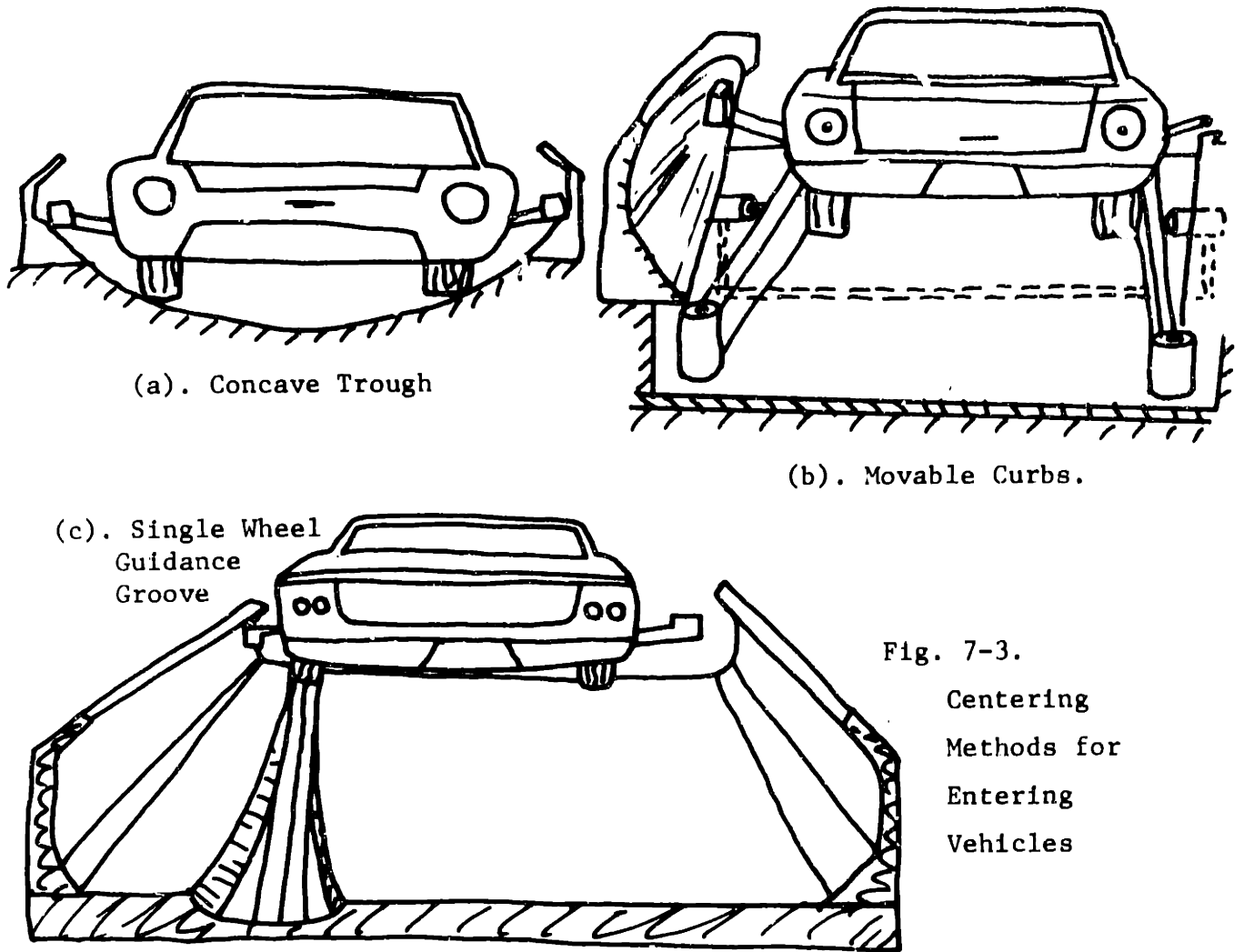


Fig. 7-2. Physical Schematic of Entrance Booth



rapidly including speed and braking control when the follower firmly grips the rail. For early demonstration systems, there are 6+7 options for power transfer, depending upon the vehicle transmission and whether pure-electric or combined power is used:

1. Driver shifts manual transmission to neutral; pure electric drive.
2. Driver shifts automatic transmission to neutral; pure electric.
3. Manual transmission shifted automatically to neutral; electric.
4. Automatic transmission shifted internally to neutral; electric.
5. Driver shifts manual trans, to 3rd (or 4th) gear, clutch automatically pulled in; combined electric and ICE power.
6. Manual transmission shifted automatically to 3rd or 4th gear; clutch automatically pulled in; combined electric and ICE.
7. Automatic transmission remains in Drive; combined electric/ICE.

Because of physical detentes in the transmission selector linkage systems, automatic shifting of manual transmissions is quite difficult, so that part of the entrance preparations as the car undergoes entrance inspection is that the driver set the transmission selector in its proper place, depending upon his own vehicle type. The four remaining types of control transfer (Table 7-1) should be tried and checked out in the demonstration system to determine the best overall performance package.

The timing and process of control takeover is also a function of how "firm" is the automatic control in terms of manual control overrides. For reasons of guidance and speed control, the system should remain firm to any manual inputs

TABLE 7-1 SEQUENCE OF AUTOMATIC CONTROL TAKEOVER

* ELECTRIC POWER MANUAL	* COMBINED POWER TRANSMISSION	* ELECTRIC POWER AUTOMATIC	* COMBINED POWER TRANSMISSION
* Steering ↓	* Steering ↓	* Steering ↓	* Steering ↓
* Brakes/clutch accelerator ↓	* Brakes/clutch/ accelerator ↓	* Brakes/ accelerator ↓	* Brakes/ accelerator ↓
* Transmission hand shifted to neutral; ↓	* Transmission hand shifted to 3rd or 4th gear ↓	* Transmission set to Neutral (hand or automatic shift) ↓	* Transmission set to Drive (hand or automatic shift) ↓
* Signal light : automatic control takeover ↓	* Signal light : automatic control takeover ↓	* Signal light. ↓	* Signal light ↓
* Static test and checkout ↓	* Static test and checkout : both engines ↓	* Static test and checkout ↓	* Static test and checkout ↓
* Reject OR	* Reject OR	* Reject OR	* Reject OR
* Acceptance ↓	* Acceptance ↓	* Acceptance ↓	* Acceptance ↓
* ICE engine turned off ↓	* Accelerate to 20, clutch releases ICE set at constant throttle ↓	* ICE engine turned off ↓	* ICE set to constant throttle ↓
* Accelerate to 60 mph ↓	* Accelerate to 60 mph ↓	* Accelerate to 60 mph ↓	* Accelerate to 60 mph ↓

ENTER STREAM FLOW

except warning signals to the system or request to take the immediate next exit. All extraneous inputs to the steering wheel, accelerator, clutch and brake must be blocked by clamps or non-compliant control.

Within the entrance booth, the vehicles undergo a static or low-speed inspection of wheels, brakes, tires and switching action of the arms, possibly including a simulated speed control test run. Either a direct dynamic check could be run on vehicle power or internal vehicle monitors could be queried on systems status. All vehicle transmitters and receivers would be checked out.

If the vehicle fails to pass inspection, a "Reject" signal is flashed and it is driven off manually or automatically on a low-speed reject lane. Quick diagnosis and repair is possible or the vehicle can travel manually to the desired destination.

If the vehicle passes inspection, acceleration to cruise follows, and either the gas engine is shut off (pure electric) or the combined power plants together provide power and speed regulation. If the vehicle is unable to reach cruising speed quickly enough, it must be treated as defective and handled according to one of the following methods :

- (a). Divert the vehicle to an intermediate breakdown lane (Fig. 7-5a)
- (b). Divert vehicle down an emergency reject ramp before it reaches the main stream and return it to manual streets (Fig. 7-5b).

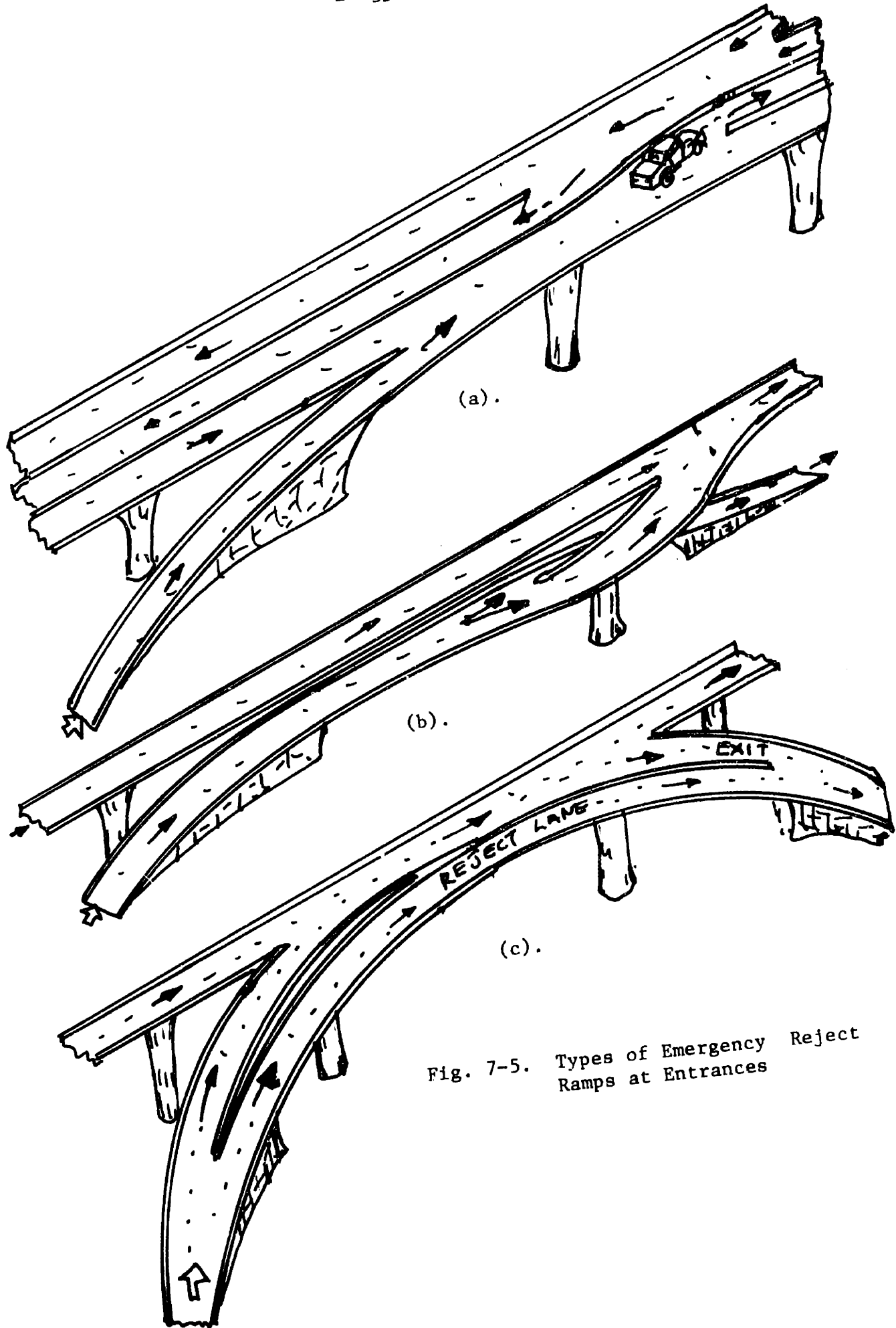


Fig. 7-5. Types of Emergency Reject Ramps at Entrances

- (c). Divert the vehicle to an emergency reject ramp connected to an immediately downstream exit ramp (Fig. 7-5c).
- (d). Signal the oncoming stream of mainline vehicles to reduce speed or seek detour to permit the straggler to reach cruising speed over a longer distance or proceed at low speed to the next exit.

Option (a) is preferable because it offers multiple use of the existing breakdown lane and for minor problems can be combined with option (d). Unfortunately, the vehicle is stranded and must either be checked out and restarted or recovered by an emergency tow truck and pulled to the next exit or destination. The combined electric/ICE drive arrangement permits greater redundancy and reliability, at least to reach the next exit under fall-back control. Statistically, if one car in 1,000,000 encounters acceleration failure, an entrance carrying between 1000 to 10,000 ADT would have 3 to 30 ejections every 10 years, which should be tolerable if not optimum.

Once the vehicle is satisfactorily on the main guideway, performance checks could be run where merges are far between -- involving canceling slot-shifts forward and backward, as traffic density permits. Vehicles accelerate to move up a slot and then brake or coast to slip back one, and deficient performance would result in special routing or scheduling through critical merges. Whenever it becomes necessary to switch a defective vehicle off the guideway, a full diagnosis should be given of the ailment and the driver given the option of driving on manually or leaving his

vehicle to pick up a guideway bus or car pool schedule at the entrance.

Exits are not simply entrances operated in reverse. As each vehicle switches off the main line onto the exit ramp, preparations must be made to alert the driver and prepare him to resume manual control. During braking, a recorded message could be carried through the console, giving the exit name, location and direction -- and possibly local street traffic conditions. Several checks can be made to determine driver alertness and preparation : the engine must be running, and he must put the transmission into Drive or first gear, and then punch a button signaling that he is ready to drive off.

When the cars have been slowed to 3 to 5 mph, the left rail discontinues, and they proceed under one-arm automatic control (Fig. 7-6) . Final relinquishment of automatic control occurs when the driver touches the brake lightly (and depresses the clutch pedal) and begins to steer to the left, with the right arm cutting electric power and releasing its grip on the rail. As the car moves out into the left access lane (Fig. 7-7) and begins its approach to the street, the guidance arms raise into the fender recesses and the protective doors close over them.

If the engines will not restart or drivers are unable to resume manual control within a certain time, the cars continue to track the right-hand guiderail until they reach a storage

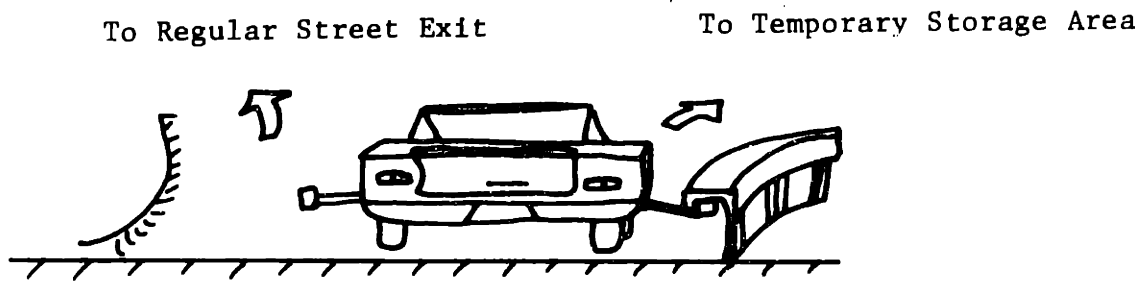


Fig. 7-6. Method of Assuming Manual Control at Exits.

(Steer manually to the left for exit;
Otherwise vehicle continues to track
to the Right)

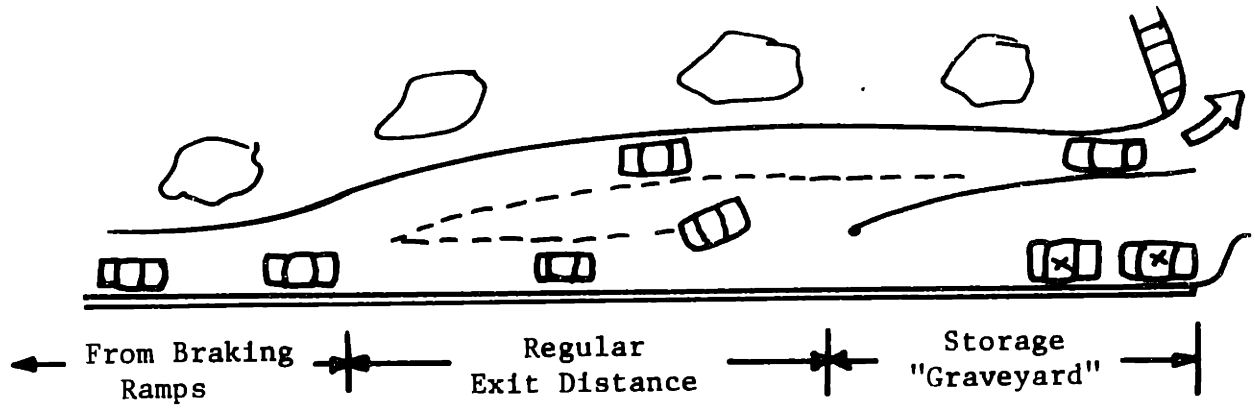


Fig. 7-7. Physical Schematic of Exit Area.

"graveyard", a queuing area which brings vehicles to a complete halt and drops the guidance arm. Drivers who badly failed the preparation test would be given attendant service or checked for inebriation. Other drivers would find themselves in an identical situation to curbside parking, and simply start their cars and steer out to the left onto the street. If 10% of all exiting drivers are unprepared to take over control immediately and took from 1 to 5 minutes to get restarted, a queuing area of 3 to 6 slots for a 10,000 ADT exit would be sufficient.

VEHICLE IDENTIFICATION AND DESTINATION INDICATION

Vehicle identification and destination indication are accomplished during low-speed inspection, and the driver has the option of dialing a limited change of destination during guideway travel, although some slowdown or waiting might be required. Each vehicle will have its own control console for ID, destination indication and voice communications. The driver slides his ID card into the vehicle console slot and is not required to reach outside the vehicle to give or receive a card. Console location could either be in the transmission hump of four-passenger vehicles or be attached to the left of the steering column. Adherence to good safety design and standards is critical, with proper padding and protection of knees. Good console design and displays include :

INFORMATION TRANSMITTED BY
THE PASSENGER

- * Destination (number or name)
- * Driver ID number (card)
- * Emergency exit next stop
- * Driver ready : manual control
- * Vehicle transmission properly shifted
- * Accident or emergency information
- * Send vehicle to Station or exit X.

INFORMATION TRANSMITTED BY
THE GUIDEWAY

- * Request destination
- * Destination received
- * Vehicle rejected
- * Emergency/detour ahead
- * Exit approaching
- * Prepare for manual takeover of control
- * Driver alert

One of the more interesting forms of roadway/driver communication now undergoing experiment is the ERGS system (Experimental Route Guidance System) being developed by General Motors and the Bureau of Public Roads. At the start of a manual driving trip, the driver turns lettered thumb wheels on an encoder box to spell the name of the destination. The encoder is a radio transmitter/receiver built into the car's instrument panel and broadcasts the destination to roadside ERGS stations, thence to central computers for analysis and routing instructions relayed back to the cars via the ERGS stations. The driver watches a screen which instructs him to turn left or right, etc.

Each ERGS car is fitted with two low-power antennae mounted under the car. The roadside ERGS station has loop antennae operating at 170kHz and a small trigger antenna at 230 kHz buried

in each traffic lane. The communications link requires very low power (2 watts) and offers the driver the choice of three best routes -- fastest, most scenic and easiest to drive. More conveniences are planned for later prototypes.

For the guideway trip, destination selection must be a very simple and unconfusing process. It is uncertain whether a number or word code (or both) should be used : some commuters might prefer the simplicity of numbers, while other people who are occasional travelers or use many destinations may prefer to spell out their destination. The lettered thumb wheels of the ERGS system could be used or a set of sliding bars, as on a money order machine, with a coordinated letter display window; after the name or number had been set to the satisfaction of the traveler, a register button is pushed indicating this acceptance. For regular routes, a set of small embossed cards could be inserted, each having a pre-set destination (note that telephone type dials, though familiar, are difficult for accurate spelling and checking tasks).

The sequential process of the car driver dialing in his destination, traveling, leaving the car at a station and then returning to the station to pick it up, including billing, is outlined in Fig. 7-8. There is further discussion in Chapter 8 on stations.

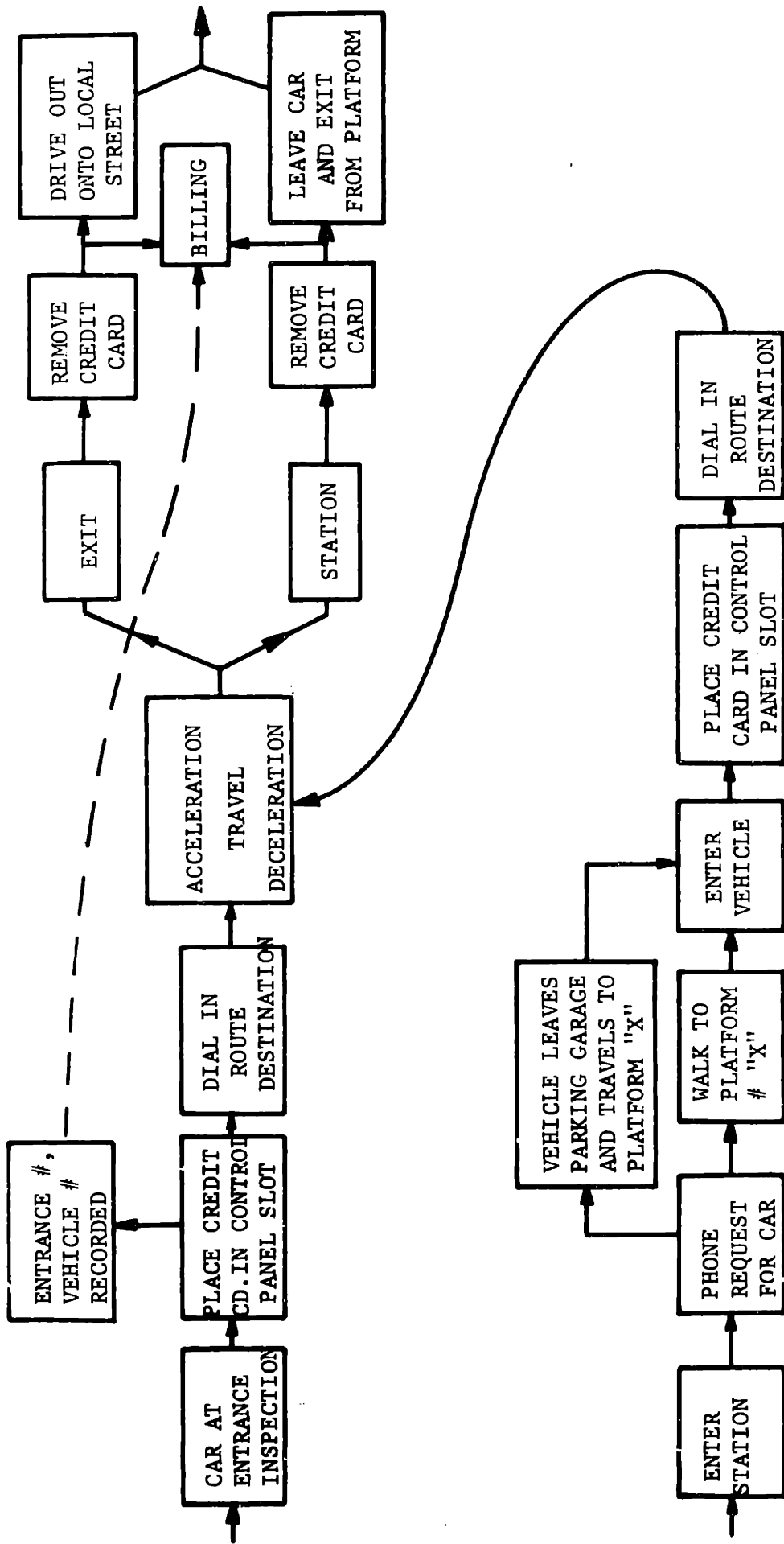


Fig. 7-8. Sequence of Actions for Identification, Destination Indication, and Billing Process for Car Driver at Entrances, Exits and Stations.

One difficulty with automatic billing schemes that must be avoided is overzealous computer billing and credit checks. The guideway system must service credit risks fairly and should follow the better example of the gas and telephone companies in this regard. In fact, the bills could easily be included in the gas and electric monthly charges. The rates could be graduated by distances and time of day, as well as age and infirmity or income. For a guideway system, vehicles are billed, not the operators. Additional deductions or comparative savings can be achieved by car pools, since counts could readily be made at entrances, with a priority lane for such multiple-occupancy vehicles.

For automated and dual-mode buses on the guideway system, there are several methods of fare collection possible : (Fig. 7-9)

- (a). Coin or token in turnstile
- (b). Credit cards in slot
- (c). Punched card zonal tickets
- (d). Season tickets or stored value travel voucher cards

The small size of the vehicles, option for no driver and high cost of vending and changemaking machines (\$1500 to \$4000) makes in-vehicle fare collection unwise, particularly for a many-door van. Arriving buses at station platforms are express, local or semi-local. Many express commuter buses will carry no driver, since the driver will get off at the guideway entrance

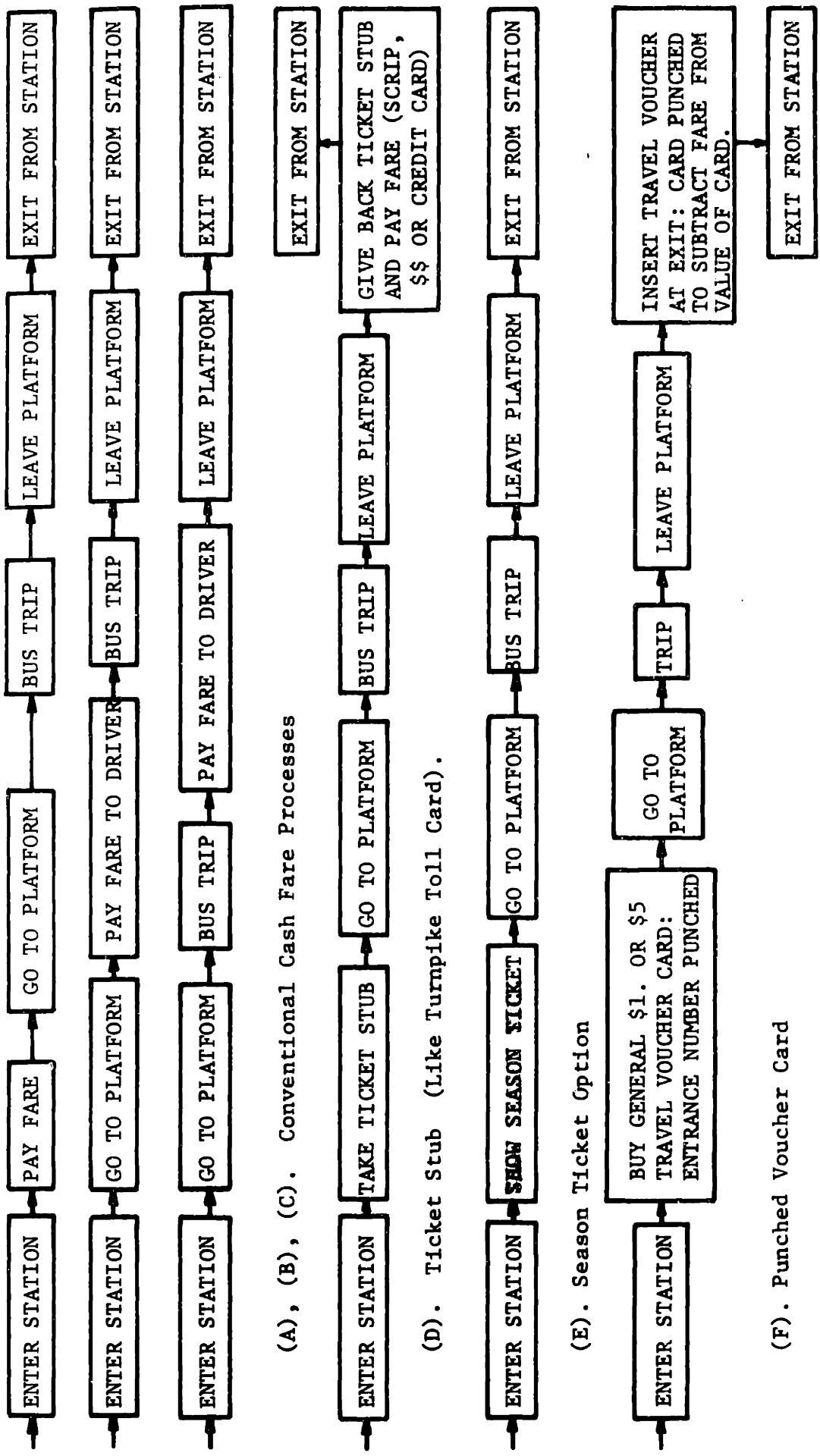


Fig. 7-9. Sequence of Actions for Fare Processing Options for Automated and Manual Bus Routines at Stations.

and go to the nearest exit or bus storage depot to begin another trip to pick up passengers. Paying the fare initially at the station is best, since destination can also be indicated and the proper bus can be diverted out of the main stream to make the pick-up. Flat fare systems may be preferable to zonal systems, or at most 2 to 3 main zones, since the additional complexity of fare checking is not justified by the price inelasticity of transit. Rather, fair incentives should be given to certain groups or localities by reimbursements of ticket stubs, for the young, poor and elderly.

The flat fare system also offers some interesting flexibilities for the entire transit system. For example, there could be an area of the CBD where all stations have no fare collection or turnstiles, while in abutting and periferal areas one paid on entering and leaving the stations. A cross-town traveler could request a dated ticket stub, which he would present at the exit station in lieu of paying twice. Therefore the congestion at the CBD transit stations and the frantic scrambling for change could be reduced and all station-to-station travel in the CBD area is effectively free, which it should be. These stations are now "liberated" to offer free access and connection to basements, shops and underground pedestrian areas which -- lacking the auto congestion of above ground streets -- could be quite an active, pleasant and comfortable place, with good design.

PHYSICAL DESIGN OF ENTRANCES AND EXITS

Entrances and exits must service efficiently an environmentally compatible capacity of vehicles, while limiting the amount of land area consumed. A medium-sized entrance with a single inspection booth requires :

* Manual entrance lanes and queuing	3,000 sq. ft.
* Inspection booth	1,000
* Low speed reject lane	1,000
* Acceleration ramps (depending upon final elevation)	5,000 to 7,000

total : 10,000 to 12,000 sq. ft.

With adept planning, adjacent lots or temporary loading areas can be used for entrance queuing or low speed reject ramps, so that the total area can be reduced to about 8,000 to 10,000 sq. ft.

The capacity of the entrance is determined by the flow rate of vehicles through the inspection area. If the turnover time (from one vehicle to the next) is 5 secs., capacity is 720 veh/hr. At 8 secs. total, capacity is 450 veh/hr, and 300 at 12 secs.

At exits, the land use components are :

*Deceleration ramps	6,000 sq.ft.
* Manual takeover area	1,000

(continued)

* queuing and manual exit area	2,000 sq.ft.
* "Graveyard" storage area	2,000

total : 11,000 sq. ft. (exit).

An exit booth could have manual off-ramp queuing areas overlapping with dial-a-bus storage yards. At peak hours when the queuing capacity is most needed, the bus storage area is vacant because the buses will also be at peak usage. For an exit speed of 5 mph at 30-foot slot spacings, capacity is 880 veh/hr. or about 15 veh/min.

The land use efficiency η of entrances and exits is a useful measure of compactness and is defined as the capacity per unit area, $\frac{Q}{A}$ or

$$\eta_{ent} = 3 \text{ to } 7 \times 10^{-2} \frac{\text{veh}}{\text{hr-ft}^2} \quad (7.1)$$

and

$$\eta_{ex} = 9 \times 10^{-2} \frac{\text{veh}}{\text{hr-ft}^2} \quad (7.2)$$

Because of access and egress constraints at the local street level, entrances and exits should probably not exceed 10,000 ADT or 1000 veh in the peak hour. The largest conceivable facility would occur at the terminal connection with an expressway or major arterial, with possibly 4,000 to 5,000 vehicles being handled in the peak hour. Depending upon the inspection times, the

branch-out is similar to a turnpike toll plaza, with 7 to 15 entrance booths needed, merging into two ramps at 15 mph and one ramp after 30 mph. To avoid the complexity of a large number of merges, it might be appropriate to group vehicles into platoons of 2 to 4 cars and lengthen the inspection booth area.

Existing problems of freeways and their ramps creating a scar in the urban fabric are sufficiently critical that guideway design must consciously go beyond mere goals of high capacity and slender line-haul guideway that is unobtrusive. Despite good basic aesthetic design of the guideway and its supports, long entrance and exit ramps might tend to create a bad profile and a small barrier effect. One interesting method of reducing these objections (as well as demolition and land consumption associated with ramps) is the installation in dense and important areas or residential and commercial services of elevators to bring vehicles down or up to grade (Fig. 7-10).

Elevators still require that acceleration and braking ramps be spurred off the mainline, but these ramps are parallel to the main line, or the same profile and can be 20 to 30% shorter. Roof-top areas could be used very efficiently to support or cover for these ramps, and the elevators can be sandwiched between various buildings or into vacant lots and parking areas, with minimal occupation of surface land area. The vicinity directly in front of the entrance doors and leading

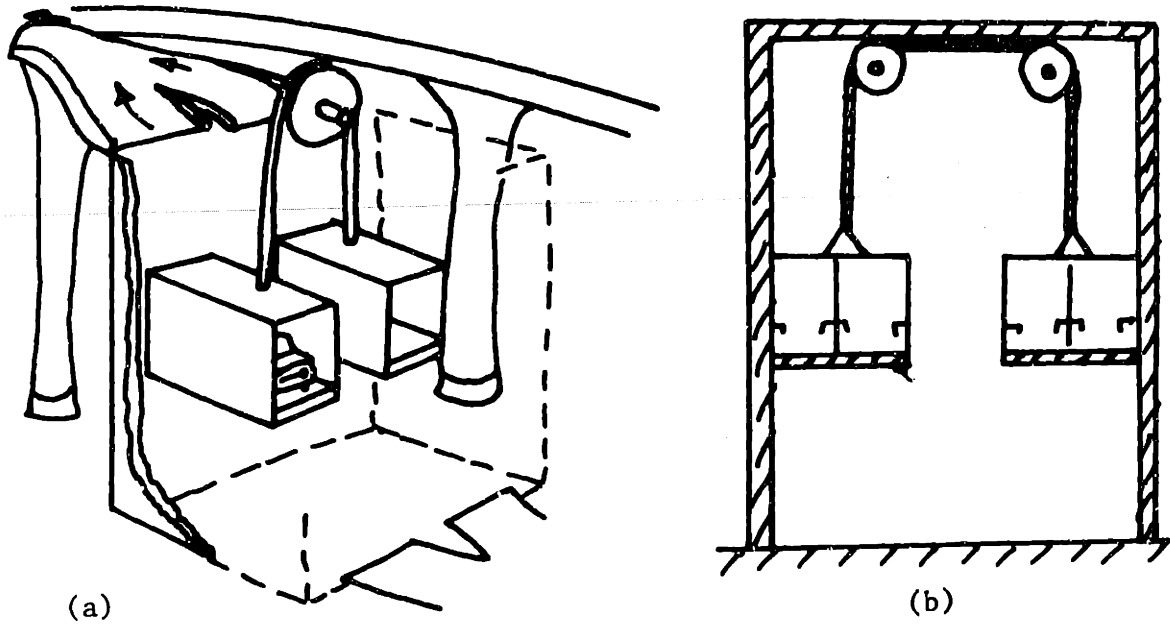


Fig. 7-10. Elevator-type Exit & Entrance (a) Dual, (b) Quad

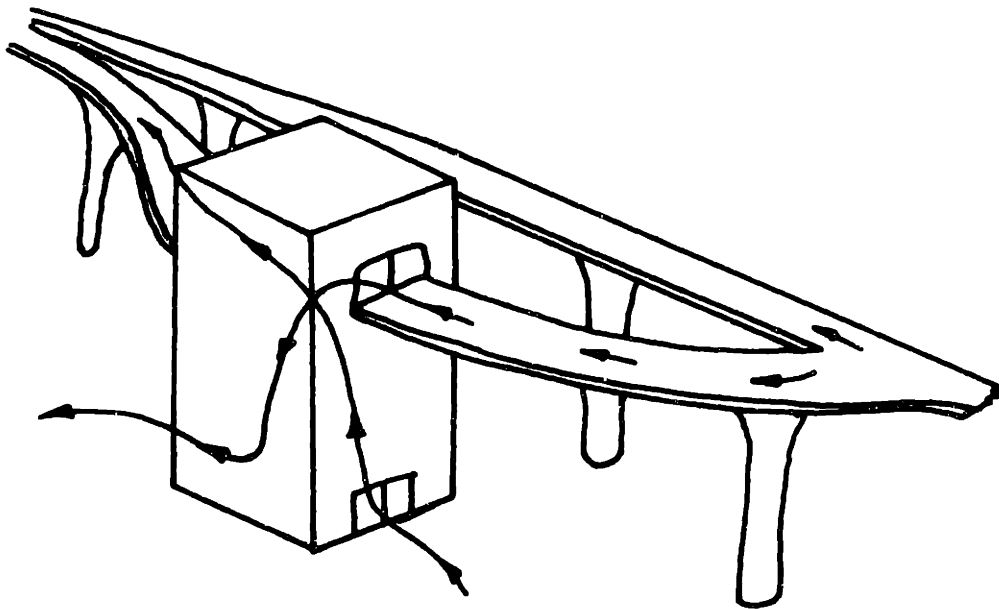


Fig. 7-11. Combination of Entrance and Exit in Same Elevator

to a limited queuing area could be used for a drive-on oscillating platform which shunts vehicles in and out of the elevator quite swiftly and accurately, while also checking vehicles as part of the entrance inspection.

The sequence of entrance/exit operations and timing is :

* Vehicle moves in at ground level	4 sec.
* Elevator door shuts	1 sec.
* Elevator rises up to 60 ft. (max. 1/8 G)	8 sec.
* Door opens	1 sec.
* Vehicle moves out	4 sec.
* Door closes	1 sec.
* Elevator travels down	8 sec.
* Door opens	1 sec.

total : 28 sec.

Failure of the vehicle to pass its entrance and simulated switching tests causes the vehicle to be returned to ground level, as the elevator becomes its own reject ramp. The elevator tower can also be used as an exit, during the downward travel of the elevator, so that net ground space saved is at least 60%.

Naturally, there are limitations to the feasibility of elevator exits/entrances, just as there are special advantages. The one-way capacity of a dual-elevator system is about 250 veh/hr, a rather conservative figure caused by the pulsating motion of the

elevator. However, the elevator exit is most useful in crowded situations, namely urban areas of congested local streets and parking problems where exits in the range of 1000veh/hr or more would quickly saturate local thoroughfares. The limited capacity of the elevator is a safeguard against exit overloading, as well as being very efficient in land use. Moreover, such a downtown exit is most properly reserved in rush hours solely for special vehicles such as police & emergency vehicles, minibuses and taxis, and the control system of the guideway could be programmed to give preference to these vehicles.

THE INTERMEDIATE BREAKDOWN LANE

Automated vehicles will be statistically subject to breakdown and accidents capable of causing guideway slowdowns and blockages. One method particularly adaptable to two-way guideway links is the intermediate or central lane servicing both directions (Fig. 7-12) to provide :

- (a) Access for emergency vehicles
- (b) Single vehicle emergency detours or ejects, caused by accidents, breakdown, or merge overflows.
- (c) Major detours of guideway stream flow
- (d) Possible use as an acceleration ramp reject lane

If a traveling car begins to slip gradually out of synchronism with the slot flow, the following traffic is alerted to proceed under reduced speed or caution conditions, until the disabled vehicle is

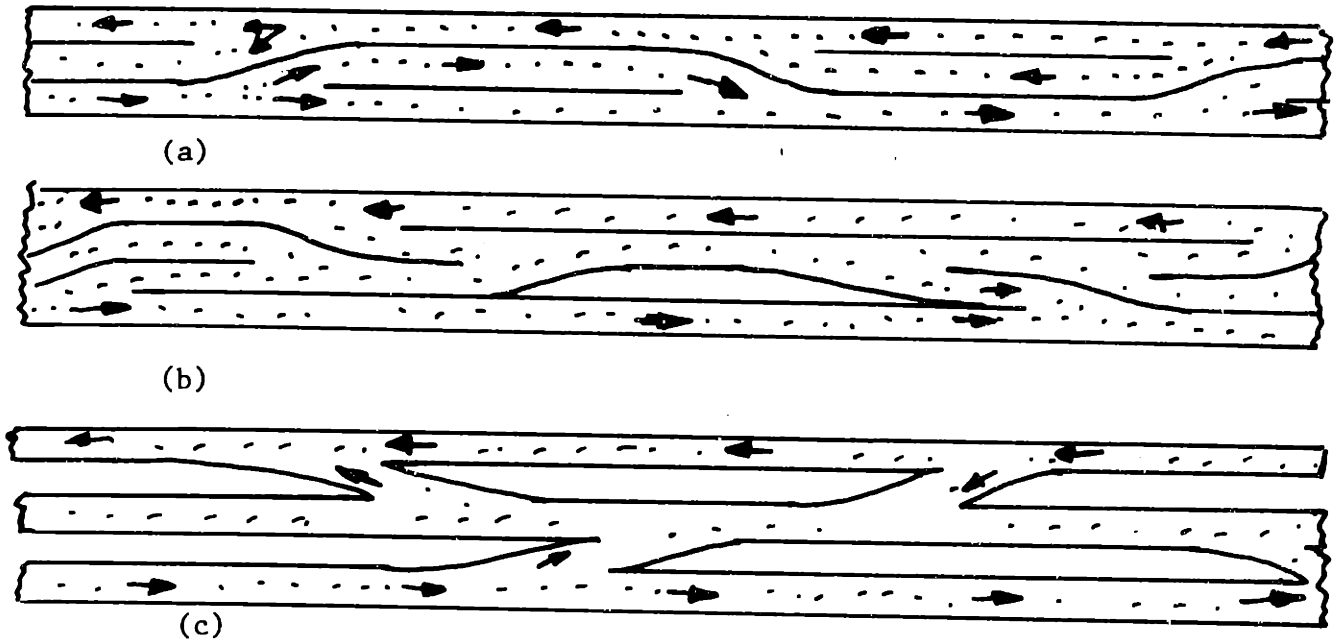


Fig. 7-12. Central Lane for Emergency Use by Disabled Vehicles

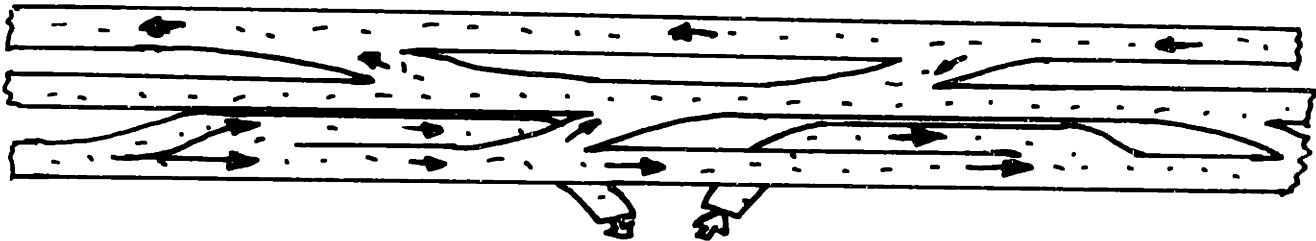


Fig. 7-13. Incorporation of Entrance and Exit within Guideway ROW

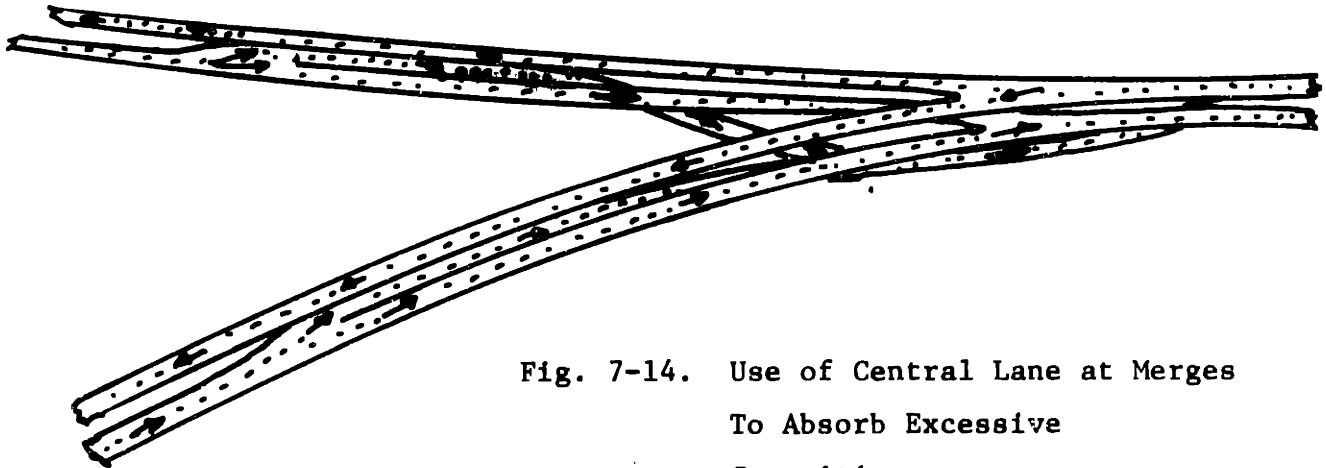


Fig. 7-14. Use of Central Lane at Merges To Absorb Excessive Capacities

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switched off the mainline. If a vehicle becomes stalled on the mainline, following traffic is shunted around it via the intermediate lane. An emergency vehicle would be sent to the site to remove the disabled vehicle.

The overall structure width varies depending on the design (Fig. 7-12 abc) : a discontinuous center lane alternatively serving each side, an S-shaped center lane approximately 4-lane widths wide overall (36 ft.), and the straight center lane (45 ft.) with periodic ramp access. Entrances and exit ramps could be built into the structure of Fig. 7-12c without necessarily increasing the ROW width (Fig. 7-13). At merges, the absorbtive capacity of the center lane can be employed to siphon off vehicles which present serious merging problems (Fig. 7-14). In all cases, caution must be used to avoid any collisions through multiple use of the center lane.

For dense city segments of the guideway, the intermediate lane is only partially continuous, being deleted where property acquisition costs are high or where a slim guideway sturcture is aesthetically necessary. One must recall that on many expressways, the breakdown lane is discontinuous in the vicinity of bridges and overpasses, yet this situation rarely causes flow restrictions or emergency problems. There is no need for multilane guideways, because of the tendency to overload corridors instead of seeking to achieve a finer distributional network.

TRANSPORTATION BREAKDOWNS

Highways have many problems of congestion instability, exacerbated by breakdowns and the resulting flow constriction process which is familiar on roads such as the Central Artery, Southeast Expressway and Route 128 in Boston. Because of congestion around a breakdown scene, it often takes 20 to 30 minutes for a tow truck to reach the scene, and in the meantime traffic backs up even more. Often a tangle of fender benders or truck jack-knifing causes incredible difficulty bordering on legend -- such as the Tokyo truck carrying 150 beehives which overturned and spilled out 1 million frenzied bees, causing a 2-hour jam; or the fish truck which flipped over and covered four traffic lanes with a foot depth of fish; or the famous hot fudge truck in San Francisco which split open on an overpass and dripped gooey hot fudge onto the roadway below; or the overloaded (15 tons) oleomargarine truck which split its sides on a Central Artery upramp at 6:00 AM one day and couldn't be removed for 3 hours. Bad weather complicates matters, as was all too clear in the freak snowstorm of Nov. 15, 1967, when salt spreading trucks were caught in the jams and it took 7 hours before good work could start.

Expressway collisions can assume vast proportions : as many as 100 cars, including two highway patrol cars, have been involved in one occurrence of rear end collisions in Los Angeles.

Railroad grade-crossing accidents and derailments have increased in frequency, and New York City transit system recently had three fatalities in a cluster, the first since August 1928. The transit fatality record generally has been good, with 4.5 million people per day using the New York system, with 7.8 riders per every 1,000,000 carried being injured (including falls on stairs, and assaults by fellow riders). This rate has remained fairly constant over the last decade.

Accidents abound in society. Home accidents from consumer products cause injury to 20 million Americans each year, with 110,000 permanently disabled and 30,000 killed, while the annual cost exceeds \$5.5 million.¹ Each day over 55 workers are killed on the job in industrial accidents, while annually 25 million workers are injured and 500,000 suffer permanent occupational disabilities. Nevertheless, there are only 1600 state safety inspectors to look out for the welfare of 80 million workers.

The automotive traffic toll is equivalent to wiping out 60% of the population of Cambridge every year. In 1966, the year of the auto safety crisis, traffic deaths numbered 53,041 and thereafter increased to 52,924 in 1967, 55,200 in 1968 and 56,400 in 1969, despite the advances in auto safety, belts, and advertising. Of the traffic dead, 10% were children, 1/3 were between 15 and 24 years of age, 10,000 were pedestrians, and over 12,000 fatalities were due to the more than 3 million yearly truck

accidents. Over 4.4 million auto injuries resulted from the 14.6 million accidents in 1968, with more than \$14 billion in direct costs to the public and untold billions in indirect costs. Despite increased enforcement against speeders and drunk drivers, at least 10 million motorists are driving without a valid drivers license². While the number of casualties per crash is declining (due to improved design and seat belts), the number of highway accidents is increasing sharply, and there appears to be serious empirical evidence that this nation is willing to accept 50,000 auto fatalities per year regardless of auto design, driver training and safety crusades -- unless there is a radical change in public thinking. The other possibility is to have vehicle control partly controlled automatically and thus surrendered by the driver. If the result is better vehicle and driver inspections and less frustration and aggression on the road, the death toll might drop, an important consideration over the next five years when the number of drivers below 25 years of age is expected to increase 50%, compared to an 11% increase in the over-25 age bracket.

In addition to driver reliability, the value of improved vehicle reliability can be seen from the number of vehicles entering Boston daily and suffering breakdowns. If 750,000 cars enter the city each day on a ten-mile average trip, a total of 15 million vehicle-miles/day is generated, and one breakdown per million veh-miles means 15 breakdowns per day. Improved vehicle

inspections are appropriate for both manual and dual-mode vehicles, although only four states have significant auto inspection procedures, Pennsylvania, New Jersey, Delaware and Virginia, and those of the Commonwealth of Massachusetts are very inadequate indeed. Good inspections yield an average failure rate of 45% the first time through, with faulty lights accounting for about 40%, tires 5-10%, brakes 30% and steering 10%. For breakdowns during travel, the contribution of the electrical system, flat tires and lack of car is the largest component.

The personal consequences of vehicular breakdown -- in terms of delays, inconvenience and possible injury -- are very frustrating, but become almost tolerable compared to recent transit experiences. A recent tunnel fire in New York has been described as follows :³

More than 1000 commuters terrorized by a Penn Central train fire groped their way to safety through an unlighted, smoke-filled tunnel yesterday, gasping for breath and slipping in mud and slime.

All but one made it without injury, many using dampened handkerchiefs to keep the acrid smoke from their lungs.

On November 19, 1970, a five-hour transit tie-up was caused when an organized group pulled all the emergency cords and stalled the trains. Meanwhile, rolling stock gets older and receives poorer maintenance. A New York transit car logs 250 miles a day, and about 45 cars of a 7000 car fleet break down daily, for an average of twice a year per car. One transit car, new in December 1957 at a cost of \$102,900 has gone to the repair shop 27 times since and has undergone extensive repair 6 times in a recent 8-month period.⁴

The inexperienced maintenance crews and poor morale is matched by the attitude of management who, when a questioner observed that in at least one recent accident a passenger was killed when he was caught in a train door and dragged into the path of another train, responded through an MTA spokesman that "No one has any business getting engaged in the doors when they are closing."⁵ Such an attitude toward maintenance and passenger safety must be strictly avoided in any dual-mode operation.

DUAL-MODE SAFETY AND RELIABILITY

The guideway will be strongly challenged in times of operational and reliability deficiencies. When a malfunction does occur, the system should seek to achieve a "graceful degradation of service" without catastrophic paralysis. One notes by analogy that a tunnel is a manual parallel to the case of guideways, in terms of possible impacts of breakdowns. The Sumner and Callahan Tunnels carry 62,000 vehicles per day two-way, and not a single fatality has occurred. There have been no major explosions or fires, because of a ban on the transport of flammable and explosive materials. Guards patrol the tunnel and report small auto fires or accidents, while tow trucks stationed at both ends of the tunnels are quick to enter the tunnels and remove disabled vehicles.

On manual roads, collisions can occur without a mechanical breakdown as the cause, but collision on a guideway are necessarily

the result of some form of breakdown or loss of traction. This spectrum of possible breakdowns ranges from a guidance arm that functions improperly to a skidding vehicle that collides with another or with the guiderail. Any forcible accident is a threat to obstruct and damage the guideway. Since, like a tunnel, cars can only stop or move forward, special provisions must be made to keep breakdowns to a minimum, guarantee swift emergency vehicle access and emergency rerouting or detour instructions. Guideways do offer the advantage that there are fewer false stops to change tires or have an argument in the middle of traffic and reduced chance of flow deterioration in the opposite lane due to the "rubbernecking" phenomenon which often slows traffic across from an expressway accident scene, but the fundamental costs or poor reliability still apply to guideways :

- (a) The frustration of poor performance and the expectation gap.
- (b) Actual dollar costs
- (c) Man-hours lost directly or indirectly
- (d) Reduced capacity, land use efficiency
- (e) Poor utilization of rolling stock, schedule confusion.

All transportation systems are affected in their performance by their natural enemies of weather, accidents and overuse. Weather factors include rain, ice, snow, dirt/mud/leaves, excessive heat or cold, flooding, smog and road spray, wind gusts and lightning, and these effects will influence guideway performance variables such

as traction, rolling drag, air drag, icing of the rail, arm and fender doors, heating of the follower, rail and follower corrosion, and short circuits.

In response to the severity of breakdown, "emergency slow" and "emergency halt" strategies can be implemented, comparable to similar policies used in auto racing :

- (a). Speed reduction or "yellow flag" control along a guideway segment, with full speed resumed after the problem is cleared up.
- (b). Full stop emergency or "black flag" control, halting one segment and invoking detour routes either in the same corridor (use of the emergency lane) or an alternate corridor. Vehicles in the halted segment are either restarted later or towed past the obstruction.

Where there are steeply banked, constant speed curves, the applicability of "yellow flag" procedures will have to be restricted, since a speed mismatch could result in lateral sliding.

In anticipation of various accident contingencies, two major types of blackflagging strategies can be developed :

1. A Holding strategy -- requiring on the spot repairs with only minor delays in backed-up traffic
2. A Closing strategy -- requiring lengthy repairs and closure of links or loops for hours at a time; backed-up cars would be individually moved to the nearest exit or merge.

The judgment of the severity of the accident and the appropriate

strategy to follow is rendered upon information obtained from closed-circuit TV, system checkpoints and analysers or on-site repair crews.

The goal of a demonstration guideway is to specify all the failure modes for dual-mode systems, based on analysis and empirical experience. The main functional categories of system defects in operation are

1. Vehicular breakdown.....rolling or non-rolling vehicle
guidable or not ; manual or automatic
2. Guideway breakdownexcessive surface roughness; poor
rail alignment; loss of power in any
section; loss of signal
3. Entrance/exit or station malfunction
4. Combined vehicular/guideway accident
5. General systems breakdown, service degradation or shut-down.

An extensive list should be made of all components and their weaknesses, such as :

- * VEHICLES : flat tires, loss of wheel or driveshaft, bearing failure, brakes, suspension, speed control system failure, motors non-functional mechanical steering linkage, guidance arms and follower actuation or jamming, improperly executed switch, passenger problems (illness, fire)
- * GUIDEWAY : electric power supply - overloading, shorts, corrosion, bad electrical connections; poor rail alignment; debris on guideway (tree limbs, trash, etc.)
reduced traction or rough surface.

Table 7-2 relates these factors to Holding and Closing strategies.

Hopefully, bumping and collision accidents when they occur will be kept within the Holding strategy range, and even permit non-stop yellow flag operation. As discussed in Chapter 5, rear-end collisions can be reduced in severity by controlled headways and small relative speeds, as well as shock-absorbing bumpers and standardization of bumper heights. Bills have been submitted in many legislatures and in Congress to require new vehicles to withstand 5 mph and 10 mph collision without major damage, with implementation dates ranging from Jan. 1, 1972 to 1975, and several manufacturers are making progress in spring loaded bumpers. The basic approaches to cushioning collisions are

- (a). Water-filled bumpers or telescoping bumpers (water, oil, & springs or deformable steel.)
- (b). Inertial barriers (filled with sand or water) and telescoping guardrail (oil chamber or steel drum)

The weight of the water bumper adds 100 lbs. to the vehicle weight, with a cost increment of \$200 plus \$35 installation costs. Today, replacement chrome bumpers cost \$50 to \$100 plus \$25 in labor expenses. Guideway switches could adopt versions of the gore crash cushions being tested on several highways, which can stop a 3200 lb. sedan from 60 mph in 13.3 feet, with an average deceleration of 9 G and only minor damage to one of four headlights. The Fitch Inertial Barrier, composed of plastic barrels filled with a honeycomb core and varying degrees of sand has been test located at the Rt. 129

exit gore at Rt. 1 Northbound in Lynnfield.

What statistical reliability is necessary for the guideway at its various stages of development? It has certain inherent reliability advances, such as the use of electric power, fail-safe control, removal of driver variances, better guardrails, more accurate merging, less car speed differential and the chance to establish good quality controls from the beginning, following the example of Japan's Tokaido line rather than the less successful Metroliner, which was handicapped by its Penn Central affiliation. Today 3% of all scheduled airport departures are canceled and some major carriers do better : between 1 and 2%. Would a 3% rejection rate at entrances be acceptable to guideway users? The answer is probably yes, since this would mean one or more rejections per month. A 1% rejection rate seems a good initial goal, with consequent vehicle reliabilities in the 1 per 1,000,000 veh-miles range during demonstrations and 1 per 10,000,000 veh-miles thereafter. The reliability goal should probably be one order of magnitude higher than what is the minimum tolerable condition for guideway users, to avoid borderline reliability operations such as many expressways and antiquated transit lines incur.

Added reliability can be achieved by extensive reliability testing of components and development of redundancy in control systems. The redundancy idea for propulsion is a well understood concept, since a four-engine plane can operate on two engines if

necessary. Redundancy principles have been successfully applied to the Boeing 747, since every flight control system has at least one back-up system. However, redundancy brings with it increased complexity, and simplicity with testing is often a good alternative. The Bell Telephone Laboratory, in designing repeater amplifiers for long-term under-sea cable operations has demonstrated the equivalent validity of simplicity of well developed and tested components.

In summary, a serious accident which paralyzes a guideway system serves to underline the marked discrepancy between optimum and minimum performance. As a nation we spend considerable amounts of money on elaborate defense systems we hope we will never need to use, and a guideway system should have first-rate fallback capability to ensure adequate safety, reliability and rapid repair. Guideways must not be susceptible to the equivalent of bad weather conditions which ground airports or bring roadway traffic to a pulsating crawl. Ideally, the designer should be seeking the all-weather reliability of the railroads, with the ability of the multiple access roadway facilities to remove disabled cars and rehabilitate the system.

The overall program for reliability optimization includes :

- (a). Adequate funding and planning effort to overcome the traditional low priority for maintenance.
- (b). Improved manual vehicle maintenance & owner incentives
- (c). Electronic testing of vehicles at guideway entrances
- (d). Basic vehicle reliability and/or redundancy to continue operations and travel under limited conditions.

- (e). Breakdown lane or spur track capability in heavily traveled sections.
- (f). Detection of vehicle malfunction at early time and determination of appropriate detour strategies around the affected link.
- (g). Quick response, access to, aid of and removal of disabled vehicles.

The electronic testing of entering vehicles can be aided by an umbilical cord connection to check out car components and performance variables, similar to the Volkswagen system which gives a total of 87 readouts on electrical and motor elements in current vehicles. A small grouping of electronic testing equipment in compact formation relays data to computers for quick analysis, diagnosis of problems, cost estimates and even print-out of repair instructions. For the guideway, all motor controls and voltages and the system response to signal inputs for speed, monitoring, manual/automated transfer, and guidance equipment could be tested in a short period of less than 5 secs., while the initial plug connection from the umbilical cord to the vehicle socket is made underneath the vehicle via a concave disk with a central socket for location and connection, or a plug connection in the follower or on the guidance arm.

The quick response of any highway or rail ambulance service is usually the most cost-effective way of reducing fatality rates. This factor plus the ability for quick reporting of accidents can avoid the tragically common occurrence on highways

when accident victims stay trapped for several minutes, losing blood and the precious chance to live, while the possibility of fire increases, before passerbys or other motorists stop to offer aid or call the authorities. A guideway system could have a direct access to a hospital such as Mass. General Hospital or Peter Bent Brigham, so that dual-mode ambulances could rush people to hospitals either directly from the guideway or from local communities near guideway entrances. Demonstration or operating expenses might be forthcoming for the medical services so rendered to local communities, and guideway ambulances would have further beneficial community impacts by the reduction of noise, since sirens are not needed on the guideway.

RESCUE AND REPAIR VEHICLES

An emergency vehicle must conform to a number of design requirements :

- (a). Good line haul performance -- quick response to reach accident.
- (b). Bypassing of back-up traffic.
- (c). Ability to serve as ambulance, tow truck, repair truck
- (d). Reliability under almost all weather conditions.
- (e). Reasonable aesthetics; minimal effect of adjacent areas.
- (f). Reasonable cost : purchase and maintenance.

Hopefully, the emergency vehicle could patrol 5 to 20 miles

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RESCUE AND REPAIR VEHICLES

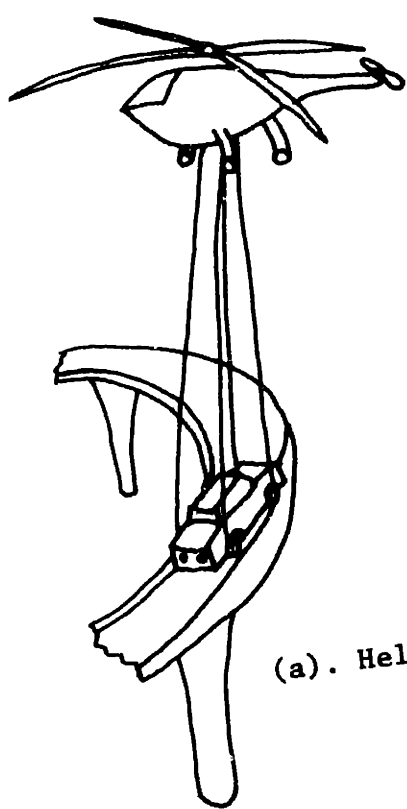
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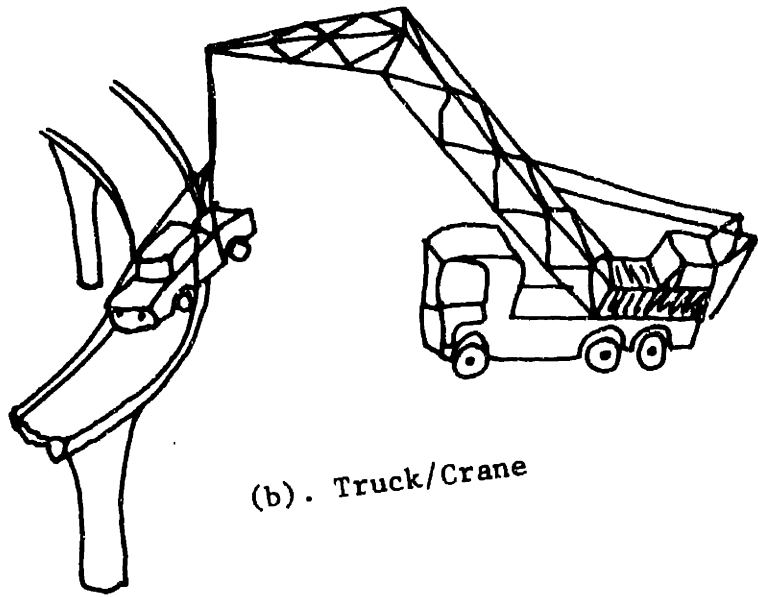
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Fig. 7-15.

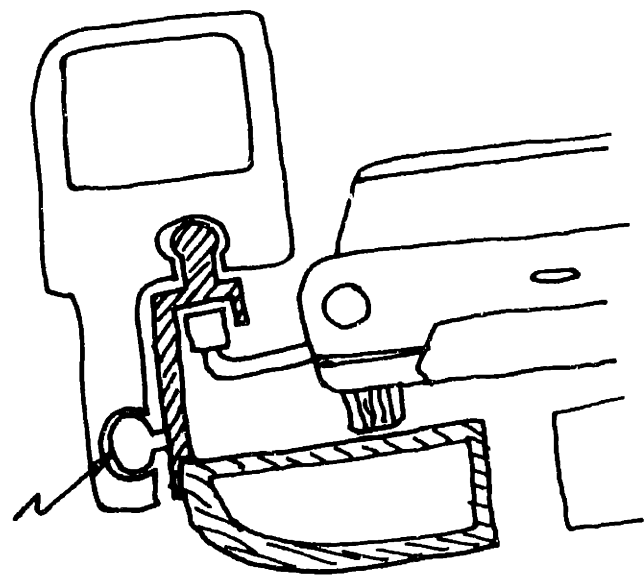
Types of Emergency Vehicles



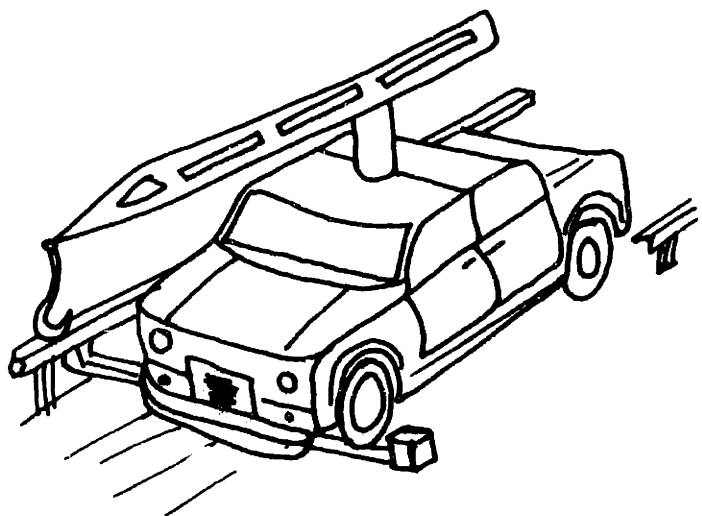
(a). Helicopter



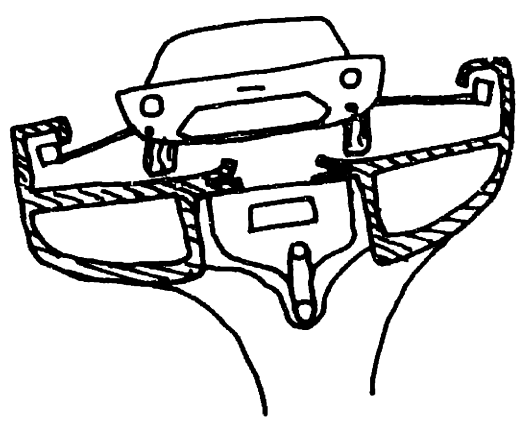
(b). Truck/Crane



(d). Lateral Monorail



(e) Bi-directional Tow Truck



(f). Vehicle Below Guidew

of guideway and be able to speed to an accident site within 10 minutes. Of the wide range of options available -- from blimps to street cranes -- a half-dozen appear conceivably feasible (Fig. 7-15) : a helicopter, a truck/crane operating from abutting streets, a suspended monorail traveling along one of the lateral guiderails, a two-way towtruck riding on the guideway, and a special device running underneath the guideway. An overhead, suspended monorail track would be ugly and costly; also rejected was a grasshopper stance straddling both lateral guiderails, because difficulties are encountered at switches where guiderails spread out.

Helicopters offer rapid access and response, yet would be noisy, dusty and difficult to maneuver in close quarters. First cost is \$500,000 to \$800,000 plus maintenance costs of \$1000 per day for two hours use. A tow truck costs \$5,000 to \$6,000, lasts ten years, and costs little to maintain. A small crane (on or off the guideway) might be necessary in absolute crisis conditions to remove vehicles, although access could be difficult and time-consuming (except along railroad ROW, where railroad cranes can be used).

The lateral monorail suffers from low range because of its absence of switching and merging capability, difficulties in towing or removing disabled vehicles, and the absence of dual-mode capability. The underneath-guideway vehicle would nestle in

the gap between the separated guideway pontoons, while performance on curves and straights should be adequate. Switching and access of personnel to the roadway pose serious technical problems, and other deficiencies include the loss of guideway cross-sectional rigidity, increase in construction cost and the cost of the specially designed and fabricated emergency vehicle.

The bi-directional towtruck is the best choice and can be constructed by mating two front halves of four-wheel drive trucks and adding guidance arms front and rear. With no special aesthetic problems, the truck is independent of guideway design because it travels much like any other guideway vehicle. Towing and switching capabilities are excellent, as are dual-mode, off-guideway operations. However, the truck could not bypass stalled traffic directly, unless an intermediate lane were available or traffic on a two-way link could be momentarily halted while the truck traveled in the opposite lane. Ordinarily, the towtruck could count on traffic clearing out the segment in front of a blocked link, and the truck would travel "in reverse" to reach the site, and then tow the disabled vehicle out in the forward direction (Fig. 7-17). Low speed towing around banked curves might require vehicles to be supported on wheel trolleys (Fig. 7-18) to prevent towed vehicles from sliding against the inside rail. The tow truck, under these conditions, is supported by all four arms in the passive fallback condition.

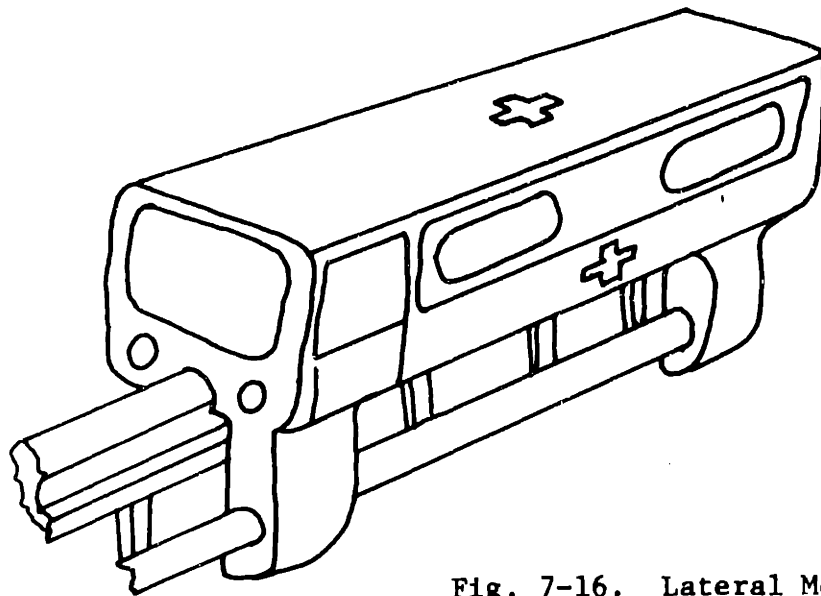


Fig. 7-16. Lateral Monorail Vehicle

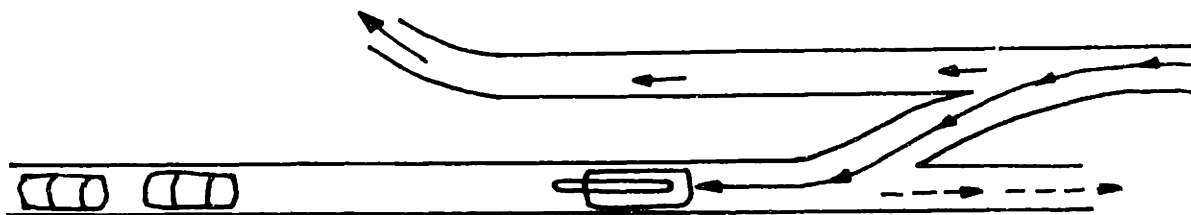
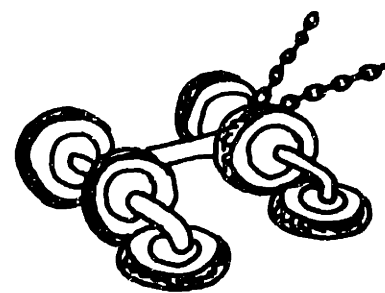
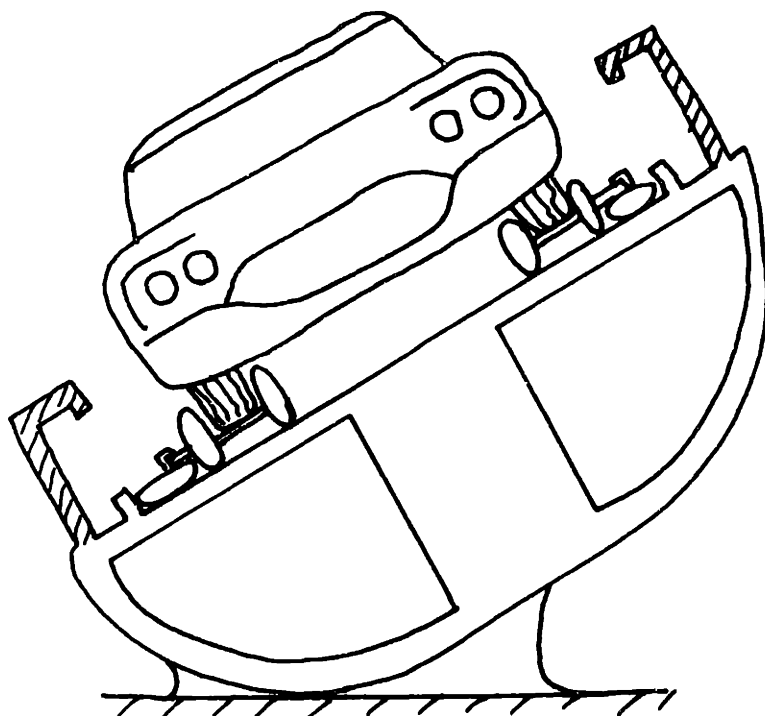


Fig. 7-17. Tow Truck Routing for Access to Breakdown.



Trolley

Fig. 7-18. Towing Disabled Cars on Banked Curves : The Use of Adjustable Wheel Trolleys.

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CRIME, VANDALISM AND POLICING THE GUIDEWAY

An uncomfortable but vital issue which must be considered is that of crime and policing on guideway systems. Highways must be fenced off, bus stations become centers of theft and hustlers, while crime in the New York subway system is sufficiently severe that the underground police force is larger than the total police force of any other American city.

Some automated devices such as moving sidewalks and escalators present no serious difficulties, but self-service elevators in tall buildings with no access control often become crime traps, especially for women with pocketbooks. Deterrent effects are contributed by the self-policing function of a large crowd or by an elevator operator or doorman. Inducements to crime are the lack of surveillance, the no-windows insularity of internal elevators, and the multiplicity of escape routes provided by many floors and elevators, as well as the lack of any emergency warning button to request help. A guideway resembles a horizontal elevator in many cases, except that it makes fewer stops, the capsules have windows and the likelihood of passenger and system surveillance are better. In addition, ladies-only buses or bus compartments could be provided, similar to those on European trains.

Vandalism on many transportation systems is a widespread problem, as train switches are thrown and water balloons are dropped

on expressway vehicles. Guideways could become perfect shooting galleries for young snowball throwers, unless physically shielded? Railroad problems are most extreme, with trains such as the Penn Central Metroliner under heavy bombardment from rock throwers. Many commuters in New York City keep the blinds drawn for protection, and railroad fences are cut almost as fast as they can be repaired, which is not often. Often, disgruntled riders become vandals, as on the Long Island Railroad, which reported 5,000 fire extinguishers stolen last year -- most of them torn out soon after installation. The Railroad is trying to set up loud speakers at 83 platforms, but they are being removed even before they are connected.

Design responses could range from from the Tokaido line of express trains, which are entirely fenced in where open to possible trespass to full elevation of the system to policies of good community relations, such as BART has sought in providing park and playground space along its right-of-way. Any system should seek to encourage self-policing by riders and abutters, by emphasizing how vandalism cuts service and using ads or billboards noting that "It's your guideway and you're paying for good service. If you see a vandal defacing or destroying property, stop him. Even better, call a guard, but do it yourself." The apathy of the individual in the crowd must be reduced, and personal action legitimized. More direct approaches could be made towards children who usually cause much of the damage and are more difficult to reach. Initially, many free rides could be provided for kids or special season tickets can be provided for them. Teenagers can be employed to clean up

nearby parks and right-of-way, and thereby earn a season ticket to go anywhere on the system. Hopefully, one could generate a new breed of "rail fans" as guideway advocates who will respond with the type of enthusiasm familiar years ago when the railroad image was better and children dreamed of becoming a railroad engineer rather than a spaceman.

REGULATION AND STANDARDS

Who regulates rates and fares on a guideway system? Almost inevitably, dual-mode in each city will be a monopoly and effectively a public utility. The lack of competition and the ineffectiveness of many regulatory bodies such as the ICC suggest that the function of the "Nader's Raiders" should be designed into the system, so that the regulators are stimulated to encourage adequate service and standards. The Federal Government may well begin with a basic conflict of interest, as it seeks both to promote and regulate dual-mode concepts, but this conflict may be so evident that the agencies will tend to bend over backwards to demonstrate that there is no laxity or collusion -- as has been seen recently at various levels of DOT. Both Congress and the Bureau of Motor Carrier Safety should be brought into the picture, to insure a balance between public and lobbying interests.

The setting of guideway standards will be a rather novel experience and should be more of an open than a closed process,

with Government engineers, industry personnel and customer representatives contributing to a mutual process of testing and evaluation. The standards can range from excessive simplicity to confining inflexibility : America's Western Indians would collect all the village squaws together and herd them across a new bridge before they would trust it to support their more valuable cattle, and in a number of Northeastern states around the turn of the century, the maximum load for bridges was fixed on the basis of the weight of an elephant -- six tons, and in some cases even less. Today, Interstate highway standards are often so high that they undermine and obliterate the public objectives and goals the roads are intended to serve : engineers now tend to "design by the book" rather than develop a highway to suit its geographical environment.

Guideway promoters need to establish credible and public standards of design, to demonstrate that efforts have been made to assure reasonable safety and that many groups have been contacted in developing the standards. The standards process must be combined with a flaw-detection procedure which would actively seek out problems, identify their source and report their severity without any attempt at cover-up or downgrading the seriousness of the problem.

LIABILITY QUESTIONS

Any form of highway automation and control has liability problems, especially as the user's rights to protection become more established in modern law. For guideways, the problem of liability and the willingness of insurance companies to provide reasonable services may be a function of both the net size of damage and insurance claims and the annoyance factors of complex court litigation, delays, legal fees and the simply uncertainty of justice and legal rulings.

A demonstration guideway will be acted upon by two social attitudes, one of combined tolerance and devil-may-care attitude towards safety (the understanding that "bugs need to be worked out and it takes time" and the primitive sportsmanship when the auto and the airplane had their wild reckless drivers) to immediate condemnations of new technology and criticism of "boondoggles" such as the F-111 and the C-5A. When the first automotive fatality occurred in New York City in 1899 with a delivery truck running over a little girl, an immediate outburst of public resentment arose and demands were made that autos be banned from the streets or preceded by a pedestrian waving a red flag. A more recent development is that of consumerism, the concept that essential public services or hardware must be safe and reliable, that the unsuspecting consumer must be reimbursed for damages, and that

henceforth, "Let the Buyer Beware."

Because of the public's careless attention to seat belts and lack of crisis over 60,000 highway fatalities each year, the cynic may take the viewpoint that there is no way of selling safety to the public, but the present consumer revolt is a measure of the underlying concern for safety. Part of the problem may be that safety has been treated as a marketable luxury, something which must be sold in the style of Madison Avenue, that people should seek safety for the same reasons they want a new color TV set. Among highway safety agencies, the issue takes the form of a "crusade" to bring the "message" to the people, as if safety should be preached and inculcated as a religion. Similarly, schools and educational programs make the same mistake of monologue preaching. Efforts must be made to get people to *think* safety, rather than parrot catch phrases and to understand what risk is all about and what the value of preventative action is. If some element of useful dialogue between the public and the guideway operators could be established, the public would benefit, take more precautions and be more understanding, while the vital role of maintenance in assuring system safety can maintain its proper degree of pre-eminence.

This concern for liability standards, insurance problems and public interaction will have an additional positive impact, since improved safety standards can be generated. The entire

safety and liability issue must permeate the entire dual-mode agency and a wide range of the public, and not be left -- in the case of auto safety and railroads -- to a few private crusaders, some defensive statements from top management and occasional efforts by publicity seeking Congressmen.

The driver will be relieved of considerable responsibility because of the heavy liability burden which now falls on the manual driver. Auto accident claims have risen from \$3.5 Billion in 1958 to \$4.3 Billion in 1962 and to \$7 Billion in 1967, with corresponding rises in premiums. Thus the dual-mode owner could expect a rebate from the insurance company (which would be most feasible if the auto insurance companies then began insuring guideway vehicles, with either the guideway operators or the manufacturers liable.) Since drivers would not be undergoing the strain of driving on the guideway, nor could claims be made against them, there would be greater relaxation, particularly for people who hate to drive.

The liability burden of any guideway accident will be directed at any of a combination of guideway operator, components manufacturer, repair shop, vehicle inspector (private or public), or regulatory body -- depending upon the structure of the dual-mode operation (Chapter 10.). By the theory of "strict liability in tort," a seller of goods is liable for injuries resulting from the malfunction of a product, when the product has, at the time of being sold, a defect which made it unreasonably dangerous to life

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and limb. Whether any of the defendants will be liable for damages generally involves a test of "negligence," which is the converse of "reasonableness." By definition, negligence is the failure to do what a reasonable person (the reasonably prudent man) similarly situated would have done. There is no requirement that the product be 100% accidentproof or foolproof. It is not in itself a breach of duty to supply materials which are reasonably safe and customarily used, even though the product might conceivably be made more safe. Using deception or hiding defects from the unsuspecting is the main "crime" inherent in liability cases, and it is not required that an auto manufacturer build cars capable of surviving a 70-mph crash into an abutment, when the dangers of speeding are obvious to all. If the guideway system publicly advertised and guaranteed a certain level of reliability and payments to anyone injured by the system (similar to a health insurance plan), the system would be covered against random and outrageous claims. The reliability levels could be set based on demonstration system experience at each stage of development.

The concept that a service system is highly liable for accidents and that the assertion that "An Act of God" can no longer be used to excuse system breakdowns is difficult for managers to accept readily, but is rapidly becoming an element of modern law. The New York Court of Appeals recently in a 5-2 ruling held the state responsible for several accidents and a

death on the New York Thruway during a foggy day in November 1964, by allowing traffic to proceed along a four-mile section of road where a forest fire had been blazing for several days. Similarly, cities have been held negligent for malfunctioning traffic lights. In some cases, the regulatory process can be blamed, e.g. the crash of an Eastern Airlines Electra in 1967 at Logan Airport due to a flock of starlings fouling the engines -- so commonly admitted a weakness of Electras that the government certificate award was held to be "negligent." On the other hand, a system or manufacturer which institutes voluntary standards can submit this act as evidence that overall negligence did not occur.

It is not enough to consider liability problems directly associated with guideways and to ignore the indirect effects. For example, the claims for excellent safety on Interstate highways are based on accident records on the expressways only, and do not take account of speeding and merging errors caused on local streets by the exiting of high speed vehicles. Thus, if an expressway driver has his senses dulled by high speed monotony and then loses control on a local street, this accident is attributed statistically to local hazards, and not to the expressway. Guideway exits could have a comparable effect, if drivers were not ready to drive on local streets or became disoriented and less able to concentrate on the manual driving task. However, guideway drivers are not dulled by speed, nor do they exit above 5 mph, so that the experience is more akin to switching from watching

television to starting up one's car from curbside.

Any guideway insurance scheme must be protected against unfair advantages, to exclude coverage in cases of :

- (a). purposely caused injuries, or exaggerated injuries -- as perpetrated by insurance fakers and the semi-professional "flpp artists" who make a practice of walking into the side of a car and then suing for damages.
- (b). operating a vehicle without legal authorization.
- (c). those drunk or under the influence of drugs
- (d). injuries incurred while committing a criminal or illegal act.

As proper evidence in both fair and illegitimate cases, the guideway equivalent of an aircraft flight recorder can be used, having a 30-sec. memory of all instructions and speed signal positioning monitoring. Accidents could be given instant replay and stop action.

Insurance companies must become interested in guideway systems, and their support can be gained by emphasizing efforts at good standards, reliability, demonstrations and maintenance. Because of system inspections, guideway vehicles would be less prone to theft and would be in better operating condition, and it becomes more feasible to check on drunken drivers. However, since the insurance companies perform \$11 billion in auto insurance premium collections each year, and there are \$23 billion worth of cars and trucks produced annually, the consumer must not be caught without a voice in the process, and as amicable a functional relationship as possible must be maintained among the insurance

companies, the manufacturers, the system operating companies, the inspectors & regulators and the customers.

MAINTENANCE LIABILITY

The responsibility for adequate maintenance could fall on the guideway operators, the inspection and maintenance facilities on the system, private maintenance shops or on the individual owner himself, if he fails to have inspections or repairs made. Today, the auto maintenance business grosses over \$30 billion a year, and the field contains many inexperienced repairmen, unskilled butchers and even outright repair thieves, so that a guideway system would have to proceed on the strictest training and certification of repair and maintenance services, both private and public. The presence of a Consumers Service for advice and evaluation might be an inducement to better quality repairs.

Auto warranties are being trimmed back extensively, after a brief flurry of competition between the companies, and the 5-year, 50,000 mile power train warranty is disappearing. Recalls for defective vehicles are continuing, but the process is distorted because the dealer involved in the recall often uses the opportunity to sell a brand new car to the customer. Dual-mode repairs and maintenance should be accomplished without the pressure for a new sale and could involve some measure of user compensation for

special transportation costs and inconveniences caused by repair work under warranty or otherwise. Access to the computerized car pool or rent-a-car process is a reasonable option for users stranded with a defective vehicle.

Today, maintenance is often an empirical function of system glamour, being at its worst for old trolley cars and transit buses, somewhat better for Interstate buses, better for rented cars than for taxis and best of all for airlines. The maintenance costs over the life of a commercial airliner often amount to twice the original purchase price, and for certain components and systems, maintenance runs from ten to 1000 times the original cost. Such expenses can can up to 25% of the direct operating costs.⁶ Downtime begins to cost more than the maintenance labor, as much maintenance is "waste time" because no major defects are found and hence alertness drops off, allowing some defects to slip through undetected. Hence there is a need on a guideway system where good reliability is so important to use automated inspection devices -- not to reduce the work force, but instead to maintain better vigilance. Even on well organized aircraft maintenance routines,⁷

...it is conservatively estimated that at least 60% of the direct labor expended upon scheduled line checks and about 30% of that applied to scheduled main-base checks does not restore, retain or improve the original capacity of the design.

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For guideways, there is a strong need for troubleshooting guides for both scheduled and unscheduled maintenance -- guides which have not been developed for airlines or for trucks, cars and buses. Most maintenance is an inefficient, unglamorous, often underfinanced process, usually taking the form more of a proletarian art than a professional science. Worst of all, maintenance is quite uneven, occasionally approaching the danger of over-maintenance, causing impaired reliability because inspectors are careless about reassembly. Thus non-destructive testing and umbilical cord plug-in checks are the best techniques for rapid, efficient, consistent and productive maintenance. Furthermore, the dual-mode design should be developed from early stages with good maintenance in mind, since most new systems emphasize optimal performance and first cost, only later taking safety and reliability into account.

PUBLICITY ON A DEMONSTRATION SYSTEM

In today's society of frequent overheated publicity and media headlines, new transportation systems often fall into the trap of excessive press promotionals, glamorized demonstrations with VIP's and press conferences, and guideway systems development should not make the same mistake. The emphasis should be on low-key contacts with the public during the early demonstration stages, and not to sell the system to Congressmen only. All experimental

concepts and strategies should be tackled and tested one at a time, with initial experiments and weekends, holidays and nights, while reliability testing would occur during weekday working hours and more suitable publicity conditions. Excessive expectations can be quite disappointing, as occurred when the second Boeing 747 to be delivered ripped off a wing flap and an engine and tore up much of the runway in landing, or when the first commercial 747 flight was halted with engine trouble on the ground, and one of the passengers, producer David Susskind, announced to the press that there was "absolutely no sensation of being airborne."

Chicago transit recently had early trouble when it opened a new modernized line without sufficient personnel training and experienced several accidents in the first week. It may be necessary in a dual-mode demonstration to implement the equivalent of a "grounding" policy if defects occur which severely impair performance or reliability. Only a centralized system operation has the option of grounding or halting functions, whether they be aircraft or trains, as in the case of the Canadian Turbo trains, which were successfully returned to service after a lay-off. One cannot afford, as in the cases of the Edsel or Vietnam, to let success and optimism be exaggerated and institutionalized, in direct opposition to reality. In analogy to military concepts, the implementation of dual-mode is a protracted strategy -- a process of careful planning, accepted delays, testing and probing,

and never being drawn into doing anything before the system is ready. The urge to demonstrate and prove the system at every conceivable opportunity must be restrained within mechanical and human limits, so that the normal activities of public relations officials should be dramatically curtailed. It will be most unwise to build up an image of invincibility for dual-mode, so that the image is badly shattered by a tragic accident, as the Apollo fire damaged public confidence in NASA and the Hindenberg fire sealed the fate of the airship.

Neither is it advisable to go to the opposite extreme and play up the dangers of travel, as best exemplified by Pacific Airlines 1967 advertising campaign which parodied the possibilities of an accidental crash, complete with Linus security blanket and Stan Freberg lyrics. Rather, the plan should begin with a professional version of Murphy's Law and then working backwards towards a good reliability program, rather than initial overselling and optimism followed by aggravating discovery of various failure modes. However, over-design in initial stages can lead to overconfidence and consequent breakdowns, as apparently occurred in early 727 landing approach mishaps, so vigilance must be present at every stage of development. After initial system shake-down, reliability should improve considerably, since the fatal accident rate on both the Boeing 707 and 727 in the first year or two was two to three times the level it settled to in later years,

due to improved pilots and ground personnel experience and plane modifications. However, in the case of aircraft, a cyclic process of better reliability in service, leading to overconfidence in pilots and service personnel and leading to worse reliability causes performance to stabilize as less than optimum levels. Guideway automation of control and inspection procedures permits removal of the overconfidence factor and better stable performance levels, so that reliability improvements of 5 to 10 times those of demonstration systems might feasibly be attained.

Reliability improvements in equipment can lead to a rapid obsolescence cycle which is out of phase with the actual amortization cycle, and could be more disruptive and costly than the Detroit styling changes. Proper attention should be paid to standardized attachments and adaptors on every vehicle and slide-out circuit trays with plug-in units, both for easy maintenance and for rapid updating of equipment. Again, good maintenance design will aid in keeping depreciation low, and with proper implementation of standards, excessive obsolescence for marketing's sake can be restricted to the luxury market, and not be a functional necessity for the guideway.

SUMMARY

The most important interrelationships between manual and automated control take place at entrances, exits and during emergency situations. At entrances, vehicles are centered, arms engaged in the rail, and automatic control takes over from the driver. A brief vehicle inspection follows, with rejection possible if the car fails to meet standards. Drivers then dial in their desired destination.

At exits, cars are slowed to 5 mph and the drivers must indicate that they are prepared to resume manual control. By steering to the left, cars manually move away from the guiderail. Those unable to continue manually are moved over to a waiting area.

In dense urban areas where long ramps are highly destructive to the urban fabric, and low-capacity exits are all that is needed, double-ended elevators can be used to save space and bring vehicles safely down to local streets, without inundating the streets.

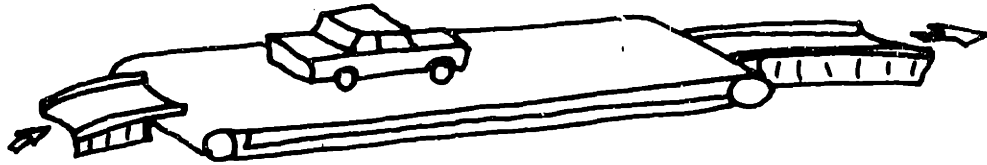
System reliability is critical, and a coordinated series of emergency strategies would be used in even of breakdown. Inspections, control circuit redundancy/testing/overdesign, quick detours to prevent backups, intermediate breakdown lanes, and a two-way dual-mode tow truck could all reduce the incidence and severity of breakdowns. Good maintenance is crucial and will also pay off in terms of improved liability considerations and insurance rates.

CHAPTER 8 STATION DESIGN

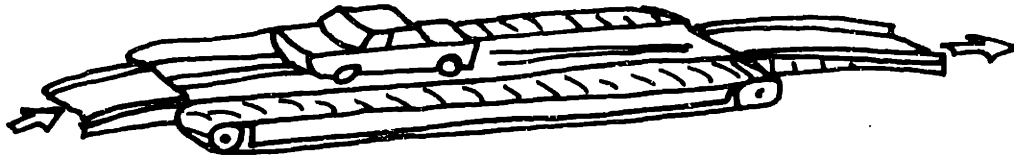
Public transit aspects of dual-mode systems is concentrated in the use and distribution of guideway stations. Passengers enter or leave personal vehicles, rented cars, and public minibuses, as the vehicles are diverted off the main line, directed to the station platforms, and then accelerated back onto the main line again. Unlike mass transit, autos and buses do not stop at every station, and vehicles are scheduled through the guideway network to avoid transfers. Subject to telephone recall, private autos are stored at automated parking garages, while buses and rented vehicles return immediately to circulate on the system or be stored in marshalling yards during off-peak hours. The numerous station design goals are illustrated in Table 8-1.

For vehicle flow through stations, the most important measure of station design is the land use efficiency, or capacity per unit land area. Mass transit is most efficient in this regard, automobile commuter parking lots are the least. Station operation is a flow phenomenon, and generally, movement types can be described as (Fig. 8-1) :

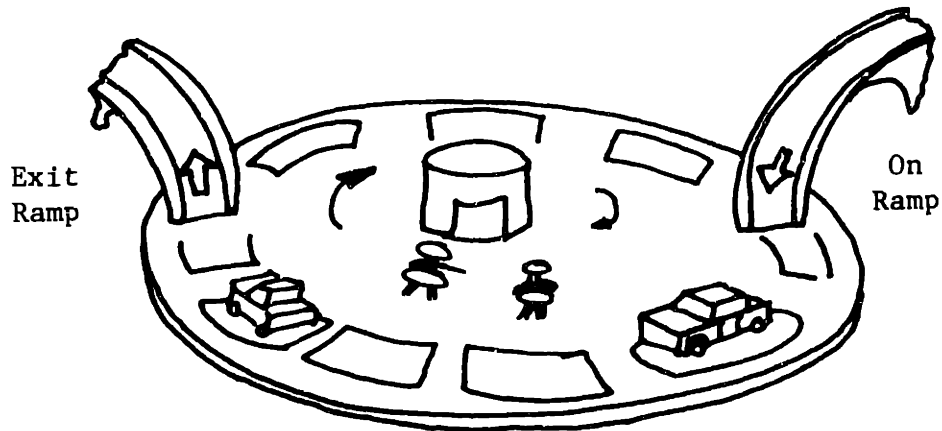
- (a) CONSTANT SPEED . Vehicles are transferred to a moving belt, or moved along at a constant 2 to 5 mph beside a moving sidewalk.
- (b) PULSED FLOW . Vehicles are moved in a stop-and-go manner, stopping at queues or at a platform berth, then moving out.



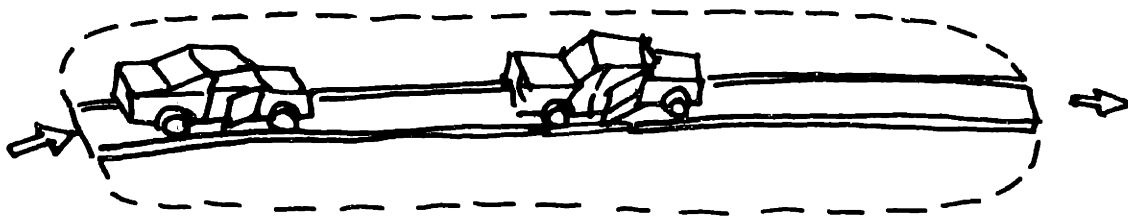
(a). Continuous Vehicle Motion : Moving Sidewalk with Full-width Belt



(b). Continuous Vehicle Motion : Moving Sidewalk only, with Fixed Guideway



(c). Continuous Vehicle Motion : Rotating Platen



(d). Pulsed Flow : Straight Channel

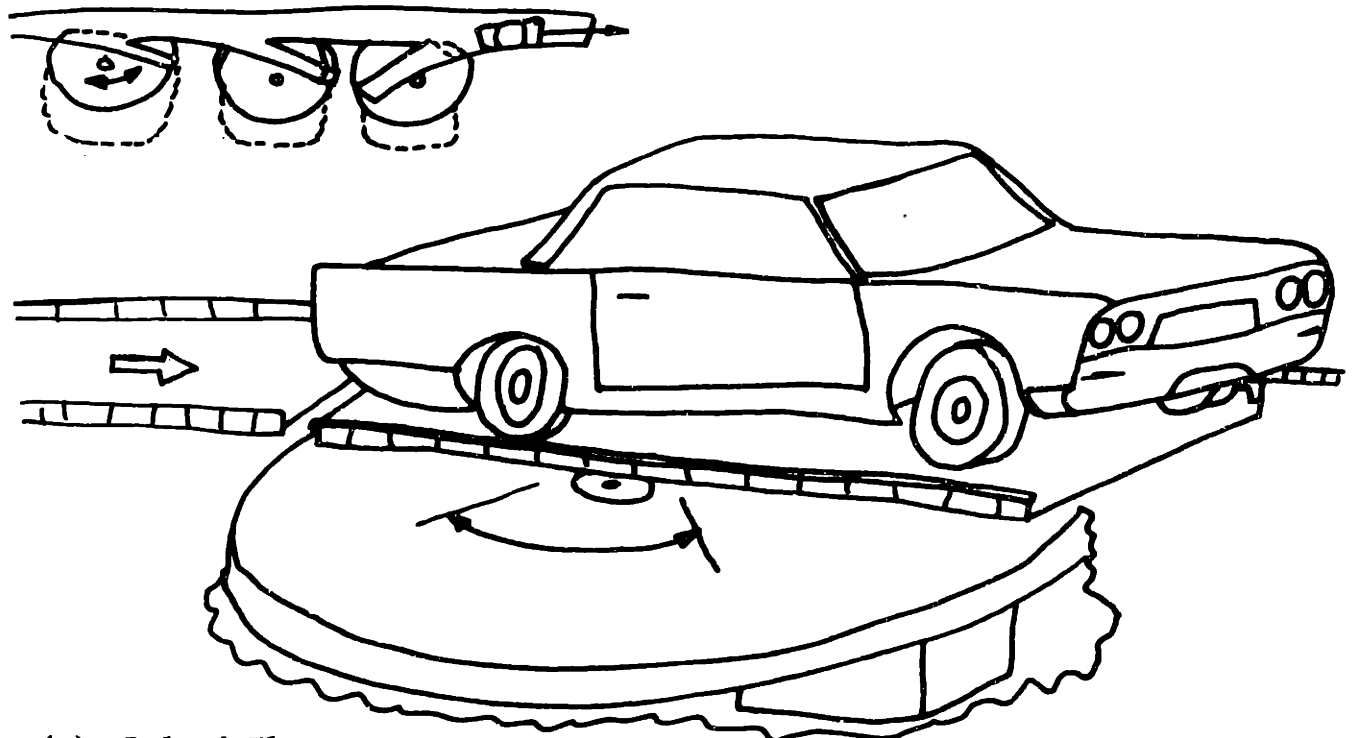
Fig. 8-1. Types of Vehicle Distribution Motion in Stations.



(e). Pulsed Flow : Single Slot Parallel Park

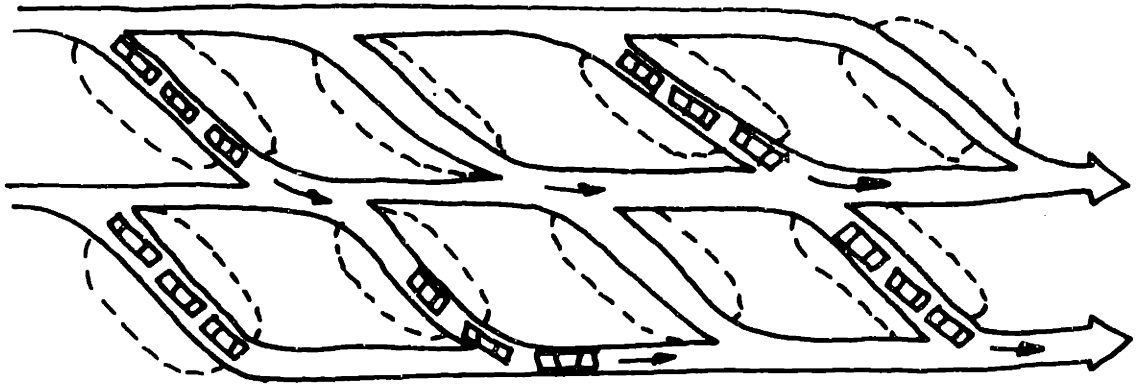


(f). Pulsed Flow : Multiple Slot, Parallel Park

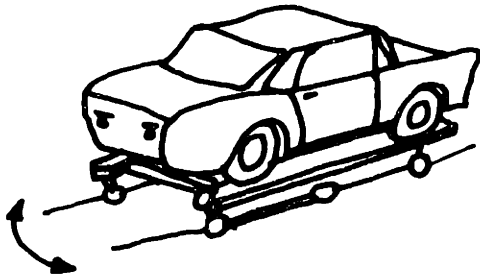


(g). Pulsed Flow :
Angle Park, Rotating/Oscillating Slot

Fig. 8-1 (cont.). Types of Vehicle Distribution Motion



(h). Pulsed Flow : Angle Park, connected Arteries,
Multiple Slot.



(i). Low Speed Trolley or Pallet

Fig. 8-1 (cont.). Types of Vehicle Distribution Motion
in Stations.

TABLE 8-1 STATION DESIGN OBJECTIVES

1. Land use efficiency η_s	Comparable to bus terminals or better
2. Average total time in station	Less than 60 - 90 secs. at rest.
3. Maximum time in station, including delays	Less than 5 minutes
4. Flexible time for entering and leaving vehicles	Range from 30 to 120 secs.
5. Two sided access to vehicle	All vehicle doors open.
6. Guidance arm and guiderail do not block access or cause major inconvenience	Access should be no more difficult than entering a car at curbside.
7. Pedestrians should be able to cross guideway	Possible at given times and under precautions
8. Private vehicle pick-up and scheduling; queuing capacity to hold vehicles	Cars can be summoned to a specific platform by phone or credit card.
9. Street access to stations	Fairly central locations; good weather protection elevators & escalators
10. Holding zone for cars	Platform area for tardy pass. arrivals.
11. Bus-only lanes	Separate platform lanes
12. Forward/lateral acceleration	Max 0.2 G forward; 0.05 G lateral
13. Speed control	\pm 2 ft. headway; good reliability
14. Pedestrian safety *Mechanical/electrical sensor *Human monitor/police	Pressure detector pad/electric eye protected power rail TV monitor, emerg. stop switch
15. Aesthetics : interior/exterior	Interior : equal to airport Exterior : unobtrusive
16. Geometrical design flexibility	Numerous shapes fit land use
17. Combined building functions	Shops & office buildings possible
18. Initial & operating costs	Comparable to bus stations or less.

(c). PALLET MOTION . Autos are mounted on a cradle or pallet at the station entrance and are shunted into a fixed berth or stopping line.

Pulsed flow is the most familiar concept, being the basis for operation of almost all transportation terminals, from subways to bus and airline terminals. Pallets are somewhat exotic and expensive, but moving belts have a conceptual simplicity which may balance their constraints of geometry and reliability.

The closest analogy to a pulsed flow guideway station is a large bus terminal. Vehicles move up to platforms, stop, and discharge passengers, before taking on others, while the main line is kept clear for through or departing traffic. Although 20 years old and far beyond design capacity, the New York Port Authority Bus Terminal remains an important design landmark, with its 1 million sq. ft. handling more than 40,000 passengers per hour and plans for 50% expansion beginning in 1971 and costing \$80 million over 2 1/2 years. The current land use efficiency

$$\eta_{\text{bus}} = \frac{Q}{A} = 4 \times 10^{-2} \text{ pass/hr-ft}^2 \quad (8.1)$$

and the cost efficiency of the structure additions is

$$\eta_{\text{\$bus}} = \frac{\Delta Q}{\Delta \$} = 0.25 \times 10^{-3} \text{ pass/hr-}\$ \quad (8.2)$$

with probably half the cost being land and property acquisition

to 42nd street in New York. For comparison, the new Boston Government Center Garage for 1850 cars cost \$6.5 million, which includes urban renewal land writedown, or

$$\eta_{\$car} = \frac{Q}{\$} = 0.05 \times 10^{-3} \text{ pass/hr-}\$ \quad (8.3)$$

for all-day commuter parking and 0.2×10^{-3} pass/hr- $\$$ for av. 2-hour shopper parking. The land use efficiency of the garage in terms of floor space for approx. 350 ft^2 per car is

$$\eta_{car} = \frac{Q}{A} = 0.05 \times 10^{-2} \text{ pass/hr-ft}^2 \quad (8.4)$$

for commuters and 0.2×10^{-2} pass/hr-ft² for shopper parking.

Bus terminals with long stop-over times such as the Port Authority Terminal employ the principle of angle parking around a central platform island, with departing buses backing into the service lane prior to leaving the terminal. In other cases where bus flow is greater and fewer persons board or leave per stop, one-way pulsed flow past main platforms or spur platforms can be achieved at some loss to platform centralization (Fig. 8-2). Normally, a single lane bus platform can accomodate 120 to 180 buses per hour when only a limited number of passengers board or leave at any one terminal, according to Berry¹. Operations of the buses in platoons with several loading locations at each platform -- together with an outside bypass lane -- can substantially increase the loading rate and capacity.

The pulsed flow guideway station lends itself easily to

platoon flow, with the size of the platoons depending on optimization analysis and demonstration testing. The basic station concept includes an exit ramp off the mainline guideway and a fan-out into a number of low-speed ramps depending upon the capacity of the station. (Fig. 8-3). Immediately preceding the platform area is a queuing region in which station queues are formed prior to the platoon moving up to the platforms. If each platoon contained five cars (or a combination of cars and vacant slots during off-peak hours) the queue length is approximately 100 feet. The maximum wait of the lead car in the queue will be no more than 10 to 20 seconds. The queuing area serves two functions : grouping cars together to improve platform capacity and efficiency while lengthening the entrance/egress time for passengers, and providing emergency capacitance for incoming vehicles when the station suffers overloading due to statistical traffic concentrations.

A platoon of vehicles moves into a platform area at about 10 mph and comes to a halt, with a platoon turnover time from the previous one leaving to the new one moving into the platform is about 10 sec, to which is added the actual platform waiting time. Pulsed flow has the advantage over moving belts in that loading times can be set in increments of time, e.g. 30, 60,90 and 120 secs. depending upon the time each platoon needs to load and unload -- buses and vehicles with elderly taking longer. A station-master watching TV monitors of the platforms could function like a

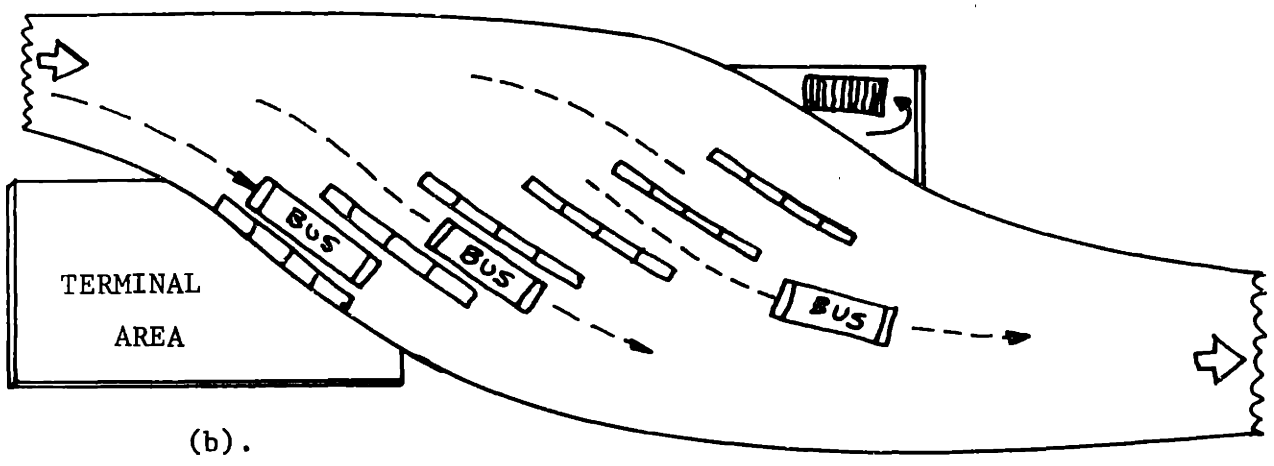
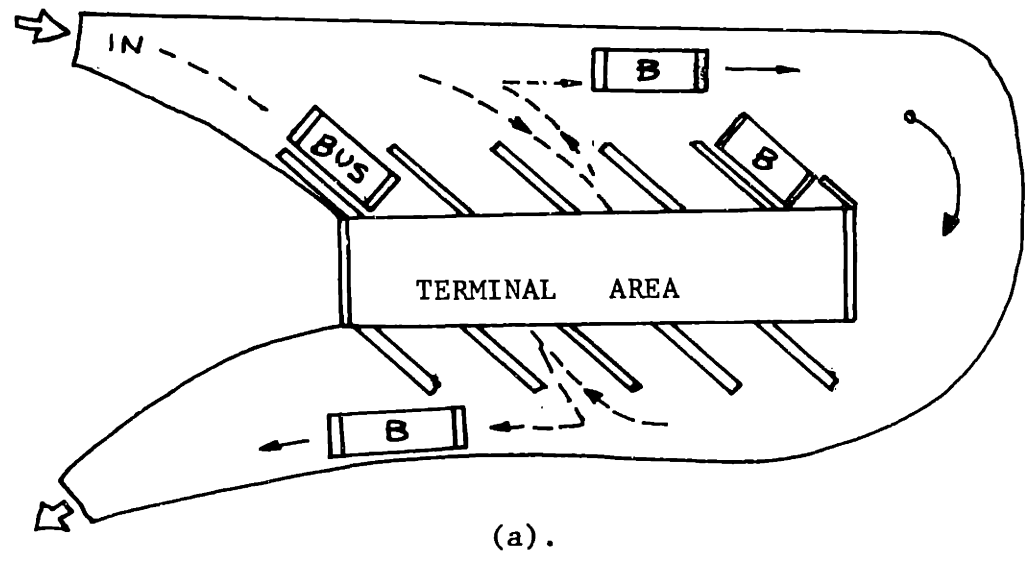


Fig. 8-2. Parallel-Park, Pulsed Flow Types of Bus Terminals.

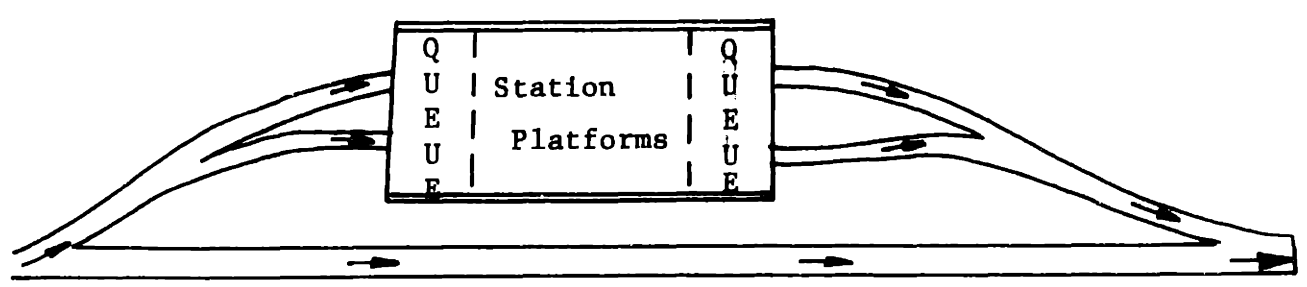


Fig. 8-3. Basic Guideway Station: Ramps and Queuing Capacity.

subway conductor, signaling departure when all passengers are settled with doors closed. Certain lanes can be programmed as express lanes (30 sec. average stop) while 60 sec. can be used for normal traffic and a 90 sec. lane is reserved for buses and shoppers.

Station capacity depends upon waiting time and the number of persons per vehicle who get in or out. For 30-sec. stops, and 5 vehicles per platoon,

Platform waiting time = 30 sec.

Move-out turnover time = 10 sec.

40 sec. per platoon

or 450 vehicles per hour.

For a 60-sec. stop, the capacity is 256 veh/hr. per platform and 180 veh/hr. for 90-sec. waiting times. For an average station with a mix of 30-, 60- and 90-sec. stops, the average platform berth has a capacity of 70 veh/hr., with a maximum of 90 veh/hr. possible.

The physical form of the pulsed flow guideway station is derived in part from the drive-through bus terminal format (Fig. 8-2b) and can be represented as a multilane, multiple platform structure (Fig. 8-4) which could have curved platforms or different ramp configurations to permit design flexibility of the station with respect to its geographical location. Excluding the fan-out ramps,

this 1450 veh/hr. capacity station has an overall building floor area of 16,000 sq. ft. (0.36 acre) at the platform level, an equivalent average area per berth of 1000 sq. ft. and a lane use efficiency

$$\eta_s \Big|_{\max} = 9.0 \times 10^{-2} \text{ veh/hr-ft}^2 \quad (8.5)$$

and

$$\eta_s \Big|_{\text{av}} = 7.2 \times 10^{-2} \text{ veh/hr-ft}^2 \quad (8.6)$$

with $\pm 10\%$ variation depending on size and configuration, with larger stations tending to be more efficient.

Stacking of levels for better land use effectively multiplies η_s by the number of levels \bar{n} , except that larger escalators are needed at the lower levels. Stacking provides more light and less shadow but greater height and horizontal profile, particularly on the access ramps. Land savings are the main important factor.

As an alternative to pulsed flow, the moving belt concept at stations has a steady flow continuity to its operation and appears readily adaptable to automatic vehicle control systems. The platforms will require an escalator to bring customers directly onto the moving belt (Fig. 8-5), and then a static waiting area is provided for persons to sit and await the arrival of their vehicles on the belt (Fig. 8-6). There appears to be little advantage in limiting the moving belt to the platform

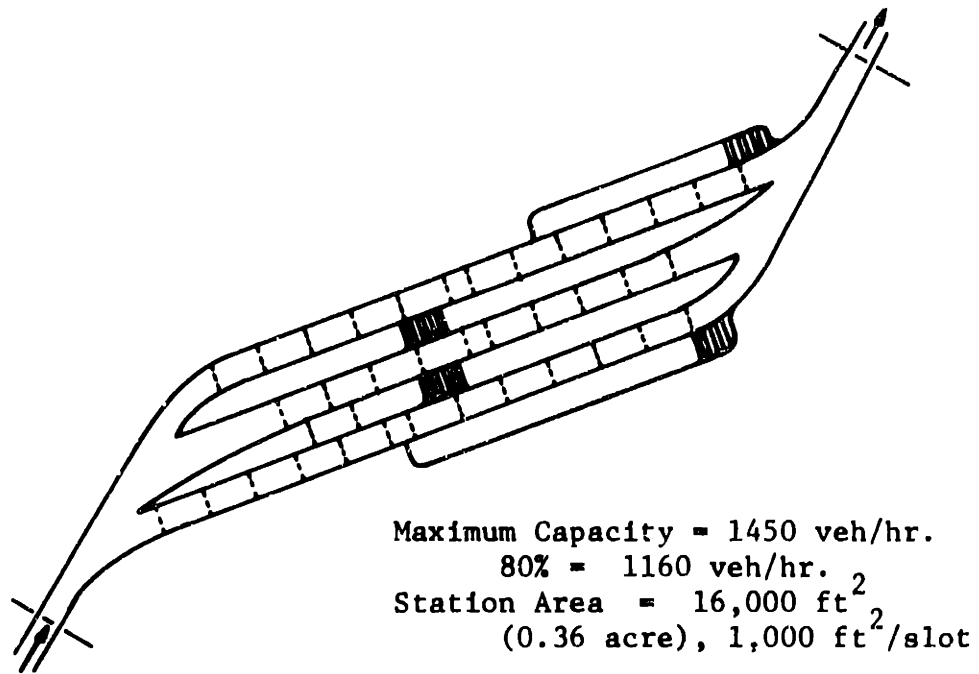


Fig. 8-4. Representative Pulsed Flow Guideway Station

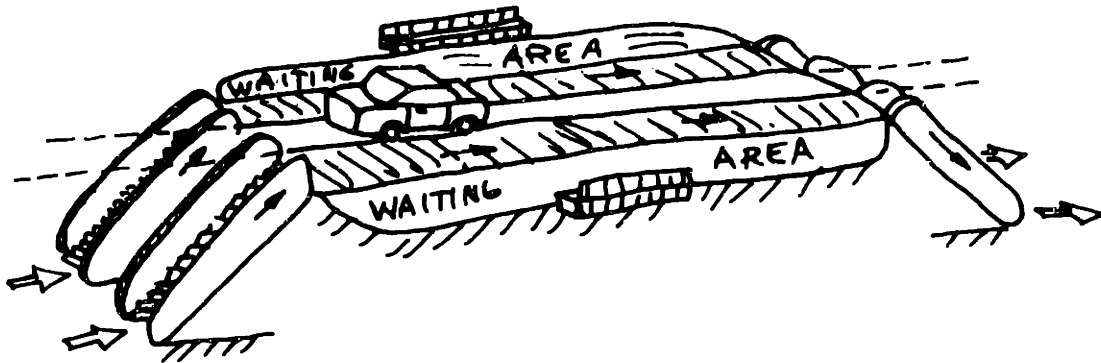


Fig. 8-5. Moving Belt Platform and Access Escalators,
Waiting Areas.

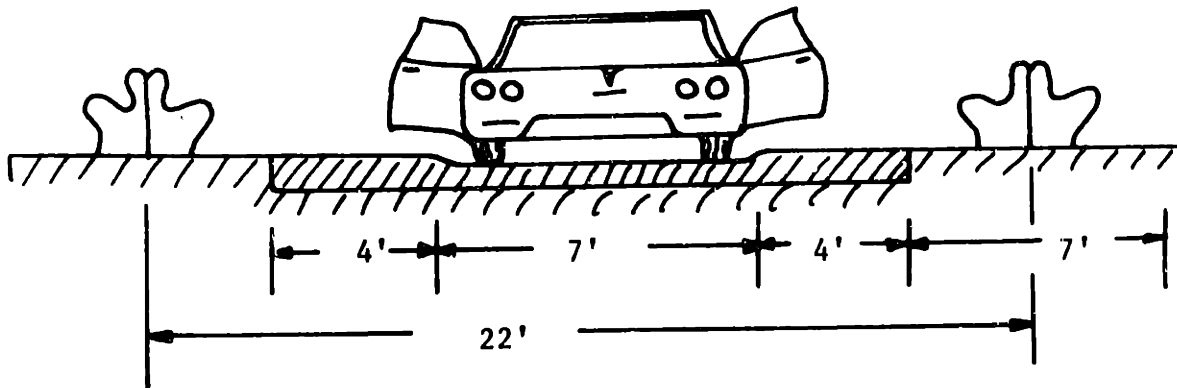


Fig. 8-6. Moving Belt Station Cross-Section

section only (with the guideway fixed and the autos speed-controlled in synchronization with the belt at 3 to 5 mph) since it would not be possible to cross between vehicles as it would be for a full-width belt.

An interesting characteristic of the belt station is that η_s is independent of the belt speed : the higher the velocity, the greater is the vehicle flow, but the station must also be longer for a given unloading time, t_p . For platform length, L_p , and belt speed V_s , and for slot length d_s and station width \bar{w} ,

$$t_p = \frac{L_p}{V_s} = \text{constant} \quad (8.7)$$

and

$$Q_s = \frac{V_s}{d_s} \quad (8.8)$$

so that with

$$A_s = L_p \times w \quad (8.9)$$

the land use efficiency of the moving belt station

$$\eta_s = \frac{Q_s}{A_s} = \frac{V_s}{d_s L_p w} = \frac{1}{d_s t_p w} \quad (8.10)$$

corresponds to theoretical flow considerations. However, decreased belt speed can result in improved safety and less hesitation for passengers to leave the waiting area, get on the belt and walk to their vehicle. On the other hand, increased belt speed reduces the passenger density on the platform and decreases the crush at the upper end of the belt (since passengers will tend to congregate there

to maximize the time they can have to recognize and enter their vehicles). Because of the constant speed feature, $t_p \geq 90$ sec. so that $\eta_s = 9.0 \times 10^{-2}$, offering comparable performance to pulsed flow. However, any delayed vehicle would stop the whole belt, and a certain queuing capacitance would be needed prior to and after the platforms, reducing η_s by 10 to 20%.

Pulsed flow stations are superior because of improved safety through stationary platforms, the flexibility of varied waiting times, less sensitivity to mishaps and malfunction, and geometric flexibility.

Guidance and speed control in stations must be placed in quite a different context, compared to high speed cruising. Merges and switches will be more closely spaced and turns will be made sharply without significant banking. Moreover, the arms and guiderails must not hinder vehicle access by passengers at platforms. Conceivably, the guiderail could swing or slide downwards at platforms, but the motion could be dangerous and cumbersome. A better approach is to drop the guiderail elevation to grade level at platforms (Fig. 8-7) with the guidance arm pivoting downwards also, and the resulting curb of 5 to 6 in. height is a familiar situation for entering a parked car and therefore presents a minimal barrier. The arm would still be drawing power and speed control information, although at low station speeds the lateral support function of the arms is no longer necessary.

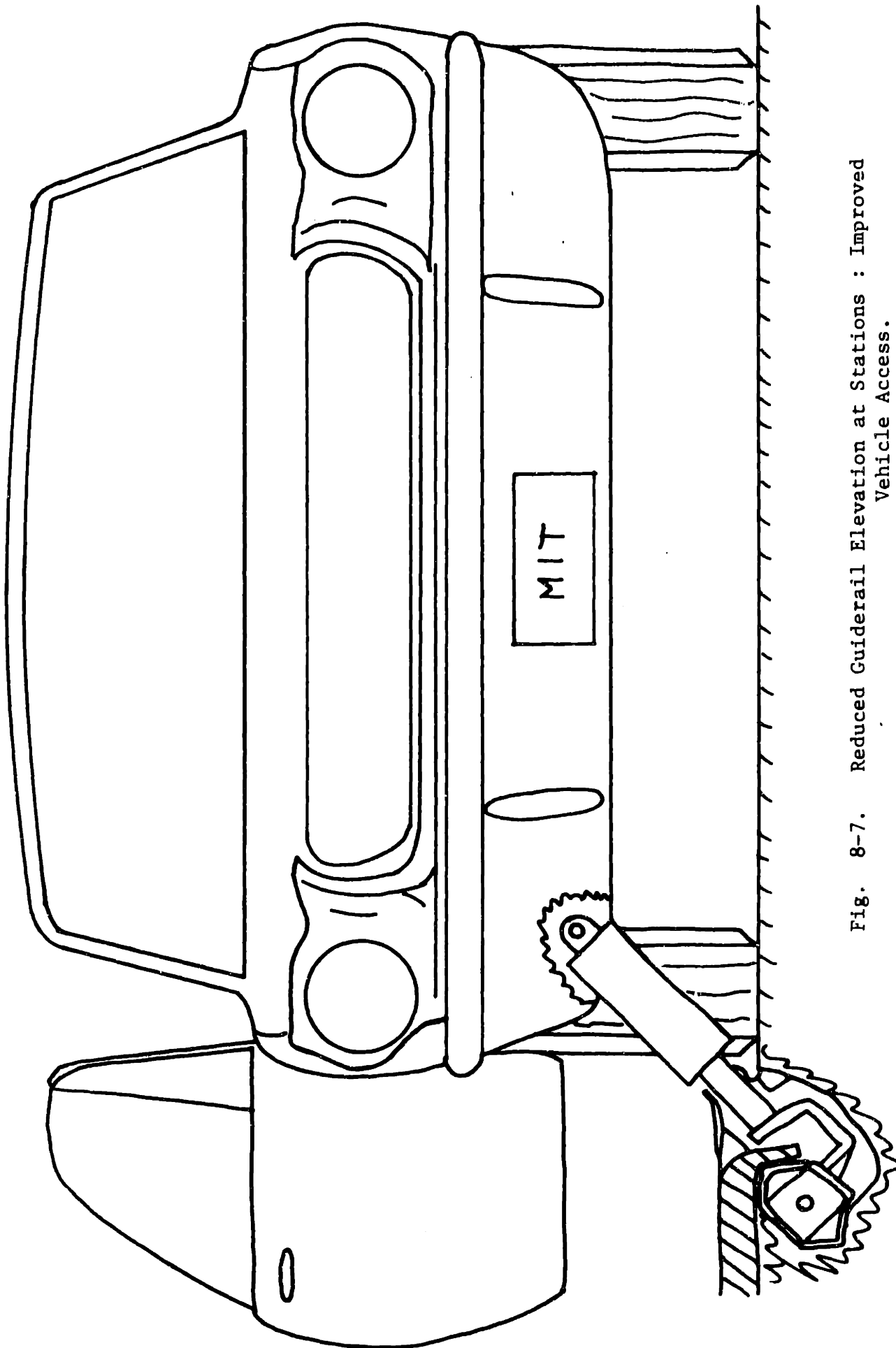


Fig. 8-7. Reduced Guiderrail Elevation at Stations : Improved Vehicle Access.

Because steering angles are much larger at low speeds, the arm transducer gain must be increased in stations or possibly could be zeroed, so that vehicles are guided solely by preview information from the guideway. Speed control by accurate guideway marker counting could maintain safe platoon formation and flow through the platform area, in response to varying carrier frequencies to each platoon and individual instructions to each vehicle.

TICKET/FARE PROCESSING AND PASSENGER SAFETY

The safety of passengers and pedestrians is vital at stations, both to preventing collisions between vehicles and pedestrian/vehicle conflicts. Once the incoming vehicle platoon has stopped, pedestrians can be permitted to cross the guideway between the stopped vehicles governed by "walk"/"Don't Walk" signals and weight-sensitive safety pads in the guideway, as well as audible warning signals (Fig. 8-8). The entering sequence for patrons would be :

- * Pick up ticket or insert credit card at platform entrance.
- * Enter platform but wait behind warning line
(similar to safety line at subway and train stations).
- * Stay behind safety line until one's vehicle has entered the platform area and come to a stop.
- * Cross the guideway to enter the other side of the vehicle, as desired.

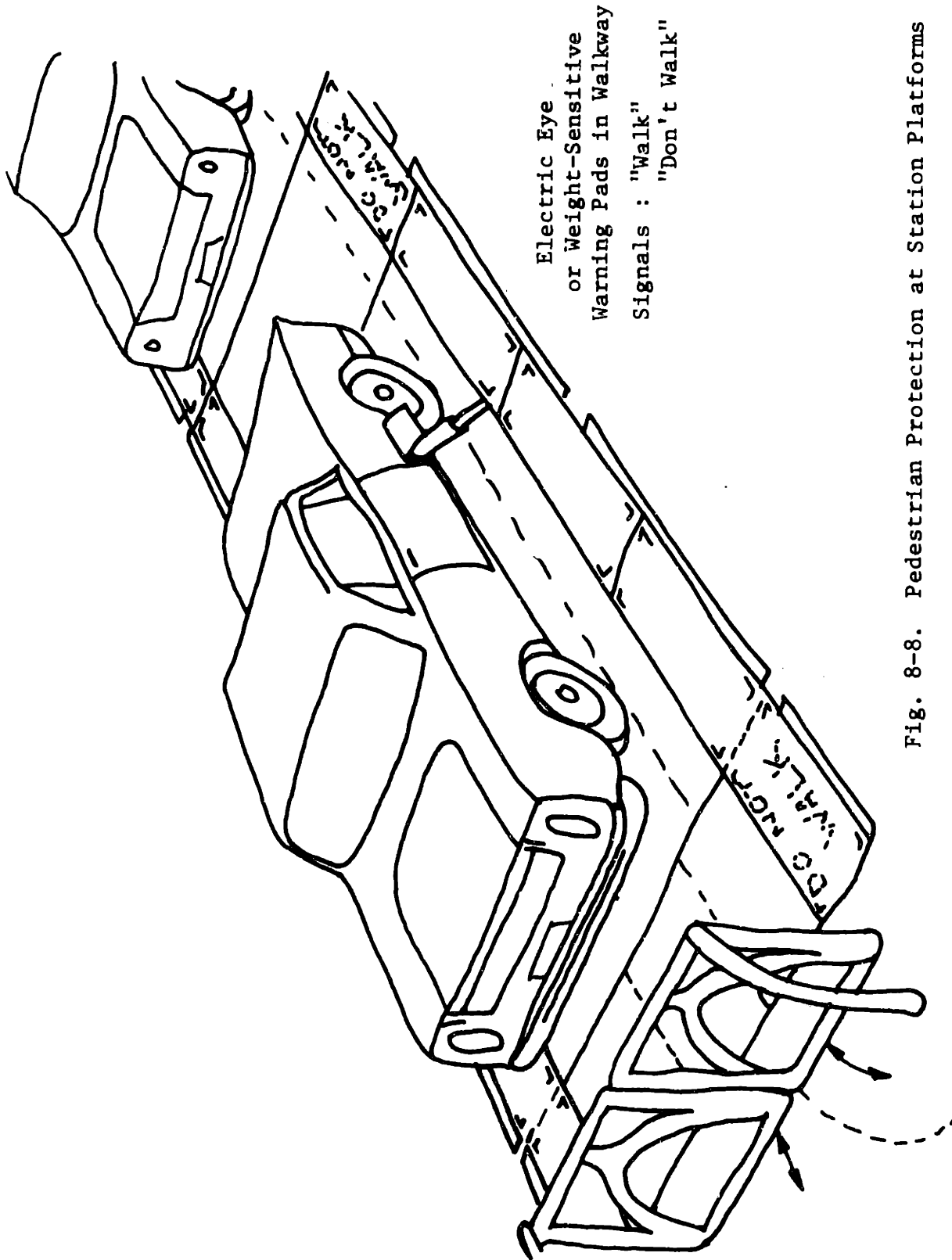


Fig. 8-8. Pedestrian Protection at Station Platforms

* Enter vehicle and indicate destination.

* Lock doors and fasten safety belts as necessary.

The operating instructions for arriving passengers are similar, emphasizing the need to wait for a complete stop, to cross the guideway with care and under proper conditions, and to leave the platform area by the closest escalator or stairwell.

In the afternoon rush hour, there is a compounded problem of a higher peak and the complexity of matching cars from parking garages with their desirous owners at the right time and place. The process is similar to that of handling airline baggage -- matching the owner with his bags after they have become separated. Fortunately, vehicles can be labeled, stored and scheduled, so the main problem is in assuring that the owners are at the right platform at the right times.

The sequence of requesting one's car and finally entering it at the station platform begins with entrance onto the main concourse (Fig. 8-9) and submitting one's credit card to request the vehicle stored at the parking facility. The computer schedules the car's arrival at the station, based on overall access time, and indicates which platform to walk to. The passenger takes the escalator to the platform and waits until a video or loudspeaker signal reads off his last name or otherwise indicates that his car is entering the station. Because each platform is two-sided and would abut eight to ten berths, the vehicle scheduling does not

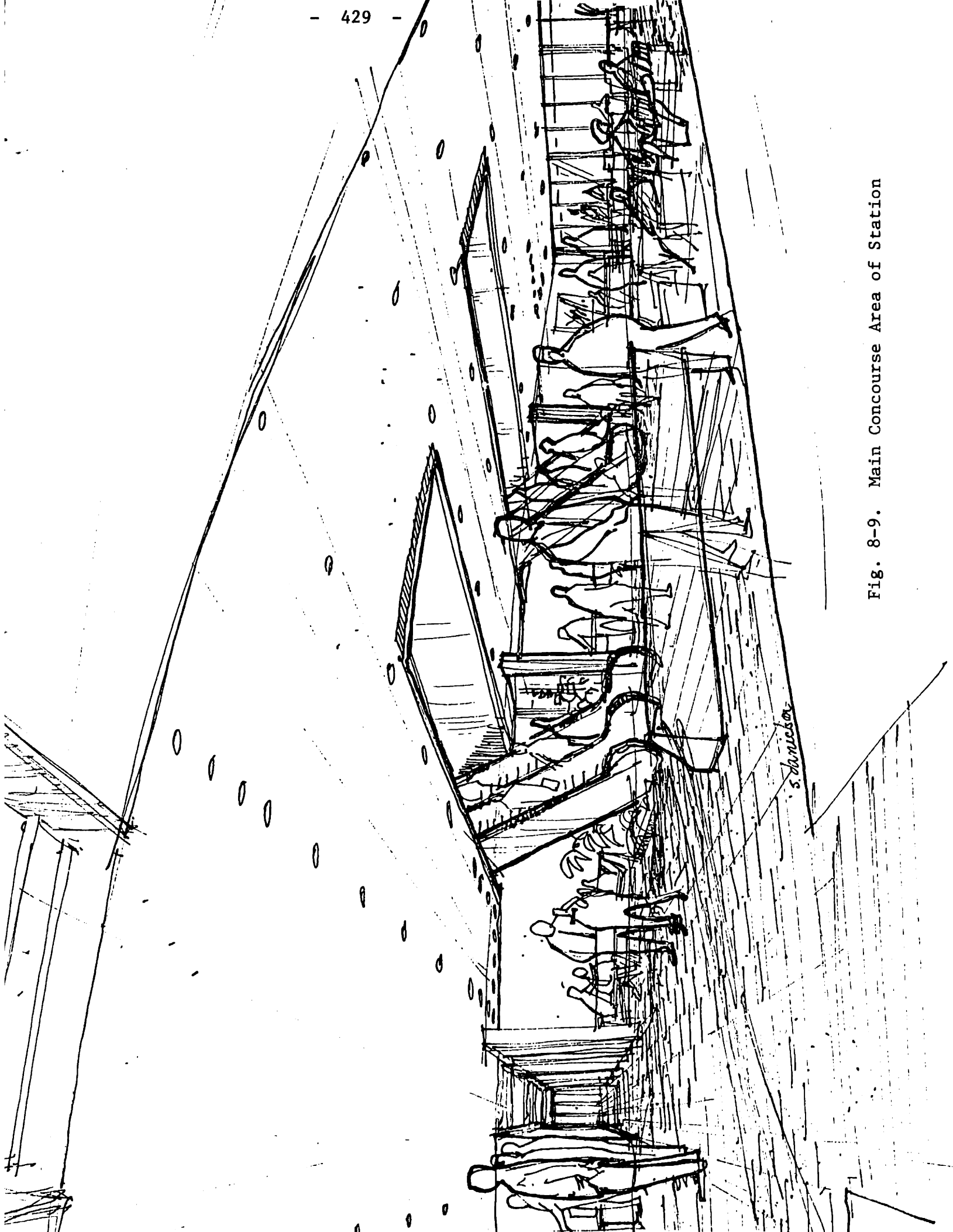


Fig. 8-9. Main Concourse Area of Station

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have to be absolutely exact and the patron can easily walk to any of the berths. At smaller stations, the user could walk directly to the platform and request his car to be scheduled directly to this platform, so that one less instruction is given to the rider. Passenger scheduling on public automated vehicles is less difficult, since a separate bus platform can be provided and either scheduled express or random local buses can be used. During rush hours, because of crowding, the free-scheduling dial-a-bus nature of the system could be downplayed and a set of scheduled times of arrival and departure instituted.

Because of the inevitable problem of people missing connections with the proper platform or their car, there could be a holding platform provided for cars which are held for a short period, while the loudspeaker instructs the user to pick his car up at that location. Because each vehicle stops either to drop off or pick up a passenger, the chances of persons illegally getting into the wrong car is minimal.

Ticket purchasing and processing schemes have already been discussed in Chapter 7, but an added note here is valuable on the advantages of coordinated ticket services in the whole city, transit as well as guideway. In Hamburg, Germany, season tickets are sold for transportation on public facilities, and today 60% of Hamburg transit passengers are season ticket owners, up 20% from two years ago. There are no turnstiles or ticket punchers,

although spot checkers watch for violators, with fines up to \$50 for passengers trying to get a free ride. The apparent cheating rate is low and most passengers are trustworthy, and the concept has been so successful -- 3% annual increase in transit usage vs. 5 - 10% losses in other German cities -- that there are plans to extend the ticket concept to the city's 8000 taxicabs. This system is simple and offers a minimum of irritation to passengers : whether it could be applied to both transit and dual-mode guideways in a City such as Boston will depend on the individual success and health of both. Guideway must prove itself operationally before the complex tie-in to a transit system, while transit authorities such as the MBTA are so sick in image and finances that guideways should not become enmeshed in regular transit controversies and malaise.

Guideway stations are not required to be simple spur connections to the mainline link or loop. They can exist on a two-way perpendicular spur, thus increasing the area coverage of dual-mode, or can be located on a one-way reversible spur for improved lane utilization, since guideway control does permit easy reversibility.

In conclusion, guideway stations -- when compared to other types of stations -- range from poor to good in land use efficiency. A typical two-track transit station achieves a capacity of 50,000 pass/hr. for a 60/40 split if half the passengers get off and half

get on at a busy station, and for a typical total platform area of 10,000 ft²,

$$\eta_s = 0.5 \text{ pass/hr-ft}^2 \quad (8.11)$$

For platform area only, bus terminals with drive-through movement offer comparable efficiencies, since for 40 to 70 buses typically processed per hour per berth for prepaid tickets,

$$\eta_s = \frac{Q_s}{A_p} = 0.30 \text{ to } 0.45 \text{ pass/hr-ft}^2 \quad (8.12)$$

where an average of 30 to 40 total loading/unloading passengers are handled at each stop. Double doors help in the passenger flow, but the passenger-to-door ratio is still about 20 : 1, which limits rapid loading and unloading and lengthens stops.

Guideway station capacity would depend on the mix of autos and buses, with the exclusively auto station described earlier

$$\eta_s = 0.072 \text{ veh/hr-ft}^2 = 0.11 \text{ pass/hr-ft}^2 \quad (8.13)$$

for an average car occupancy of 1.5 persons. Thus auto-guideway stations are only 20% as land efficient as transit. However, if half of the berths in Fig 8-4 are used by express buses unloading 80% of 12-passenger capacity and loading 40%,

$$\eta_s = 0.53 \text{ pass/hr-ft}^2 \quad (8.14)$$

which is quite reasonable. However, neither the bus nor the guideway calculation include the area or volume consumed by ramps off the

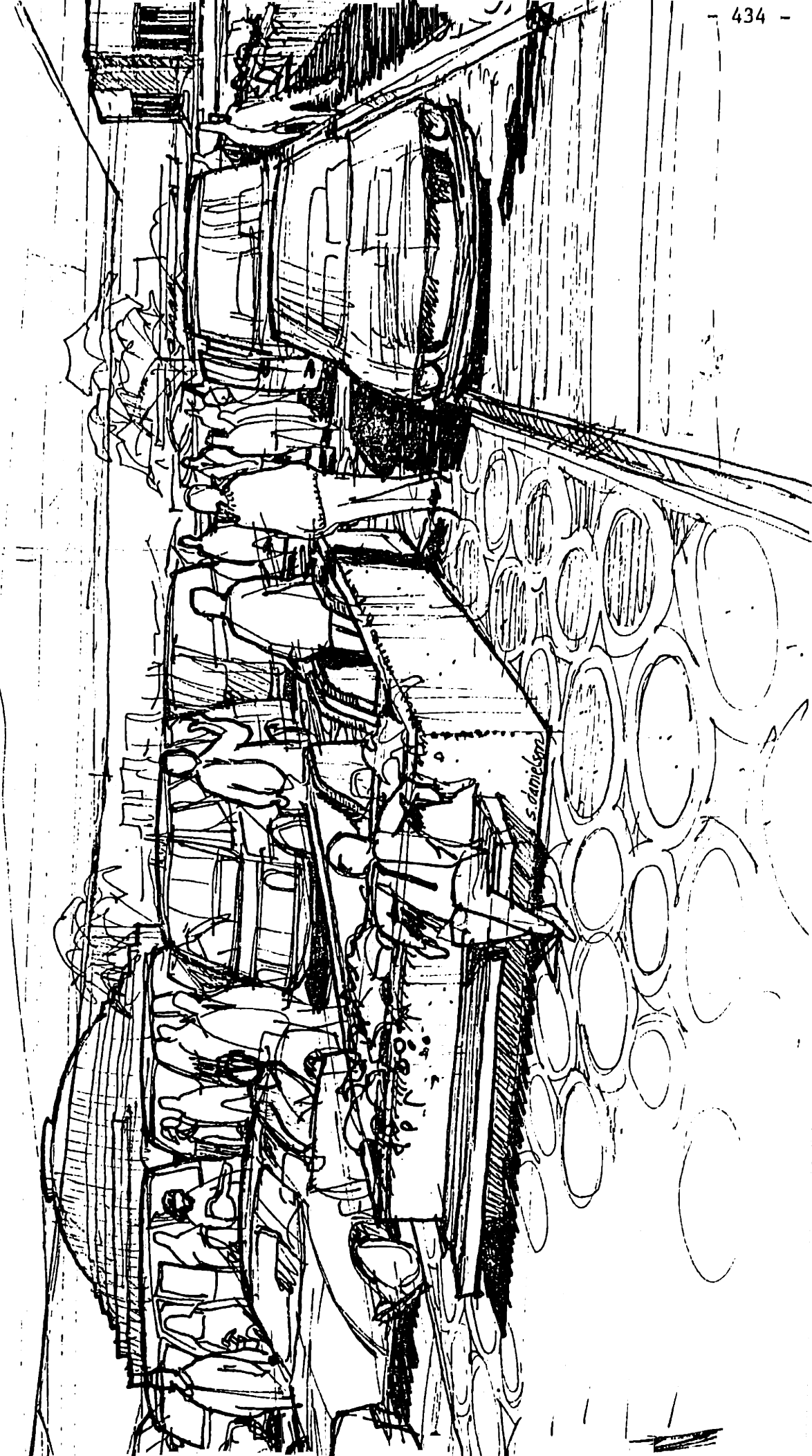
mainline. The costs of the guideway fan-out ramps must be balanced against the advantages gained from direct scheduling with no intermediate stops or changes and better utilization of the stations themselves, since many transit stations not at interchanges are often barren and underutilized.

STRUCTURAL DESIGN AND AESTHETICS

Guideway stations, as discussed in Chapter 6, must conform to good standards of appearance and scale. Smaller stations can be aligned parallel to guideway/railroad ROW, elevated in a cut, or located over nearby buildings at rooftop level and built on short stilts. Separate combined facility new buildings can be built to incorporate a guideway station at roof-top, internal or sub-basement level. Depending upon the need, guideway stations can be open, semi-enclosed or completely enclosed for protection against the weather (Fig. 8-10).

The design requirements for stations are two-fold : how to design good facilities and how not to design bad ones. Because of the non-dominance aspect of guideways, the stations must be compact, low profile and attractive in detail without reliance on overpowering bulk. There is no better example of what a station should *not* be like than the new Boston City Hall, with its excessively bold, angular and frigid neo-Brutalesque architecture, its overpowering use of concrete and brick and the creation of ghostly voids

Fig. 8-10. Open-Air Guideway Station



rather than open space. The surrounding Plaza is a paved moonscape monotony, nicknamed "The Desert of Boston," which contrasts with confining interior walls and disorienting hallways, with few places to sit down and relax, and internal functions of government and activity which are agonizing and infuriating to use. The \$26 million structure was chosen in competition with 255 others, as the selection committee of the American Institute of Architects heralded it as "impressive, functional, economical and harmonious with its surroundings,"² although the building actually seems to have the most dubious distinctions in the latter three areas.

The guideway stations cannot become monuments to the fantasy of architects any more than the guideway can become a monument to a structural engineer. One of the primary functions of a guideway demonstration is to build up from simplicity and from the very beginning generate customer and abutter comments on the design and function of facilities as inputs to architects and engineers, rather than giving the latter parties free rein. Guideway stations must be pleasant and comfortable in appearance and conformance with locale, whether this be modern or old-fashioned design. Stations should not be "avant garde" or modern for that reason alone. The Stockholm subway has a quite flexible decor, with Spanish tiles and pillars with reliefs and carvings in concrete, mosaic and stone, while the decorations of the outer walls at track level incorporate colored glass prism tiles. However,

keeping these facilities clean in years to come may be a very difficult problem. The crucial element in good internal guideway station aesthetics is not the opening day splendor, but the willingness and ability to keep the facility clean year in and year out, since probably the most common complaint about transit -- particularly from non-users -- is not the service and drabness but the filth of subways and buses. Incorporating stores within guideway stations will help, since cleanliness and good appearances are usually essential to good business as well.

The sound environment of most subway stations is poor, ranging from dullness to the clatter of women's heels to the bone-shaking rattle of the trains and the squeal of their brakes. Music in a public place is unwise because of the differences in taste and monotony aspects, but the silence and off-peak loneliness could be reduced by piping in the sounds of store sounds and street crowds up above. A more novel idea is the installation and sound transmission of an underground waterfall and fountain, operating year-round and creating a soothing sound and serving as a public attraction. One notes that the most successful aspects of both the barren Copley Square and City Hall Plazas are the fountains there.

The location and function of stations are closely linked to the role of the pedestrian in the city, that walking is often unpleasant and difficult -- as well as deterred by the auto. The main subway parking lot in Toronto attracts only 1/3 of its 1416

capacity because the lot is 1500 ft or a ten-minute walk from the trains. Walking in the city must be made more pleasant and less of a dirty, uncomfortable endurance contest fighting the weather, fatigue and other pedestrians. The city should accept the task of enhancing the role of the pedestrian, which today has the connotation of the dull, the everyday and the lackluster, and to stop the process whereby sidewalks are pushed to the side as appendages to vehicular streets and used for snow storage in the winter. The first step is the establishment of an expanded city Traffic and Parking Department, which would explicitly include pedestrian and bicycle functions within it. Pedestrian access to buildings, transit stations, and guideway stations could then be developed in a more coordinated manner, and relieve some of the mobility constriction on the central city because walking in so unpleasant.

Second story walkways have been proposed for many cities to aid pedestrian movement, and in Minneapolis seven pedestrian skyways link the building network for protection against cold weather and street crossings. The goal is access to 54 blocks, with 13 others accessible by tunnels or street level passageways. These walkways are carpeted and airconditioned and -- like elevators -- have all been built at private expense for \$100,000 to \$250,000 each, and can carry 18,000 people in an 8-hr. winter day, 7000 in summer. For a more temperate city such as Boston the idea makes

sense because of the numerous old and narrow streets and the advisability of achieving a choice of two pedestrian levels, one for more relaxed shopping and the other for more through passage -- and not to achieve a grade separation whereby pedestrians give up the street level to vehicles. Guideway stations could service either of these levels, but again a sense of scale must be maintained so that larger stations do not cause too great a concentration of flow of pedestrians in any one area.

SUMMARY

Stations along the guideway have a direct transit counterpart : passengers leave or enter vehicles at a platform. On guideways, parking occurs at some periferal location after leaving the station, and private vehicles can be summoned to the station on demand.

Of the two primary types of stations -- moving belt and pulsed flow -- the method of pulsing platoons of vehicles past platforms appears superior, in terms of architectural flexibility, avoidance of costly and potentially hazardous belts, and variability of stoppage time at a station. A pulsed flow station of 1450 veh/hr. capacity would occupy an area of 16,000 ft², including queuing slots but excluding braking and acceleration ramps.

Vehicles would switch through a fan-out network to reach individual platforms, and guidance arms drop to permit two-sided access to vehicles. A station monitoring agent via closed circuit TV observes and signals a warning when a platoon of vehicles is entering or leaving a platform. Buses dramatically improve the efficiency of dual-mode stations, compared to passenger cars.

CHAPTER 9. GUIDEWAY COST ESTIMATES

The hazards of cost estimates and predictions are many, and elementary errors and assumptions can entrap even the best construction and operations analysts. Issues of jurisdiction, inflation, standards, specific location, property value assessments, politics, payoffs, mistakes and grantsmanship all become relevant factors influencing the final cost estimate, and in periods of tight public monies and budgets, the pressures will be to come in with a low initial estimate and then try to survive the cost overruns that develop. Errors of analysis can spring from at least three basic sources, inadequate study, insurmountable ignorance due to truly unpredictable factors, and sins of commission -- in order to keep the cost estimate low for initial approval.

The Interstate Highway program is an interesting case of all three basic sources of error interacting, of early optimism in 1956 for a \$27 Billion system giving way to the most recent estimates of \$73.4 billion, due to high costs of urban links, tightened standards due to heavy truck traffic and numerous other factors. The sheer magnitude of the project can overwhelm one's sense of accuracy, since a billion dollars is equivalent to a person standing beside a hole in the ground and tossing in a \$10-bill every minute every hour of the day and night for 190 years. However, uncertainty errors apply in microcosm as well

as macrocosm, since the Holland Tunnel, originally estimated to cost \$12 million, was built for \$50 million, and Boston's Leverett Circle Bridge plan in the early 1960s was estimated as a \$3 million project, but the price tag has now risen to \$15 to \$20 million. Inflation has been phenomenal in the construction field, with labor costs between 1950 and 1968 have risen from 66.44 to 158.0 (on a 1957-59 base period = 0), materials from 71 to 127, overhead from 71 to 131 and the total construction costs from 70 to 141.¹ Today, the rate is a startling 12% per year and sometimes more.

Because of a greater concern for adjacent impacts, many projects must include costs to cover changes in access or in overloaded street intersections. Moreover, assessments on "condemned" land for takings are becoming more generous, for the example of the Suffolk Franklin Savings Bank in Boston which took to court the BRA assessment of \$700,000 of its building and won an award of \$2.3 million.

Cost estimates for dual-mode guideways and systems must be made and interpreted with full understanding of the uncertainties in technology, reliability, performance, R&D costs and delays. At best, system costs can be indicated at the present level of development within 50 to 100%, although certain aspects can be predicted to within 10 to 20%. A separate thesis on costing is required -- one based on construction experience as well as on design concepts and more extensive testing.

FULL COSTING OF HIGHWAYS AND GUIDEWAYS

Too often the cost of highways has been calculated on the basis of construction costs alone, possibly with the addition of some ROW costs. The Interstate average for urban expressways of \$3.7 million per mile is the bare reportable cost, and does not include parking, tax loss (or gain), construction period cost impacts & detours, congested local streets and intersection impacts, policing and full displacement/inconvenience costs, as well as the environmental costs of air and noise pollution, and the Chinese Wall effect. The cost of an 8-lane highway as a function of net residential density increases linearly virtually from zero -- from \$1,000,000 per mile for zero residences to more than \$14,000,000 per mile for net residential density of 180,000 per square mile.² For the proposed Cross Manhattan Expressway in New York, land acquisition costs were 50% of the total. This expensive land is often taken off the tax rolls, and additional intrusion of parking lots further reduces the tax base.

Maintenance costs are imposed on states and local communities without adequate cost sharing by the Federal Government commensurate with construction subsidies. Even seemingly periferal expenses can become significant, since in 1969, it cost \$748,924 simply to clean up the litter and rubbish on Massachusetts State highways alone. Traffic congestion on expressways and local streets has a high cost, with the costs to a city such as Munich being estimated as a loss of

3.5 million workdays annually³. The losses due to accidents are also substantial, but seldom accurately included in any cost-benefit calculation:

- (a). Goods and other property consumed
- (b). Emergency and interim transportation and communications
- (c). Personal services rendered : legal, medical, additional hire, etc.
- (d). Time consumed by all persons affected.
- (e). Indirect damages, insurance and payments
- (f). Anguish, anxiety, misery and suffering
- (g). Government service and operations
- (h). Consequent increased policing, emergency details, construction.

Any substantial cost estimate of guideway system costs must include adequate consideration of these factors, and no effort can be made to consider them in this thesis.

RAIL TRANSIT COSTS

Construction costs for rail transit lines can approach or exceed \$20 million per mile in downtown locations, as tunneling and station costs increase. However, ROW costs tend to be low or non-existent, and general efficiency is excellent. Rolling stock and maintenance, as well as mounting labor costs, are contributing to financial problems, as Pullman Standard cars for Boston transit have risen from \$110,000 per unit in the early 1960s to \$161,000 to \$175,000 per car for the 92-car

"silver train" fleet for the MBTA Red Line, for a total of \$13 million. Diesel Buddliners cost \$250,000 per car, and the maintenance of regular transit cars is approaching \$10,000 per year per car, although newer models offer a 20% power and maintenance reduction through improved design.

The running costs for the automated BART transit line are revealing, in terms of their implications for dual-mode :

* Power	13.8¢
* Way and Structure Maintenance	10.2¢
* Maintenance of Cars	6.6¢
* Injuries and Damages	2.4¢
* Administrative Overhead	6.0¢
	<hr/>
	subtotal : 39.0¢
* Motormen and Security	21.0¢
	<hr/>
	60.0¢

where car costs are on a per-mile basis.

If all charges are considered, including capital costs for rail, stations and cars, the cost to BART of carrying one passenger one mile during the early years of operation will be about 13¢,⁴ although after amortization, average costs will drop to 4¢ per passenger mile. The \$1 billion-plus cost of building the tunnels, tracks and stations, as well as cars and parking lots, is being

financed by a special property tax levied in the three counties which the 75-mile system will serve, plus a portion of the San Francisco Bay Bridge Tolls.

BUS TRANSIT COSTS

The 40 to 50 passenger diesel bus today assumes the primary role of urban transit, from a minimum of 35% of the transit load in New York City to 100% in many cities. The basic bus costs \$30,000 and is fairly reliable, driving trolley cars and buses into uneconomical oblivion. However, feeder service and off-peak hours are unprofitable operations, and the operating costs of buses are in the \$.60 to \$1.00/veh-mile range, being higher for more dense regions, but having lower patronage in sparsely populated regions. Total driver cost is \$8 an hour and amortization costs can be about \$3500/yr. Costs due to delays and trip time uncertainties are far greater than rail transit, and total yearly operating costs can approach the cost of the bus itself.

The use of smaller minibuses has been advocated as a more flexible and appealing transit solution, but high driver costs have usually plagued most proposals. A 9-passenger station wagon or bus costs \$3000 and monthly operating costs for driver, insurance, etc. will be about \$1200/month or \$14,400

per year for an 8-hour shift. A 12-hour driving cycle will produce operating costs of \$20,000 per year, and possibly \$30,000 per year for a 12-passenger small bus vehicle. A minibus in the 19 to 25 passenger range will have a much more significant first cost of \$13,000 to \$20,000 and not be as useful for multiple purposes, while operating costs should be only slightly higher than the minibus.

AUTOMOBILE COSTS

Although the average urban and suburban family spends 26% of its income on housing and only 7.2% on transportation, a car for many families is a sizeable commitment to expense for many years. A car costs twice as much to own in a city than the national average, so that a Boston driver who covers 10,000 miles a year will, according to the ALA,⁵ pay 20.92 cents a mile, and a \$3000 car commits the owner to an expenditure of \$11,000 over the next 10 years, \$19,500 (not including financing charges) if traded in every year.

However, because of manner that the driver finances his auto transportation, the sunk costs and hidden charges are seldom included in the psychological cash outlays associated with daily usage -- even the incremental 5¢ to 8¢ per city mile of travel are not felt directly because the trip has been "prepaid" by filling the gas tank at the service station, where the gas taxes are paid as well. If drivers had to insert a nickel into an

instrument panel slot for every mile traveled, car mileage would be more closely rationed by the owners.

DUAL-MODE VEHICLE MODIFICATION COSTS

The modifications discussed in earlier chapters will be a function of the design, performance and equipment of each vehicle. The incidence of types & power of ICE engines, transmissions, power steering and brakes are all important in determining both the incremental cost of guideway components and the relative tolerance of buyers to extra-cost equipment. Of all American cars sold, the factory installations of equipment has been from 1964 to 1968 :

ITEM	1964 model year	1966	1968
Automatic Transmission	77.5%	86.6%	89.1%
V-8 Engine	69.0%	80.0%	86.4%
Power Brakes	29.3%	35.3%	44.9%
Power Steering	51.9%	66.6%	77.4%
Radio	64.4%	78.9%	87.9%
Air Conditioning **	17.1%	29.3%	43.3%
Disc Brakes	-	2.9%	11.2%
Speed Control Device	-	-	4.1%
Speed Warning Device	-	-	2.3%

(** Other air conditioning units added later by private supply houses).

The existence of power steering or power brakes may mean that one less fluid pump and reservoir needs to be added to the system, the automatic transmission makes speed control easier, the radio may be used for voice communications, and the air conditioner frequency will be a measure of the parasitic load that the guideway powerplant must provide. The smaller foreign cars (12-15% of the market) will tend to have fewer options, but power requirements will be less.

Under the present design uncertainties for dual-mode, the best that can be attempted is a laundry list of components and modifications and a rough estimate of basic cost :

1. Guidance Arms, arm box and fender lids; actuators	\$150-\$250
2. High pressure pump or reservoir for steering	0 - \$25
3. Steering control valve and lock; cylinder & valve	\$ 20- 50
4. Brake control valve, actuator & lock	\$ 15- 40
5. Electric Motor and mounts	\$ 50 - 75
6. Gears and drive shafts	\$50- 100
7. Modify gas tank	\$ 0 - 20
8. Add speed control circuit, signal receiver	\$ 50- 100
9. Position counter and transducers	\$ 20 - 30
10. Switching logic processor	\$ 10 - 25
11. Dashboard control console	\$ 25 - 50

total est. range \$390-\$745.

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total est. range \$390-\$745.

This figure compares with an average of \$400 to \$800 in extras bought on most cars, and does not include other costs such as air pollution control equipment (\$100?), air bags (\$100 - 150) and improved bumpers (\$100?) which may be Federal requirements on all new vehicles. The modification cost estimate does not reflect any subsidies or driver rebates on liability insurance, nor does it adequately reflect labor costs incurred on early low-volume modifications to vehicles.

The added cost of system automation on the guideway is approximately 10% of the ROW and construction costs, or about \$100,000 to 300,000 per mile, including power distribution. However, the design life will be less, and thus the amortization rate tends to be higher. Semi-automation of the MBTA Green Line with new trolleys and signal equipment included \$18 million for new rolling stock and \$18.5 million for power distribution and signals/communications.⁷ The GM autoline system for complete buried cable automatic control included approx. \$50,000 per mile per lane for these functions.

The R&D and start-up costs will also be important special costs for a demonstration system, and a rough estimate for the distribution of staging costs can be developed from data based on industrial innovations and will be a function of local situation, time and distance duration of the demonstration and the technical complexity :

	Typical Distribution of Costs in good Product Innovations	Dual-Mode Demonstrn. Costs
* Research, advanced development, preliminary testing of dual-mode concept functions	5-10%	10%
* Engineering and product design	10-20%	20%
* Tooling and Manufacturing expenses	40-60%	40%
* Manufacturing start-up expenses	5-15%	15%
* Marketing/Demo. Advertising Start-up	10-25%	5%
* Insurance and reserves	?	10%
		100%

Since cost saving through mass production has been one of the few sciences ever entertained by Detroit -- with spark plugs costing 17¢ each and V-8 engines \$70 at the plant -- there could be important dual-mode savings achieved at later stages through improved production methods.

The general format and rough estimates for capital and operating costs for the guideway are summarized in Table 9-1, based partly on an analysis by the General Research Corp.⁹ These costs must be balanced directly by receipts from grants, subsidies, tax and fare revenues, and indirectly by the savings and services rendered to society by the system. The receipts could come from user charges, fuel taxes, license fees, parking fees, excise taxes, leasing of facilities or air rights, special taxes on cigarettes or other luxuries, advertising and concessions, computer leasing in

TABLE 9-1 ESTIMATED GUIDEWAY COSTS (PER MILE, TWO-WAY)

ITEM	Est. Useful Life, years	Capital Cost, \$ Thousands	Annual Cost Equivalent \$ thousands	Comparitive Typical System Today
(@ 6%)				
Guideway Construction (\$15-20/ft ²)				
* Elevated 20-40 ft.	40	1,500	100	\$10-15/ft ² HW
* At-grade supported	40	1,200	80	\$20-30/ft ² Tr.
* At-grade paved	40	500	33	\$10/ft ² HW
* Cut channel	40	1,200	80	\$ 2-5/ft ² HW
* Cut and cover	40	4-8,000	266-532	
* Tunnel (17-ft.diam)	40	4-15,000 ¹⁰	266-1000	\$20M/mile Tr.
Land Right-of-way				
* Air rights	∞	50-150	3-9	Factors
* Air rights plus land	∞	100-300	6-18	can range
* Land and lateral access	∞	100-300+	6-18	over 10x
* New ROW (urban)	∞	400-1000+	24-60	based on location
Maintenance				
* ROW	-	-	1	
* Structures	-	-	10	
* Power	-	-	2	
* Electrical Controls	-	-	2	
* Stations	-	-	10	
* Parking Garages	-	-	10	
* Landscaping	-	-	5	
Station Construction				
* On-route	40	300-400	18-24	\$15-20/ft ²
* Main terminal	40	500	33	(fn. #10)
* Land	∞	50	3	
On/Off Ramps & Booths	40	400	24	
Parking Garages	40	2-8,000	133-532	\$1000/space to 4000/space
Repair & Storage Shops	40	200	12	(multilevel)
Direct Operating Expenses	-	5¢/mile		
Legal & Insurance Fees	-	0.5¢/mile		
Vehicle first cost	5-10	2-5	0.2 to 1 per vehicle	
Modification Costs	0.4-0.7	0.4-0.7	0.1	
Maintenance costs	-	0.2-0.4	0.2-0.4	
Amortization costs	-	-	0.2-1.0	

off-peak hours, state local and federal subsidies, bond issues, and other special taxes. The savings can be measured in door-to-door travel time and reduced uncertainty, improved land utilization and tax base, reduced congestion on local streets and improved business, reduced pollution and less stress & strain.

Simple calculation based on 80,000 ADT and 10-mile average trip length one-way yields an unsubsidized cost rate for cars of \$0.08/mile for guideway services, \$0.05 direct operating costs and \$0.02 per mile for vehicle modification costs, or about \$.15 per mile. Parking costs average out to \$0.04 per mile, so a 10-mile trip to and from, plus parking is \$3.50, while the direct costs to a driver who parks at the Government Center Parking Garage is \$3.00 to \$3.60 in direct costs, plus all the hidden subsidy costs of highways.

Bus costs would, of course, be lower for lower income persons riding public transit, but the actual level will depend on labor arrangements and subsidy/multiple use policies on the use of guideway buses.

CHAPTER 10 IMPLEMENTATION STRATEGY AND TECHNIQUES

As early as 1632, the Virginia House of Burgesses passed a law stipulating that each man had to work a certain number of days each year on a road or pay someone to do it for him. Over the centuries, a public and private interest in roads and other transportation corridors has grown into a formidable force, and the nation has witnessed the development of what is commonly referred to as the "Highway Lobby," or the public-private interest conglomerate which seeks planning, extension and maintenance of the rubber-tired network of roadways.

Between 1945 and 1955, motor vehicle registrations increased from 34 million to 68 million, and by 1965 had risen to nearly 100 million. Nearly 13 million people -- one person out of six -- are employed in manufacturing, maintaining or driving motor vehicles. Of a total national construction business of \$80 billion a year, highways and maintenance account for \$16 to \$20 billion; eight out of the top ten largest corporations on Fortune's list have major highway interests. Because of the wide acceptance of the automobile as a popular conveyance, the dependence of shippers on truck traffic, and the large number of jobs directly and indirectly dependent on road/vehicle operations, a wide range of highway user, state agency and private industry interests will "petition" their legislators for favorable policies towards the

implementation of new and improved highway plans. As the relatively unbiased *Handbook of Highway Engineering* notes,¹

Most often, such petitioning is done through organized interests. In polite terms it is legislative representation; the less qualmish call it lobbying. But whatever the term, it is important and influential....Many groups have particular interests in highway affairs, often of a conflicting nature some of the obvious ones are the automobile and trucking associations, the highway users' conferences, the good-roads federations, the road-builders associations, and associations of automobile, truck, trailer, petroleum, and tire manufacturers and dealers. An active interest in all highway developments is maintained for obvious reasons by railroad associations....Chambers of Commerce and other business groups are interested. The granges and the farm bureaus, the Teamsters Union, and the railroad brotherhoods, the contractors and the pavement makers -- the list could go on indefinitely -- are all likely at one time or another to have something to say to legislators about highways.

A full analysis of this process and its implications for highway funding is beyond the scope of this thesis and has been attempted elsewhere² (Table 10-1 summarizes some of the leading member groups), but the important issue is the interaction of interests to support an ongoing program and the dedication of these groups to an extension of the *status quo* unless they can be convinced both of a transportation crisis and a viable alternative which appears to be a reasonable response to changing times.

If functionally, America's urban and rural areas are reaching the limits of highway usefulness, and operationally a clamp must be placed on the freeway system, the implications for the highway funding and construction cycle are enormous.

Today, highway funding is achieved primarily through user charges on gasoline, oil and rubber, with \$12.9 billion out of \$17.2 billion nationwide spent on highways being collected from user taxes. The process of use, funding and construction yields a positive feedback cycle that reinforces both the need and the funds. Many cars produce a need for highways; trust funds are used to build more roads; more trips of longer distances are made on the new roads, more new cars are sold to use the high-speed roads and more gasoline and tires are consumed -- hence more user taxes are channeled into the highway fund, and now the state can build more highways to answer the increased need for new roads.....etc. The strength of the Interstate user and the commuter has been shown in the distribution of funds, which are going extensively to expressway facilities. The new highway bill passed in late December 1970 by Congress authorized \$9.7 billion to fund the Interstate system through 1976, yet only \$200 million has been earmarked over the next two years for building or revamping major streets in cities of more than 50,000 population (matched 50-50 by state contributions) through the TOPICS program, but even this money is being partly diverted into expressway construction by state highway departments, as in the case of the 8-lane Rutherford Avenue in Boston.

The transit situation is in marked contrast, with a very weak lobby of manufacturers and users and an image which is hurt even more by transit operations which are disorganized and plagued by problems of unions and poor morale. Unpopular tax increases or bond issues

must pay for deficits and construction, and there is no invisible user levy like a gas tax which can be used to prime the pump and maintain stable financing. Boston's MBTA, which services 621,000 riders daily and 20,000 others on commuter rail lines, will have an estimated \$127.4 million record budget in 1971, with an estimated deficit of \$61 million -- an increase of \$22.5 million or almost 55% over the previous year. Unfortunately the bookkeeping of the MBTA and the fiscal estimates are so confusing and fluctuating that these dollar estimates can vary from one month to the next. In February 1970, the *Boston Globe*⁴ reported that the MBTA assessments allocated to the various communities to cover the deficit has increased from \$18,165,275 in 1964-65 to an est. 1970 figure of \$46,567,200, with some communities encountering a 5000% (50 times) increase in the last two years alone. For example, the city of Lynn is typical of many municipalities in regular fiscal difficulties, yet its MBTA assessment has risen from \$5,113 in 1964-65 to \$17,987 in 1968, \$268,620 in 1969 and \$729,452 in 1970.

The largest single sum of the MBTA budget -- 80% of the total -- goes for salaries, wages and fringe benefits, and salaries have increased at twice the cost of living index in recent years. The fare increase in December 1968 has been attributed as the cause of an estimated \$10 million in lost patronage⁵ and on a per capita rider basis the MBTA is the

most expensive urban transportation operation in the country.

When created in 1964, the MBTA was hailed as a great pioneering experiment in regional public transportation. In 1971, the Authority is perceived as an entrenched and uncoordinated "new bureaucracy" which is seemingly at the mercy of its bondholders, the Massachusetts legislature, the MBTA advisory board, the 27 separate MBTA unions and a disgruntled public, which includes the plague of common criminals and drunks who terrorize or rob bus drivers and passengers. The MBTA is basically a political creature, dependent on the approval of its advisory board and ultimately the legislature, and the unions have been quite adept at using the legislature as a trump card to aid the union cause. The 1964 act creating the MBTA district had an assessment structure which discouraged commuters from riding the MBTA and reduced the interest of communities in maximizing available service. As the 79-member community district grows to general revolt over the deficit and service mismatch, the Authority is hampered by internal conflict, resignations of key personnel and executives, major vacancies in top management, the uncertainties inherent in imminent reorganization under a state Department of Transportation and a lack of familiarity among managerial personnel of union and operating procedures & problems. The resignations of Leo Cusick and Robert Wood, as well as the criticism of the Governor's Task Force on Transportation, have combined with the effects of the

the five-man MBTA board, which stymies planning operations, so that there is little faith or likelihood that the MBTA can straighten out its problems rapidly. The overall transit Master Plan has suffered many setbacks and cost revisions, while both new construction and maintenance show the old symptoms of trouble : on the new South Shore Line, 125 out of 500 possible working days was lost due to labor disputes....while in November 1970, the new General Manager Joseph Kelley said that the trolley system "is in danger of collapsing" because 1/3 of the 343 trolley cars are laid up for lack of maintenance.⁶ And in a desperate effort to save money, the communities are willing to vote to cut \$5 million from operations, which may lead to 20% reductions in bus service.

The health of the commuter railroads is clearly visible, mainly because of the declared bankruptcy of the railroads. From 75,000 passengers per day using North Station in 1950, the figure is down to less than 10% today, although the Boston and Maine receives a \$3.8 million subsidy from the MBTA for its 11,000 riders, and Penn Central receives \$1.6 million for the 2000 persons carried on the Needham and Franklin branches. Nationally, the passenger rail deficit has risen from \$9 million in 1963 to over \$200 million in 1969, with overall derailments up 65% in the last decade.

Other forms of private urban transportation are also in

trouble. For many bus companies, the difference between red and black ink is often the express package freight service the buses provide (so that almost all the added height of intercity buses is going into the luggage compartment), and taxi drivers are also demanding higher wages -- as in New York where cabbies average \$150 a week and are seeking equality with transit workers, who receive \$175, without overtime or premium pay. Moreover, a recent report by Price, Waterhouse & Co. shows that taxicab fleet owners as a group have been losing money at the rate of \$7 million a year in New York.⁷

Incredibly, airline have now become a losing business. Compared to profits of \$147 million in 1969 for the 12 major airlines, a combined deficit of over \$200 million is projected for 1970 operations, down from a peak profit of \$400 million in 1967. The sudden drop has been attributed to high expenditures for equipment, (jumbo jets at a time of high interest rates, with commitments in excess of \$10 billion between 1970 and 1973), delays in approval of fare increases, overcompetition for routes and low load factors, a sluggish market for used aircraft, a slowdown in passenger growth rates and a general pinch caused by cutbacks in the economy and business expenses -- especially travel accounts -- all combined with soaring wages and maintenance costs. TWA could lose up to \$50 million, the largest loss ever sustained by an airline (TWA owes over \$500 million to its creditors).

The annual growth rate of 10 to 15% in the 1960s slipped to one or two percent in 1970, and there were reportedly 340 fewer daily flights operating in 1970 between the 1000 leading U.S. cities, compared to 1969.⁸

Have we as a nation reached the stage where all forms of transportation become a losing business? The idea is disconcerting, the evidence startling :

- * Deepening bus, rail and commuter rail transit losses increasing yearly and extended to all sizes of cities; service cutbacks worsen situation and decrease confidence.
- * Rail industry earnings declined 30% in 1970, with Penn Central taking a \$233.7 million net loss in the first 9 months. The impact of a bankruptcy of a company which followed the merger route to \$6 billion in assets is still reverberating through the industry
- * The major airlines not only are losing money but have experienced a \$350 million drop in net earnings in only one year. Because of air hijackings, strikes, air controller slowdowns, bad business, citizen protests over airport noise, anti-pollution requirements on jets (both smoke and noise), the cutbacks in service and prestige, the overcommitment to new capital expenditures and the uncertainty of the SST all indicate a very bleak future for the airlines and a collapse even more stunning than that of Penn Central.
- * The trucking industry has been hit by rising costs, wildcat strikes, difficulties in dealing with the teamsters, congestion losses and community resistance to trucks, esp. noisy and smelly diesels -- which may be subject to the same regulations as jet airliners.

* State and municipality highway departments are going broke because of the heavy traffic impact of the Interstate roads, the uncontrolled traffic and the facility deterioration caused by heavy trucks and the use of road salt -- esp. to old bridges. The Mass. Department of Public Works and Metropolitan District Commission have both had large highway funds financed by state user taxes, but today have no surplus for needed bridges and road improvements. Moreover, efforts to reconstruct facilities requires major construction operations, including heavy cranes, earth moving equipment and 50-ton cement trucks which cause so much damage to nearby roads and bridges that a never-ending spiral of reconstruction is required.

* The auto companies are suffering from bleak times. Chrysler took a \$20.2 million loss in 1970 and was barely saved from bankruptcy by financial maneuvering. American Motors had a \$50 million loss for the fiscal year ending Sept. 30, 1970, and mighty General Motors suffered a third-quarter loss only partly due to the UAW strike.

Equipment suppliers appear to be able to make a profit, such as tires, gasoline, optional extras for cars and construction devices, and these types of costs because of their "optional" character can be passed on to the user without major objection and hence deficit. The only other stable transportation function which makes a profit is the toll bridge : the Triborough Bridge in New York is the only self-supporting element in the entire New York transportation system, and the Mystic Bridge in Boston is a major revenue source for the Port Authority.

DEVELOPING A STRATEGY FOR DUAL-MODE ACCEPTABILITY

It is in the framework of severe strain and declining profitability in transportation that dual-mode implementation must be conceived, presented, demonstrated and accepted from both the funding and the service aspects. A strategy for this effort must be developed; in fact, contingent strategies must be developed in the event of foreseen or unforeseen failure, since implementation is a long series of interconnected steps from Research and Development to long-term operation. It is not sufficient to win all the battles and lose the war, as in the case of the Space program or the Interstate Highway system; nor can one win all the early battles and lose in the finale, as with airships, monorails, Dynasoar, the SST and aircraft carriers. Both length and breadth of planning must be present to provide for contingent "Muddling Through" and threats of either non-implementation or mis-implementation. A sequenced participation process must be outlined, to include industry, public agencies, community groups, the traveling public and elected officials. And at every stage, an appreciation must be evident of the past and possible pitfalls which historically have or can affect transportation demonstrations.

Full analysis of potential opposition is as important as the aligning of support. The existing technological heirarchy

will resist change and the threat of a competing system. The canal builders fought the road builders, the Navy fought military aircraft, the horse-and-buggy brigade combined with the railroad to resist the horseless carriage. In fact, England's Locomotive Acts (which required any mechanically propelled road vehicle to be preceded by a man on foot carrying a red flag) were originally intended to protect the railroads from the competition of road coaches. The operators of turnpikes in the 19th century fought the public roads movement, while the 20th century railroad and transit workers fought automation and assumed that every management innovation was an effort to cut labor costs -- as often was the case.

East Cambridge in the late 19th century was the site of a classic case of innovation, demonstration, resistance and defeat of a workable system. Mr. Joe Vicent Meigs of Lowell experimented on a monorail carriage from 1857 to 1879 and then developed a test prototype in 1884, built along Bridge St. which is now McGrath Highway. An elevated, single-post-supported 1/2 mile track was constructed, with a steam locomotive, tender and several cars, with the design objective of avoiding the heavy locomotive and the track heaving & freezing associated with conventional steam railroads. The engine was designed for both city and intercity application, and to control the smoke and dust of conventional railroads which caused many travelers to use

steamboats between Boston and New York. The train weighed 30 tons, seated 72 people and could turn a 50-foot curve with ease. Initial tests for the Board of Railroad Commissioners were highly successful, with a high degree of comfort, good ride and quiet performance, and the Meigs system was declared "absolutely safe, alike to passengers, employees and to those not passengers, free from all dangers attending breakage of parts, and secondary dangers, accidents and horrors resulting therefrom." However, the West End, Street Railway Company declared the design too radical for local traction uses and decided to convert to electric cars. Meigs struggled with his case right up to the state Supreme Court but lost. His business opponents sabotaged his offices, wrecked his models and plans and set fire to the shed containing his train on Feb. 4, 1887 -- ending the hopes of Mr. Joe Vincent Meigs.⁹

San Francisco's BART also had a rocky ride, but the planners have finally pressed through to completion. Rapid transit advocates pressed the California legislature to authorize a study project in 1951, and despite widespread support, it was not until 1957 that the legislature officially organized BART to begin planning the system. Once planning had been completed initially, BART spent several years mobilizing public opinion for voting support on bond issues. Even with these extensive efforts and the famous Freeway Revolt of 1959, the 1962 BART referendum could barely muster the needed 60% voting support -- 61.2%.

Progress was further delayed when four taxpayers sought a reversal in the courts, on grounds that the system was too costly. There was a crisis when San Mateo county, one of the original five, defected from the plan because officials objected to the property tax assessments levied to pay off the bond issue. Construction finally began in 1965, fourteen years after the original study project began.

A combination of funding sources reduced the impact on any one source but did lead to complexity in planning. The cost of \$1.4 billion in construction was covered by a \$792 million general obligation bond issue and from state-authorized toll bridge revenues, as well as a DOT grant of \$260 million and a special three-country sales tax of 1/2 cent per retail dollar exclusively for BART. These direct costs have been affected by indirect impacts of new office buildings in San Francisco, Oakland and Berkeley, with \$850 million in construction under way as early as May 1969 -- although the tax revenues of this building boom must be balanced against increased city services which must be supplied. This boom has been caused largely by anticipation of BART and a relaxation of zoning requirements which may threaten the preservation of the "Old San Francisco" moreso than freeways and cars ever did. So it is that BART may be introduced into service in a very sceptical and critical environment, and its success or failure will have impacts across

the nation.

The crucial questions for dual-mode start-up are :

- (a). Who will pay for the development (and at what stage)?
- (b). Who will own the system?
- (c). Who will operate and maintain the system?

The organization forms range from a non-profit government agency operating under the principle of welfare economics to a private profit-making corporation, with the more practical combinations located between these extremes. The basic problem is one of developing a large, complex public service where only rudimentary techniques or organizational structure exist.

The telephone company example and that of electric power development are prime examples of private development and investment leading to high-asset utilities after many decades and operating on a profit basis subject to Federal regulation. In the case of nuclear power and the Atomic Energy Commission, the factors of cost, national security and safety precautions combined to maintain government control over the years and only gradually to involve power companies in the construction and operation of nuclear plants. The experience has been one of excessive promise and government monopoly, and the public service impacts (in terms of environmental complaints) have been largely negative.

Military and quasi-military programs to develop civilian

transportation have had mixed results. From Hannibal's elephants and Spanish Galleons to the post Civil War railroads, the large trucks of World War I and after, and the Interstate Highways developed from World War II needs, the military has taken a great interest and innovative role in transportation -- even including ocean liners and most importantly for the modern age : aircraft. Some efforts, such as dirigibles and the B-70 bomber, may be judged as failures, and today the military has fallen into considerable disrespect. It is doubtful that dual-mode could serve any useful purpose, and that the military could serve any funding function.

Experience with the Aerospace Corporation and Foundations has given rise to a very bad image for non-profit operations, both as a tax dodge, competition with regular corporations, and the inherent power play and self-interest which still afflict a non-profit organization. The National Aeronautics and Space Administration is a classic case of an agency completely divorced from public service and quite unable to plan for its own political and project future. It's Man-on-the-Moon mandate (presented to it by Presidential fiat) was never developed into an internal decisionmaking structure for practical post-Apollo efforts, so that no supporting lobby of private and public interests could unite behind any one space program and present a case for priorities consonant with the national mood. The Space Age shattered in the environmental crisis, race relations and Vietnam

and space planners became detached from the public, its needs and service desires. On a longer time scale, the railroad companies have lived in a "Railroad Age" and have been unable to adjust to the times.

The nuclear airplane and the SST show cyclic evidence of efforts by the aircraft industry and its supporters to press the Government on a plane of questionable feasibility and high costs -- by raising the bogeyman of foreign competition once too often. The general rule seems to be the failure of the competitive/profit argument to hold after the initial glamour of special service opportunities has begun to wear thin. The nuclear plane program began in 1946 and ended unsuccessfully fifteen years later after more than \$1 billion had been spent. The Aircraft Nuclear Propulsion (ANP) program was run jointly by the Air Force and the AEC, with ANP advocates hoping that commercial atomic planes would follow the initial military planes. Three points of view arose in terms of strategy :

- (a). "Fly early" -- represented by the Air Force, AEC and Joint Congressional Committee on Atomic Energy,
- (b). "Fly later" -- represented by technical advisers to the Secretary of Defense and the President; they sought to delay flight testing until more research had created a better plane and less risk of investment,
- (c). Sceptics -- members of the Bureau of the Budget, and certain members of the House Appropriations Committee and successive Defense Secretaries : scuttle the program.

The inability of the ANP advocates to get together and plan a coherent strategy and instead to divide and conquer themselves, and not to take action which would reduce the opposition of the sceptics led to a well-deserved demise for the program.

The SST has had a similar history of excessive promise and advocacy, compounded by poor design, disregard of the opposition, and a failure to justify the transportation service role. Like the ANP, the SST will entail over \$1 billion in development cost, with the FAA offering to pay \$750 million and private industry \$250 million, although the shaky aerospace industry is hard-pressed to contribute any money at this time (one speculates what would have happened if instead of Boeing, Lockheed had won the competition for the final SST design). Despite this Federal aid, FAA officials estimate that it will take 12 to 15 years for the aircraft industry to get back its original investment and begin to make a profit on the SST.¹⁰ The SST idea began its trek through Congress in 1959, with appropriations of \$11 million in 1961, \$20 million in 1962 and \$60 million in 1963. By 1966, a total of \$291 million had been expended, and industry officials justified the project on projections of air travel expansion by 10 times between 1966 and 1990, with an estimated 500 SST's used for 1990 overseas flights and 1200 for overland flights. With the problem of the sonic boom, the sharp leveling off in air travel and the plight

of the airlines, the SST would appear to be a potential disaster for airlines and Government alike, with neither recouping the investments made. Apparently, private lending sources recognized these risks when they refused financing for the SST, forcing the aircraft companies to go to the Federal government for funding. The Government is providing an interest-free loan, in effect, which is more accurately termed risk capital than venture capital. Success of this R&D funding process through Federal aid would also have the unsettling side-effect of tightening up available sources of risk capital, because the lenders now have the excuse that the borrower "should go to the Government" as occurred for the SST. A Government-encouraged and controlled monopoly could result which is very self-defeating in the long run.

The introduction of COMSAT was heralded as a new breakthrough in the management of new technology, as a mixed private and semi-public corporation selling stock and depending on operating capital from individual shareholders who, of course, expect a profit. One major objective was the avoidance of satellite domination by one major company, AT&T, while offering international services. A natural conflict arose between profit and service and the oversell of the Space Age, so that cable operations still appear more economical than satellites. COMSAT stock began at \$20 in 1964, quickly rose to \$71.50, then oscillated down to \$35, up to \$77.88 and later dropped to a low of \$31.12.

In January 1965, the management firm of Ives, Whitehead and Co.¹¹ proposed a variation of the COMSAT structure for the SST project. An SST Development Corporation would be authorized to raise capital funds through private investment channels by issuing and selling bonds or notes or both. Then the Corporation enters into contracts with airframe and engine manufacturers whose designs have been selected by the FAA. The Corporation's obligations would be repaid by a predetermined percentage of the profits earned by industry in selling the planes to private airlines and by royalty payments added to the sale price of the plane. The plan also called for the government Corporation to supervise development up to the point where a positive go-ahead was possible. A privately-owned corporation would then be formed to carry out the production functions. The Development Corporation and the production corporation would negotiate a contract under which the latter takes over the bonds issued by the government corporation. The plan was never adopted, probably because of the complex interchange between government and private corporations.

Transportation history includes the development of canals, railroads, airlines and automobiles, all of which differ markedly either in time scale or scope from dual-mode systems. A better historical analogy is that of early urban rail transit, when as an extension of investments in the railroad, a decade-long period of transit construction flourished in many cities, as banks

and bonding institutions willingly put up the capital for the very complex and expensive subway and street railway construction at the turn of the century. Since these early years, other bonding functions have attracted the interest of investors, and often a Federally-backed note is a far less risky investment than transit and transportation development operations. The moving sidewalks and monorails at world's fairs have failed to attract the interest of investors, even after "successful" operations for lengthy periods of time.

In the absence of willing private investors in an unproved system, the Federal Government is often asked to take the lead in providing a grant or matching funds, either by appropriation or in the future by revenue sharing. Because of our capitalistic, anti-nationalization attitudes, America tends to look askance at money-losing operations propped up by outside subsidies, but in many areas of government (and extensively throughout Europe) subsidies are provided for commonly accepted essentials. Farm cooperative can borrow \$700 million in 1970 and pay the same 2% interest rate that they have since the Depression days of the 1930s, compared to 9 to 10 % on the open market. Overall, the Federal government dispenses \$7.5 billion annually in subsidized loans, including \$50 million in 1969 to subsidize ocean liners at the rate of \$275 per passenger.

Grants are generally too open, short-lived and small to

make sense for transportation applications. Because the funds used are derived from taxpayer revenues, there is considerable pressure to obtain some element of public service from R&D expenses, so that the amount of thought that goes into hardware design is quite limited, as emphasis is placed alternatively on research and demonstration (depending upon the composition of the project team) with inadequate attention to the intervening development stage. As in the case of the Flint, Michigan "Maxicab" project, a useful "negative demonstration" was achieved, whereby the concept of revitalizing the interior of a standard GM transit bus has proved to be ineffective -- however, \$1.6 million has been expended on the three-year project to carry 320 passengers, about half that needed to make a profit, and only about 1% of the total Flint GM plant workers.

In the dial-a-bus study, UMTA invested over \$1.3 million as the MIT development costs spiraled while projected fares remained in the range of 50 to 60 cents. Severe tensions and distrust developed between UMTA and project officials as costs mounted, and when UMTA withdrew from the Cambridge demonstration project, the MIT managers were inadequately prepared and had not established subsidiary support to their main effort.

Capital grants to transit tend to emphasize that transit is a loser and that the government can always be counted on to support a declining system. Authorization of these grants is often

accompanied by demands for greater budget tightening and cost-cutting efficiency -- since these cuts are often made in maintenance, capital equipment tends to deteriorate more rapidly and must be replaced, with the aid of....Federal capital grants. Meanwhile, poorer maintenance means decreased patronage and lesser revenues. When the subsidy funds stop, the transit companies are unable to manage or innovate themselves out of their financial plight.

In September 1970, the House passed a \$3.1 billion mass transit bill, 327-16, after a motion by Rep. Edward Boland (D-Mass) that \$5 billion was more money than DOT could spend or use over a 5-year period, with the amendment passing 200-145. The bill provides 2:1 matching grants for capital needs only and cannot be used for maintenance or deficits. In the first year, only \$864 million has been allotted nationwide and over \$1 billion in applications have already been received. Applicants favoring bus-only lanes will be favored for direct aid, and R&D funds are very limited. UMTA director Carlos Villereal has reflected the pressure for output : "We must show dramatic improvements in the short term to hold the interest of Congress."¹²

The recent Railpax legislation has become a disappointment to many, because the Federal contribution is only \$40 million to "assist the corporation in getting underway," although the DOT Secretary can also guarantee up to \$60 million in 2-year loans

for purchase and rehabilitation of rolling stock. Railroads must buy into the Corporation, and although \$200 million in loans is available to enable the railroads to invest in the Corporation, few railroads have any funds to pay off these loans, particularly Penn Central. Unfortunately, Railpax may be the last stop on the passenger railroad line, since the number of trains has dropped from 20,000 in 1929 to 500 at the end of 1969, 366 by December 1970 and 150 under Railpax.

The technique of the intermediary operating company has been used for the Metroliner and Turbotrain demonstrations. The Metroliner was developed with \$11 million in Federal funds and \$53 million additional from Penn Central¹³ for 12 high speed trains per day, six-cars each carrying 340 passengers max. for the 225-mile, 3-hour trip at a 76% load factor. Equipment malfunctions (mainly electrical) have sidelined 20 of the 49 Metroliner cars at any one time, and many cars must be maintained on stand-by. Agonizing delays postponed initial runs from October 1967 to January 1969, and Penn Central has shown little interest in maintaining or expanding the service.

The Turbotrain between Boston and New York is a product entirely of private initiative, with 100% funding by United Aircraft in an effort to diversify business. DOT has leased the trains for demonstration, but the effort is minimal, with one train per day, little promotion and a second train kept in reserve

mainly because of reliability problems in the train's driveline.

Certain projects can be supported if they attract the personal enthusiasm of a top official, or in particular the Secretary of Transportation. In response to the French Aerotrain, Sect. Volpe has become a firm advocate and made the basic decision to implement a demonstration line of a tracked air cushion vehicle, or TACV, serving the Los Angeles Airport by late 1972. The final goal is a Boston-to-Washington TACV line operational soon after 1980, traveling 300 mph and costing about \$3.5 billion. (By comparison, \$150 million a year would provide hourly Turbotrain operations and 3-hour running times and possibly raise service to profitable levels). Since 1966, Dot has obligated \$2.9 for preliminary TACV development and has requested \$8.2 million for FY 1972. The utility of the TACV demonstration in Los Angeles may be minimal, because average speed is only 80 mph, station access is difficult, the linear induction motor may have overheating problems, and turning radii are a minimum at 500 ft., so that a transfer point to a "people mover" must be designed to bring the passengers to the airport itself. The awkwardness of this transfer and the fact that the people mover has yet to be designed reduce the chance for success.

User taxes and trust fund restrictions are probably the more efficient and direct funding processes ever devised by man. Total collection costs are less than 0.5% and are channeled directly from vehicle use to highway construction -- not to improved autos,

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better tires or less polluting fuel, nor to improved road safety, maintenance or to transit or park-and-ride facilities. Moreover, the strength of the motorfuel lobbies and its allies have held fuel taxes relatively low, while vehicle registration fees have risen. In recent years, highway lobby sympathizers have come to support mass transit endeavors and even a transit trust fund -- partly as porkbarrel, congestion relief, and vital new mobility, and partly to protect the Interstate Highway Trust Fund. Senator William Spong (D.-Va) told a recent AASHO convention that "If there are separate trust funds" for mass transit and airports, "the threat won't be for real" to open up the highway trust fund to all forms of transportation.¹⁴

The establishment of the trust fund and dealing of strong powers to state highway departments is partly based on the administrative philosophy intending "to ride the system of politics" by setting up autonomous authorities which are deemed separate from the common political process which reformers have labeled as corrupt. Many housing and Urban Renewal authorities were founded on the same principle, but political influence simply took new forms of setting payment rates, pay-offs and favors, yet all hidden from public view and direct contact with the voter.

The MBTA region annually generates \$100 million in road user taxes and contains nearly half of the state legislators, and Governor Sargent, his Transportation Task Force, and Sen. James

McIntire (D.-Quincy) of the Joint Transportation Committee all favor a state-wide transportation trust fund, so that the State could establish a long-run fund for all transportation purposes, to pay off the MBTA deficit or provide funds for dual-mode, even if the national DOT does not, because rural and Public Works Committee Congressmen will balk at legislative changes. User charges for transit and dual-mode trips are self-defeating as methods of finance, since it is like robbing Peter to pay Peter. If either a state or national trust fund and earmarked accounts for road user receipts is maintained (as it should be because of its efficiency), the fund should be supplemented by the existing 2¢ per pack tax on cigarettes, for the MBTA -- and used as a general transportation fund to cover construction and operating expenses, for roads, rail transit, dual-mode and pedestrian facilities.

As mentioned above, the semi-public "Authority" structure has many defects, from its non-democratic structure, political influence and sensitivity, and heavy dependence on its bondholders, namely the big banks which hold most construction bonds. When agencies such as the Massachusetts Port Authority emphasize that they are responsible to their bondholders first, they add another competing ingredient to the conflict between simple profit and public service. If bonds can be sold without building in a stranglehold on agencies and their allegiances, bonding is a reasonable

choice for construction purposes. Because of the uncertainty of payment, bonding for a development stage or demonstration is risky and probably infeasible.

Bond issues usually must be ratified by state legislatures or by the public in a referendum, and interest payments are usually paid by sales or property taxes, a very unpopular route. Thus, transit bond issues have been rejected recently in Atlanta, Los Angeles, Kansas City, and Seattle (twice), while passing in San Francisco by 1 1/2%. The \$300 million bond issue for the MBTA has not been acted on favorably, and the Task Force report recommended conditional approval only if evidence of major improvements in labor relations could be demonstrated.

The double defeat in Seattle is very revealing. The monorail from the 1958 World's Fair has been maintained, with mixed results. Costing \$1.7 million a mile for structure and carrying 10,000 pass/hr in one direction, operating costs were only \$2.35 per car mile at 2 minute headways and the monorail generated much excitement and glamour. However, the cars were surprisingly noisy, with a level of 105 dB at 50 ft. for 45 mph operation, compared to auto noise of 80 dB in the area. Many complaints were heard from businessmen in the vicinity, and it is uncertain whether the monorail had a net positive or negative outcome on the bond referendum. Twice within two years the \$440 million transit bond issue was defeated, despite a total investment

in planning and promotion of over \$2.5 million. A Louis Harris poll taken several weeks prior to the more recent vote showed that 84% of the voters favored rapid transit vs. more freeways, 73% favored a transit bond issue, but only 64% were willing to pay an additional \$10 a year in property taxes to pay for transit and only 53% were willing to pay \$20.¹⁵ By extrapolation, only 47% would have supported the \$25 required rate of the bond issue, and the actual vote on May 19, 1970 was 46.3% approval, when 60% was needed. In 1968, the yes vote was higher, at 50.9%.

The reasons are many : heavy unemployment due to Boeing layoffs, with a total rate of 10%; bad economic conditions and protests over taxes; choice of the property tax option when polls showed it was the worst option among 11 possibilities with the voters; a fear by unions that the new jobs would be offset by an influx of black workers; controversial planning and projections of funding, which aroused academic and professional opposition and raised the issue of Seattle's ability to raise the balance of \$1.3 billion from the Federal Government. The director of the promotional effort, James Ellis, summed up the problem : "For transit, we have first to get a vote to set up a planning agency, then a vote to finance an operating agency. For highways, no vote is needed. You simply say yes to an offer of tax money that can be spent only on highways."¹⁶

With this history in mind, a dual-mode operational plan can be proposed.

STRUCTURE OF THE DUAL-MODE OPERATIONAL PLAN

In the development of an automated highway system, some Federal support and thus limited control of the guideway is logical, desirable and expected, simply because the government has traditionally been responsible for an indispensable part of the system, the highway itself. But unlike the experience of atomic energy and Polaris Submarines, the expertise needed to conduct dual-mode R&D on an efficient and non-duplicative basis is already existing or dormant in the automotive, computer, construction and other industries. There appear to be no insurmountable technical problems of dual-mode, and the main efforts can be centered on reliability and costing, towards assembling existing concepts and techniques in the best manner. Such cost/reliability consciousness is more properly an industry function than a government activity. Neither is there a need to depend on government facilities or scientific personnel to implement the R&D, as was needed in the case of COMSAT.

Thus, both government and private industry must be involved, with the relationship depending upon issues of reasonable competition and market practices, the management of expertise, the control of patents and trade secrets, the establishment of safety standards and systems compatibility, adequate and flexible sources of funding and proper coordination with other transportation agencies, as well as the general public and other private interests.

Government vigilance is justified by the need for high safety standards (AEC, airlines, consumer concerns), the insurance of systems compatibility (COMSAT) and acceptable standards, and the need to prevent either monopolistic or oligopolistic control on dual-mode by either private or public agencies. These vigilance functions can be served by an effective regulatory agency (esp. one within DOT rather than the ICC) just as well or better than a public-private joint venture. The real need for the government role in funding stems from the high development costs of reliable capital equipment and the unlikelihood of immediate or short-term profits.

The funding package can be composed of Federal, state, municipal and private components, but the system operation will necessarily be a public one, working to certain standards of reliability and service and holding powers of toll/fare collection and limited eminent domain. Because dual-mode shares many transit and highway aspects, a joint transportation commission could serve to administer the demonstration and later operations as well.

What are the incentives to private industry to get involved in a dual-mode research project, when risks seem so high, profits faraway, and accelerated obsolescence of existing facilities a likely side effect? The first step is to insure an element of guaranteed continuity of the project contingent upon meeting certain performance specifications at various guidepost times as the project proceeds.

Thus, grants may be unwise, as might the three-phase scheme for the SST, with evaluation and possible cut-off an option between each stage -- and political uncertainties everpresent. The key is to keep various industries in the picture or in the wings so that a competitive situation for certain profitable elements or services of dual-mode can be achieved. Probably all patents should be ceded to the public domain, or registered internationally in the name of the U.S. Government, as protection from foreign competition and open up overseas markets. Experience and conventional trade secrets would be the benefits of the industries directly involved and probably contributing to early stages.

The general strategy for dual-mode implementation (Fig. 10-1) begins at Stage I with a low-level, low publicity private consortium of industry and academics, which would develop a short one-mile demonstration guideway loop for about \$100,000 using simple paved surfaces, short guideway lengths for entrance, acceleration & braking, simple guiderail segments, a few switches and merges and a three-car station. A half-dozen second-hand vehicles of various configurations would be modified in the shop and tested as an internal demonstration only, to prove to the consortium members that the system was basically workable. Funds would be pooled, and half of them could be written off for tax purposes.

At Stage II, a larger funding consortium would be contacted, to develop a privately funded \$500,000 demonstration of a 2-mile

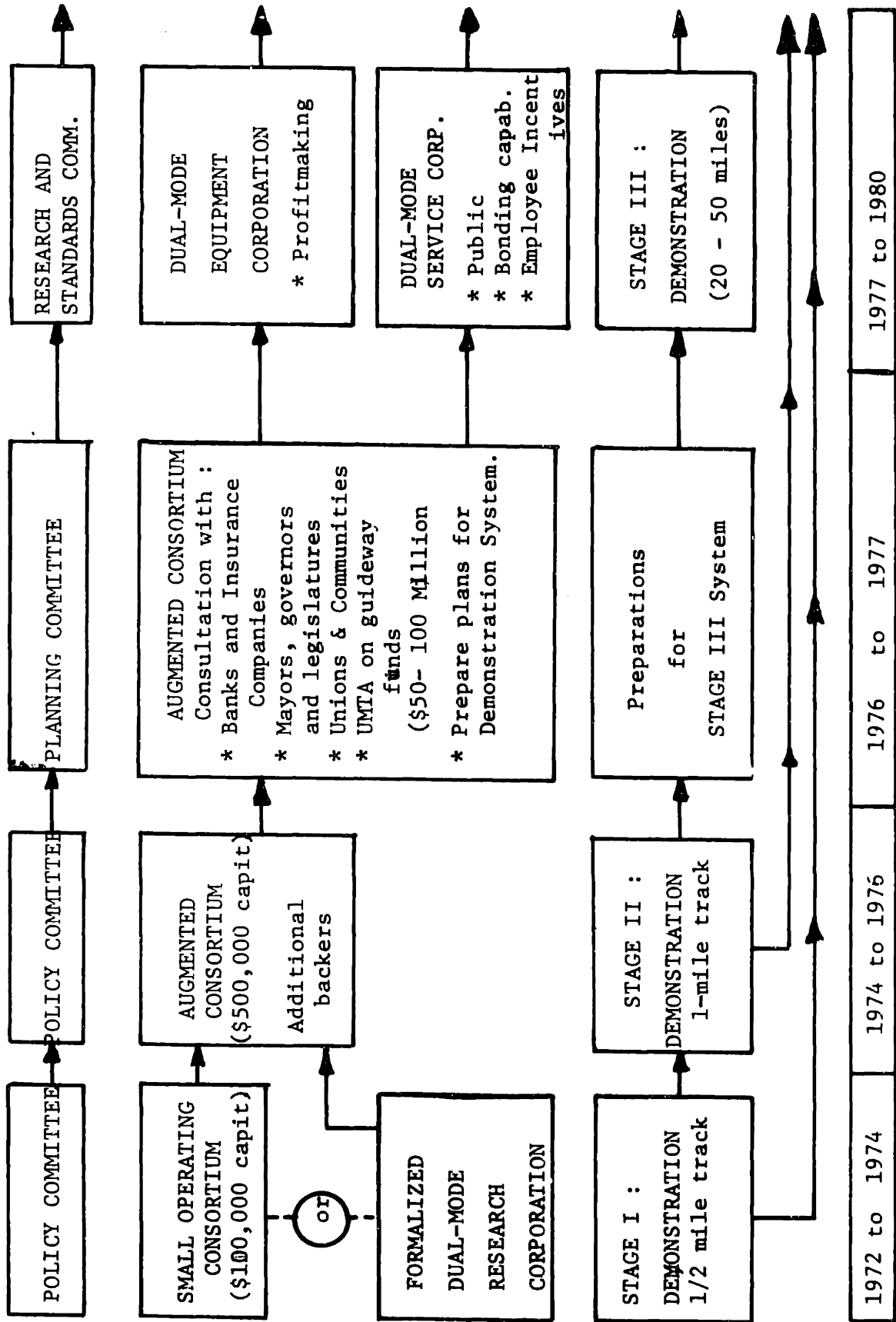


Fig. 10-1. Implementation Strategy for Demonstration Dual-mode System

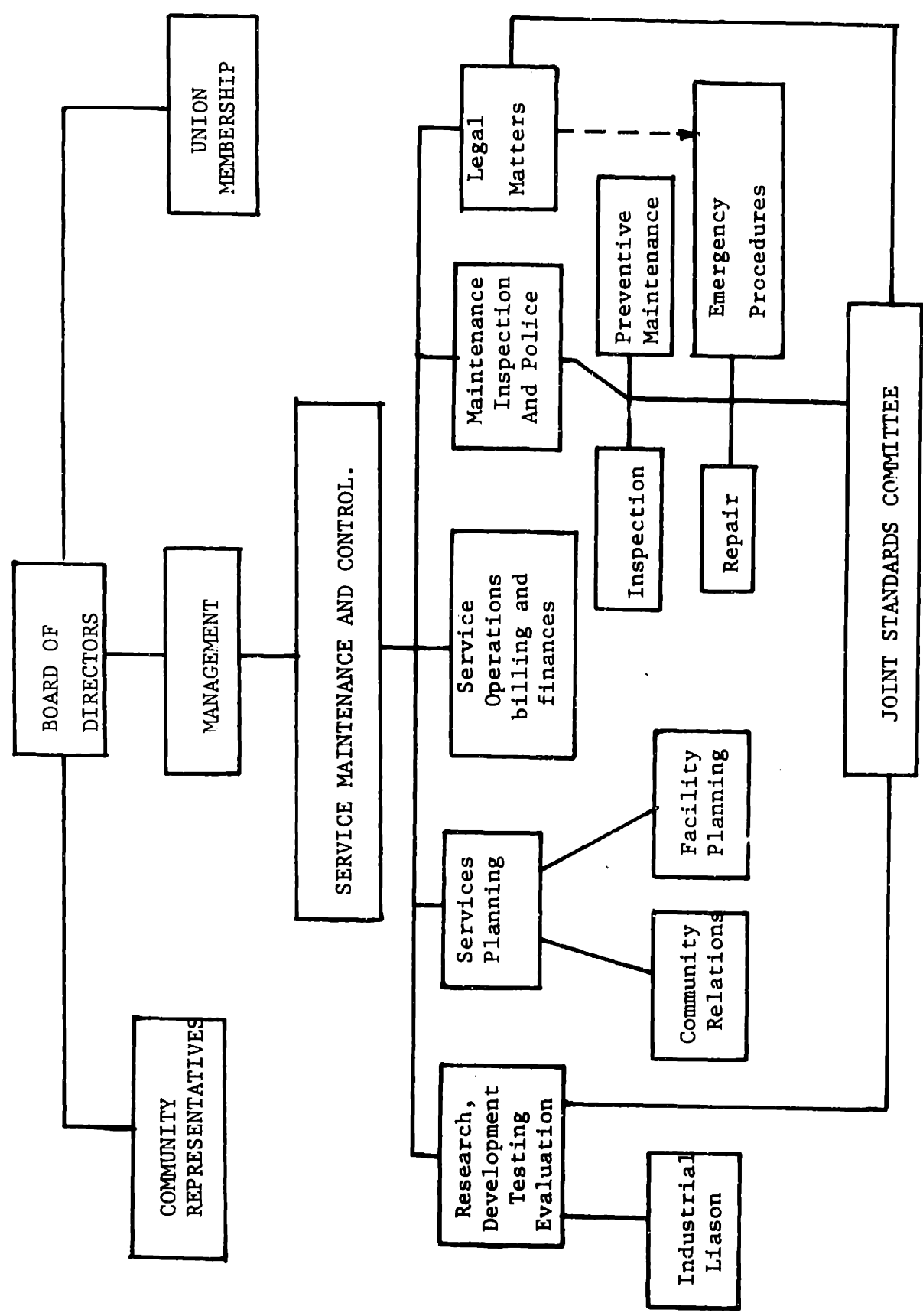


Fig. 10-2. Dual-Mode Service Corporation Structure.

track, building upon the concepts of the Stage I site and preparing for a more extensive demonstration of system capabilities and reliability to top management, UMTA officials and public representatives -- essentially second-stage hardware which can be seen and ridden in, perceived and evaluated. The actual cost to a 10-company consortium for this stage would be \$25,000 each. The Stage I test track would be maintained throughout, as would the original design shop, so that new concepts and hardware can undergo feasibility testing before being transferred to the Stage II track for reliability testing and demonstration. Thus concept testing and reliability testing would not be mixed on the same site and run havoc with demonstrations, and the feasibility testers could proceed without regard for what the equipment looked like in prototype form.

With the augmented consortium and other support, government agency contacts would be made, unions would be consulted and all bases touched before formal approach of UMTA to fund the Stage III guideway structure at least in part. The aim is to establish two separate dual-mode corporations, one profit-making venture called the Dual-Mode Equipment Corporation, which would sell equipment and maintenance services for guideway vehicles and fixed track hardware and controls to the public Corporation, the Dual-Mode Service Corporation. This service corporation fulfills the operating function of the guideway, setting the fares, handling

labor relations and overseeing maintenance, planning, auditing, and research functions. The Corporation would be responsible to an elected board and to the Governor (either would have a veto) to prevent insulation from the public, and would hold regular community "service meetings" to discuss with residents and users possible improvements in service and customer reactions, etc. Even if unable to show a profit overall, the Service Corporation would operate on an internal profit incentive basis of employee bonuses commensurate with services and fare receipts which exceed expectations -- thus employees have an incentive to aid the system, provide better system service, and settle union problems reasonably.

Local matching funds for the guideway can be obtained by access to the state highway (transportation) fund or by a bond issue, but the bond issue must not be applied against taxes, particularly property taxes. Through state and authority reorganization, the state DOT could achieve control over the Mystic Bridge and the tunnels, and could use the toll revenues to make contributions towards paying off the guideway bonds. Federal revenue sharing could be channeled into guideway funds, but the other needs of the state will absorb these even before the guideway corporation has a chance to make a request. An additional tax on cigarettes is another possibility, and the Boston Chamber of Commerce could support guideway services at a relatively small

scale the same way that stores make service investments in free elevators and escalators. The non-transportation business community could perceive the entertainment and retailing benefits of guideway operations worthy of an "investment" in partial payment of maintenance or service funds.

The Stage I consortium most likely should be composed of automobile companies, and the industries of electrical machinery, electrical components, computers, data transmission & processing, and possibly a steel company, while engineering design personnel from universities would stimulate the flow of concepts. By 1980, the data transmission business is expected to rise to \$5 to \$10 billion a year, and thus will constitute an influential growth industry.

Aerospace companies, it must sadly be concluded, should not be involved in Stage I. Although business is dropping off from \$25.2 billion in 1969 to \$19.6 billion in 1971, the aerospace companies will be looking for new markets to invest in, and legislators will be supporting efforts at conversion and full employment. Sen. Edward Kennedy (D.-Mass.) plans to introduce a \$450 million bill for subsidies to small defense contractors for diversification, and it would appear that aerospace technology and engineering personnel are ideal sources for dual-mode plans. Unfortunately, the aerospace industry carries with it a special mystique and manner of operation which is strangely foreign to

transportation needs. Aerospace technology is excessively committed to miniaturization, weight reduction, high reliability and specialized functions, all without much consideration of cost and ordinary human factors (as opposed to robotized aspects of select astronauts). Aerospace engineers are generally unable to function in a working medium of ordinary people and providing a service for them (as opposed to performing a dictated task). There is minimal appreciation of human values and priorities, and an inability to communicate either complex ideas to working engineers or simplified concepts to laymen whose support is essential.

Two practical cases illustrate the difficulty of converting aerospace personnel. First, the Cambridge NASA Electronics Research Center has been induced, through budget cuts, to seek conversion to a DOT Transportation Center, but difficulties have been found in trying to have advanced electronics engineers who are almost physicists respond to the needs of air traffic controllers, who want little more than someone to make their existing unsophisticated equipment to work more reliably. Reconversion of space engineers often means virtual complete re-education, but because of the ingrained space attitudes and experience, there is also an initial de-education process. Second, Ford Motor Company has been working for several years on dual-mode development but with limited success. Initially, Ford acquired Philco and its aerospace arm to help in

coordinating the control system design with vehicle modifications, but after several years of frustration, Ford had to drop Philco and sign up with Bendix, whose advanced engineers are far more practical and have developed practical transmissions, braking systems and test equipment -- and apparently the Ford and Bendix engineers can now communicate with each other, while the Ford people previously complained that they couldn't talk with the aerospace engineers and their multiple-abbreviated "Command-and-Control-System" terminology.

Important allies to augment the effectiveness of the consortium but with a lesser design role include auto parts suppliers, other auto and steel companies, the highway and building construction industry, concrete companies, power companies, and the coal and fuel oil industry. Aerospace companies truly seeking to diversify successfully can contribute, subject to the reservations mentioned above. Other groups contacted would be the auto associations, highway officials, the trucking industry, rapid transit groups such as the Institute for Rapid Transit, rent-a-car agencies, and auto service outlets. Truckers might feel ambivalent about guideways, since the American Trucking Associations, Inc. has been one of the staunchest defenders and public advertisers for the Interstate system, and instinctively might be anti-dual-mode. However, controls on expressway congestion and less truck/commuter friction may improve mobility as much as new

roads. However, if dual-mode planners could perform the overall planning job necessary, to ensure the viability of local street patterns and establish meaningful truck routes, the total guideway traffic plan may be operationally more acceptable to the truckers than the congestion limited expressway system.

Other groups contacted either for information, support, or neutrality at the very least would be the transit authorities, Federal Highway Administration, Port and District Authorities, regional planning commissions such as the Metropolitan Area Planning Council, freight and passenger railroads, and the airlines. Also to be briefed are groups of transportation professionals, architects, and planners, while the financial implications should be communicated to the banks, insurance companies and Chambers of Commerce. The mayors and the U.S. Conference of Mayors, the National League of Cities, the state legislatures, governors and key figures in House and Senate Committees are all essential allies for guideway systems, while good government groups and taxpayer watchdogs such as the Massachusetts Taxpayers Association must be persuaded not to oppose dual-mode financing.

Within the House, the Committee on Public Works handles all highway matters, while jurisdiction for bus and rail transit is within the House Banking Committee, under chairman Wright Patman (D.-Texas) with Henry Reuss (D.-Wis.) already an important transit and dual-mode advocate. The Public Works Committee has been

changed markedly for 1971, since Chairman George Fallon (D.-Md.) was defeated in the primary and ranking Republican William Cramer of Florida lost his race for the Senate. The present ranking Democrat, John Blatnik (D.-Minn) is less a fervent road advocate than Fallon, and maverick critic Fred Schwengel (R.-Iowa) has moved up in seniority. Rep. Silvio Conte (R.-Mass.) is now the ranking Republican on the House subcommittee on appropriations for transportation, while Springfield Congressman Edward P. Boland (D.-Mass.) is subcommittee chairman. Meanwhile, former Massachusetts Governor John Volpe sits as Secretary of Transportation.

In the Senate, Public Works Committee chairman Jennings Randolph (D.-W. Virg.), previously known as "Mr. Trust Fund," has recently been supporting environmental legislation. Senator Vance Hartke (D.-Ind.) is chairman of the Commerce Committee subcommittee on surface transportation, while Senator Proxmire, (D.-Wis.), an important force on the Economic Committee, is in favor of abolishing the Highway Trust Fund. Generally, the Senate is more environmentally conscious and more willing to diversify uses of the Highway Trust Fund, compared to the House.

At the community level, highway opponents should be approached for discussion of guideway concepts in order to get their response and to make clear that guideways are not a ploy of the highway lobby. Professional societies should be approached on the setting of standards, so that good professional quality

work will result and not lead to sloppy preparations which cause controversy and last minute corrections, with consequent decline of public confidence.

Unions must be addressed directly and extensively. As with the truckers, there are many elements of ambivalence. If guideways seek to retain manpower (and work with the Labor Department for special training grants) and provide promotional opportunities and extensive maintenance, without constant efforts to trim labor costs, the traditional tension between labor and management can be relieved somewhat. More progressive unions such as the UAW should appreciate the better beneficial effects of guideways on local environs and lower class neighborhoods, compared to expressways. However, unions may perceive the guideway as a rich man's toy and might object to various work rules or hiring/firing policies. The guideway may be opposed simply because it is change and thus appears to be a threat, while other union groups may realize that a strike may not be able to close down the system, since supervisory personnel could perform the operations. Unions should appreciate the bonus incentive, and should be encouraged to make jobs more meaningful. A typical job rule to be avoided is the railroad safety regulation that a gatekeeper shall not read newspapers or books, shall not listen to a radio or have a TV set or participate in any recreational activity, and shall have at his desk a time schedule of all trains and that shall

be the only reading material. The gatekeeper lives the life of a working recluse, a paid and voluntary prisoner to safety rules. Similarly, a transit motorman spends years of his life driving a subway car up and down a tunnel 8 hours of the day. Whatever happens, the guideway corporation must avoid the complete breakdown of relations which has apparently occurred between the MBTA and the carmen's union. Recently, the advisory board's budget committee declared that the union's refusal to work overtime was an "utterly unconscionable slap in the face of the riding and taxpaying public" and that it did not intend to "advise the MBTA management to capitulate to the 'public be damned' tactics of the union leadership."¹⁷

Public attitudes will range from interest in new technology generally, practical approval as a response to highway congestion, and reduced environmental devastation to disinterest, apathy and distrust of new technology, to a concern for economizing and lower taxes, or an anti-dual-mode reaction based on appearance or fear of the system. Consumers might be willing to accept the unsubsidized segment of the \$400-\$700 in car modification expenses, for the insurance and service benefits and because consumers spend up to \$700/yr indirectly for styling changes and retooling and \$300-\$500+ on extra equipment. There will be special requirements and demands on the dual-mode system, such as reduced fares for elderly and school children, which generally are reasonable but also reduce

receipts. Similarly, conversion subsidies for the elderly and the poor will be advisable, possibly through reconditioned equipment. The use of second-hand guidance and speed/power control equipment is closely related to matters of updating hardware through interchangeable connections, in other words compatible obsolescence. Dual-mode should not be opposed to change in the cause of improved performance, but it should avoid the Detroit malaise of wastefulness whereby, in the words of James Roche of General Motors, "Planned obsolescence in my opinion is another word for progress."¹⁸

At the state level in Massachusetts, a state Department of Transportation will have been operating since April 1971 as an umbrella over the Department of Public Works, MBTA and certain aspects of the Port Authority and Turnpike Authority. As soon as possible, a Department of Advanced Transportation Operations should be added, to include advances both in urban transportation systems and in intercity HSGT services. It might be proper that this department have the actual eminent domain powers for dual-mode, if adequate safeguards cannot be built into a representative operating corporation. Public Works might resent the competition of dual-mode, but the middle and lower echelon personnel at DPW are generally quite capable, and could aid in setting standards and guideway planning & engineering. Coordination with the MBTA on all bus and rail transit routes is

essential, both for meaningful public service and as friendly competition for the MBTA to stimulate new ideas and bring the MBTA team somewhat closer together. The degree of cooperation and competition is a function of the situation -- excessive cooperation can generate construction cliques and Ultimate Master Plans, whereas agencies which treat each other under strict practices of suspicion and minimal communication can create a planning logjam; "cooperative" competition to provide services or service concepts can be very healthy, while friendly competition to see which agency can build more can be disastrous, as is evident in Boston's North Terminal Area.

The goal of dual-mode plans in terms of good problem solving technique and coordination with other agencies and facilities is the expansion of the number of options considered and of the qualitative and quantitative factors accounted for, compared to current practices of limited options. The final guideway route plans should be in the form of a "Muddling Through" document -- flexible, aware of the uncertainties and possible inherent defects, focused on the transitional phases and the evolution rather than the "final plan", and based on a general method of small moves followed by evaluation, with consequent incremental restructuring and realignment of political support as a function of on-going developments. Such a process of "Muddling Through" is more effective at maintaining options,

both large and small, and respecting minority rights. It is consistent with the goal of dual-mode as revolutionary in concept, while evolutionary in impact and effect. One of the most difficult tasks will be the orienting of agencies, engineers and consortium members to accept the idea and explicit objective of "Urban Conservation," whereby dual-mode seeks to aid in the selective preservation of community values, homes, recreational areas, while modifying those areas which local communities would most want to change, such as decaying industrial areas, dumps, etc. In certain cases, dual-mode implementation could lead to the moving of buildings and consolidation of land areas, and possibly the opening up of isolated residential pockets, as opposed to the *destruction* of homes and buildings as the DPW demands today. The concept of conservationist building is a difficult one to understand and accept, since new construction is usually intended to change things in some major way -- and planning disputes usually center about the direction that change should take, and not its general magnitude. The concept requires a conscious effort to reduce the impacts and the scale of change, to have minimal effect on property values and minor changes on land use. The modern qualities of the guideway should not be imposing, and the structure should be designed to grow old gracefully. Not only is Urban Conservation an essential form of respect to established communities and their ecology of human activities, but we must begin to slow down

the aggravating and disorienting effects of change, so that people can adjust gradually and not be subject to a jarring bombardment of technological complexity from TV sets to jet planes and space flights, and suffer the effects of what Alvin Toffler calls "Future Shock." If dual-mode guideways are to be dramatic in any way, it must be in the form of service, and not structure.

DEMONSTRATION GOALS

The purposes of the demonstration dual-mode program include many issues of varying importance and immediacy :

- (a). The feasibility and reliability of switching, arm actuation, speed control, automatic parking and stations.
- (b). Estimate development and operating costs and the likelihood of further reduction.
- (c). Extent of initial public acceptance and use; effects of marketing and pricing policies.
- (d). Peaking characteristics of service and extent of use during during off-peak hours for shopping, goods movement, special services.
- (e). Appropriate mix and phasing of public and private vehicles.
- (f). Types and degree of environmental impacts and side-effects; appropriate traffic and land use control policies.
- (g). Mix of socio-economic groups and methods to improve services to low-income areas.
- (h). Effectiveness of funding and organizational structure; union and jurisdictional relations.

In any demonstration, there are factors one simply cannot test because of scale factors. The guideway demonstration is likely

to be mainly a simulation with inevitable distortions from the performance of a larger system. These distortions can work either way, to show unwarranted good or bad early service. The time duration and the inevitable tentativeness of a demonstration are further limitations on the accuracy of the basic concept: Can one, for example, trust the first reactions to describe the long term effects of guideways?

The minimum size of the Stage III demonstration system becomes the principal impediment to general acceptance and public service. Since Stage I and Stage II would have worked out most of the bugs, the Stage III guideway can be assumed to be functional and feasible and hopefully fairly reliable. A single short transit link, however superior its performance, is seldom likely to attract many patrons, simply because it is capable of serving very few trips. The main advantages of dual-mode that make it more attractive than buses, rail transit or cars are those which are limited by small size or periferal nature of a limited demonstration. The high-speed non-stop, no-transfer service promised by dual-mode systems results from the bypassing of intermediate stations and automatic switching and routing, in coordination with automatic parking and stations.

A negative goal of the demonstration is the avoidance of the spectacular publicized catastrophe or disablements such as the perennial hotbox which starts to smoke just as the VIPs arrive. The Canadian Turbotrain on its December 1968 inaugural press run

hit a truck at a grade crossing, slicing it in two and spewing the truck's cargo of meat all over the tracks. Winter weather problems and other accidents caused the trains to be taken out of service after only one month, after which 85 design modifications were made by United Aircraft and Canadian National and 10,000 miles of winter tests conducted before service was successfully resumed in 1970.

Careful attention must be paid to the impacts of the guideway locally, particularly in our environmentally conscious age. Among these factors are air pollution, noise pollution, visual and aesthetic factors, the Chinese Wall barrier effect, land takings, displacements, periferal housing impacts, business relocation or consolidation, on-ramp and off-ramp congestion, changes in land values & tax base, land speculators, quality of service to low-income areas, excessive use of electric power, liability problems, impacts on bus and taxi business, etc.

Closely related to this concern is the role of community design, whereby communities and abutters are contacted for their response at several stages of development -- from route layout and elevation to station location, from reactions to the Stage II guideway to ideas about pedestrian overpasses, small parks and playgrounds, and community facilities combined with stations. The range of community representation techniques includes various degrees of authoritarianism vs. democracy :

- (a). Highway agency paternalism : "Father knows best."
- (b). Open Hearing procedures : usually a rough and tumble confrontation of Damon Runyonesque proportions.
- (c). "Objective" representation through systems study techniques, consultations with academic experts, planners, etc.
- (d). Indirect representation through advocacy groups -- most appropriate when there are feuding factions within the the community or when problems become very complex and require legislative lobbying.
- (e). Semi-direct representation through appointed representation, by choice of the Mayor or City Manager.
- (f). Direct representation through elected or volunteer citizens, possibly in combination with hired or advocate staff.
- (g). Requirement that planners and designers on the project live for at least a year or two in the community their designs would be impacting, in order to gain a sympathetic and subjective viewpoint to balance against their professional biases and possibly insensitive objectivity; role playing is a more limited and laboratory version of this technique.

For a demonstration guideway, a mixture of (f) and (g) above appears best, and a statutory requirement for them should replace that for Open Hearings, which are often perfunctory and obtuse.

Phasing of the guideway demonstration and its vehicles will be governed by reliability tests and the rate of vehicle adaptation. Because not every private vehicle can use the guideway the day it is opened, critics have identified this as a "start-up" problem. However, because of the reliability need to start slowly

and not rush the implementation, this start-up problem may actually be a blessing in disguise. The first vehicles onto the system will be buses (single-mode) owned by the guideway corporation and hence subject to close maintenance, repair and modification. After the system settles down, the buses will be operated as fully dual-mode vehicles, taxis and rented-cars can be introduced to the system, and thereafter private cars of select demonstration families can be entered, with the level of success determining the date for opening up the system to the general private user.

POLITICS, SPECIAL INTERESTS & GUIDEWAYS

The guideway corporations must be prepared for a barrage of pressures from legislators, contractors, unions, real estate operators, and even underworld crime. Central coordination of parking and maintenance operations will aid greatly in reducing the chances of functional and fiscal corruption of guideways. Despite its low-impact objectives, guideways could become a new form of porkbarrel appropriation device. In general, one should try to keep "good politics" in the system, namely the community contacts and planning, and keep out "bad politics" -- namely, greed-bound favoritism and over-insulated bureaucrats working closely with political hacks. Either through collusion or simple incompetence, the guideway system can become a political scandal, of poor construction quality and cost overruns. A special

1960 Congressional investigation of the Federal highway program discovered, in the words of Sen. Clairborne Pell (D.-R.I.), "a litany of indiscretion and malfeasance." The report charged "tens of thousands of dollars" in bribes in Florida, "gross incompetence and downright collusion and fraud" in Massachusetts, and "ineptitude, inefficiency and incompetence" in West Virginia.¹⁹ Low civil service wage scales, a disinterest among good engineers in transportation, and paperwork delays have contributed to past low quality performance. Good personnel must be involved and the strictest penalties provided for any evidence of pay-offs and conflict of interest. The problem is not a simple one, since the heavy dominance of underworld and Mafia figures in North Jersey reportedly doubles the cost of construction contracts, since if the contractors do not pay off their equipment gets destroyed. The dual-mode corporation must seek to induce criminal elements or dubious merit operators to deal legitimately on a conventional profit basis with the corporation, in order to avoid scandal in a consumer and taxpayer conscious era.

CHAPTER 11. A DEMONSTRATION GUIDEWAY SYSTEM FOR BOSTON

A well-planned, well-paced demonstration strategy is critical to the success of dual-mode guideways as useful contributions to transportation service, and each phase must seek a limited objective. The initial 200-ft. guideway site and the modified Mustang constitute a Stage Zero test of hardware concepts. Stages I and II will involve more elaborate construction, including continuous roadbeds arranged in a loop, with merges and switches. Moderate to cruise speed (30 to 60 mph) guidance and speed control will be tested, as well as extended operation and reliability checks, including wear and heating in the pads and switching accuracy. A spur track could include a station and control center/shop, for entrance, low speed checks and repairs, as well as acceleration and braking ramps.

Stage III encompasses the operational demonstration and will be the main topic of this Chapter. Boston has been chosen for convenience and personal reasons, because of the writer's familiarity with road and transit conditions, geography and community needs, the existing hiatus in the Boston expressway system, and the evident needs to preserve the special urban values of Boston while contributing to a better transportation system overall for the city. The task at hand is to select the best choice for an initial demonstration line and potential link in

an expanded network. One option is an automated bus guideway along a major access route to Logan Airport, while a more general and meaningful exercise would be a single or double radial link, in combination with a loop or circumferential connector -- located primarily along underutilized railroad ROW. Although success is the objective, all or part of the system might be incompatible with the locale, while obsolescence would eventually require replacement or removal. Thus the Stage III guideway must be demountable and capable of removal without leaving permanent scars in the environs. Upon demonstration success, the links must be adaptable and extensible into the larger guideway network through evolutionary expansion.

The Eastern Massachusetts region is composed of 3.4 people in 2300 sq. miles of 152 cities and towns. The daytime population of Boston proper swells to 2 million from an overnight base of 700,000, drops off at 5:00 PM and then increases in the evening as 300,000 to 400,000 people return for social activities in the city's nightlife.

Boston is an old city, mixed with sections of skyscrapers domonating the horizon and numerous redeveloped areas. In the rebuilt areas, wide streets and sterile plazas prevail against modern office buildings of varying architectural success. The original continuous spine of the city, Washington St., has been severed by the Government Cemter complex, while near Feneuil Hall

the stubby thoroughfare of Butler Square runs all of 40 feet from Chatham St. to Butler Row and thereby becomes the shortest street in the city. The widest street in Boston is Commonwealth Avenue, most of whose 200-foot width is composed of a tree-lined median, while Ridgeway Lane on Beacon Hill is probably the narrowest street, with 2-foot sidewalks and 8-foot width curb-to-curb. There are 3275 public streets in the city totaling 800 miles in length; in addition there are 16 MDC parkways of 35 miles, two state highways of 6 miles length (within city limits) and 1847 private ways of 118 miles total length, 198 bridges and overpasses, 1620 bus stops and 1270 loading zones.¹ Boston had its basic street system laid out two centuries before the appearance of the automobile, and turn-of-the-century streetcar congestion caused Boston to construct the first subway in the country in 1897. Five public agencies build or operate auto traffic facilities in the Boston area : the Department of Public Works, Mass. Turnpike Authority, Metropolitan District Commission, Mass. Port Authority, and the individual municipalities. Other transportation services are provided by the MBTA, cab companies, and several private bus companies. No agency has specific responsibility for pedestrians, although the city usually provides some sidewalks and the MDC builds pedestrian overpasses.

The number of persons crossing the cordon line defined by the downtown peninsula south to Massachusetts Avenue) has

undergone no significant net change in 30 years, although important shifts in the modal split have occurred:²

	PRIVATE TRANSPORTATION	PUBLIC TRANSPORTATION	TOTAL : ALL MODES
1938	955,083	812,664	1,767,747
1954	912,801	758,433	1,671,234
1964	1,132,576	517,670	1,650,256

The cordon movements, in percentage changes from 1954 to 1964 have been³ : Rapid transit (-21%), streetcars (-36%), commuter railroads (-67%), buses (-27%), passenger cars (+35%), trucks (+0.3%) and pedestrians (-31%). The decline in private transportation movements between 1938 and 1954 is primarily due to a 50% drop in pedestrian travel. The peaking occurs in all modes, with commuter railroads the worst and autos the best. For the 8-9 AM peak as a fraction of ADT, Commuter rail travel is 60.4%, rapid transit 26.9%, PCC trolley cars 18.0%, bus 14.1% and auto 8.4%.⁴

The dual-mode demonstration demonstration and possible network development must be coordinated with highway and transit plans, and all are subject to various limitations and inflexibilities:

- (a). Being confined by legislation and funding
- (b). Being committed to or locked into a set of plans
- (c). Being committed to existing contracts
- (d). Being locked in by existing structures and facilities
- (e). Being confined by the interdependency of facilities.

Ideally, a fine-grained approach to transportation planning is required and must include the distributional capillaries of transport as well as the arterials. Because time and space limitations do not permit the desired detailed coverage, a summary transportation plan will be presented in this Chapter, touching on the highlights and without extensive maps and geometrical design. The design problem is manageable even by one person, but should be the subject of another thesis.

First of all, modifications to announced MBTA capital programs for expansion and line improvement :

- (a). Suspend all improvements in the Southwest Corridor (Orange Line) except for buttressing existing weak structures and station modernization. There should be no \$30-\$40 million extension beyond Forest Hills over the Penn Central tracks (total cost of line extension : \$200 million in 3-tracks).
- (b). Build extension of Harvard Line to Alewife or Arlington by way of Porter Square and possibly North Cambridge as well, using tunneling methods. The current price tag for this Red Line extension is \$150 million tunneled by a more direct route, so that \$250 million might be required for this section.
- (c). The Haymarket North branch of the Orange Line should be completed, but this line is tragically inadequate in terms of the diminished service it provides to Charlestown,

Somerville and Everett. Almost all the new Orange Line connections, including that at Wellington Circle, are poor, with a final alignment that seems to serve the railroads more than it does either pedestrians or park-and-ride users. The old Sullivan Square Station should be kept as a natural parking garage for cars from I-93 and would help to soak up the flow of vehicles into the North Terminal area. (\$6M total).

- (d). The Blue Line extension across the Revere Marshes should not be built (see following sections on highways and guideways) Instead, station modernization, newer cars, and improved access to existing park-and-ride lots should be provided. There are 48 cars on the Blue Line which were built in 1923 and 1924 and are still in use.
- (e). The South Bay Maintenance Center is the best idea in the whole MBTA package. The cost of \$35 million is a bargain in terms of potential benefits : these funds should be seen as a valuable investment.
- (f). The program to develop new trolleys should be accelerated. Interest is considerable in a BIPED concept (Bi-Powered Equipment Development) to combine electrical and non-electrical propulsion in the same vehicle, like a diesel electric locomotive or like dual-mode cars. While there are some savings in reduced electrification of railroad lines and the possibilities of higher speeds, the BIPED option

may be quite costly and complex, especially in terms of vehicle maintenance. The MBTA estimates for a new BIPED car are in the optimistic \$150,000 range, with an air-conditioned 2-car unit carry 265 people, including standees. About 100 cars, or \$15 million worth, would be sufficient to cover the Riverside line in peak hours and the whole Green Line off peak, and a total of 234 cars would be adequate for the whole line in peak hours. The BIPED design has problems of safety and pollution in tunnels, and possibly one practical option is to hitch a diesel-generator tender to the trolley as it approaches railroad routes and generate on-board electricity in that manner, without the need for trolley car modifications. The tender could also be used on regular transit cars as well, so that the Orange Line cars could use the \$17 million South Cove tunnel and run down the Penn Central tracks to Brighton and Newton, with a stop for Fenway Park.

- (g). The Lechmere Line should have a stub loop and northwest extension to Union Square, Somerville.
- (h). A fleet of surplus red London Buses should be bought and operated as combined rush-hour free CBD transit and off-peak tourist guides (paid), with leasing possible on weekends for chartered services. Existing MBTA buses should be dramatically cleaned up (exhaust & dirt) and painted solid bright colors.

Expressway construction in Greater Boston should be sharply curtailed :

(a). All plans for a Route 2 extension, I-95 North and South, the Inner Belt and any intermediate belts should be scratched.

(b). The Third Tunnel Harbor Crossing should have a changed alignment, connecting directly from the Southeast Expressway/ Central Artery South into the Fort Point Channel (without filling the whole channel) and proceeding underwater around the North End of Boston, then over towards Charlestown, out of the water at the Hoosac Pier and connect to the at-grade and 30-ft. elevated ramps of the Mystic Bridge. At this point, the existing roadway makes an awkward S-bend to avoid a bar in Charlestown (the owner had political connections) creating a severe gore which has killed 13 people in 5 years. The alignment (Fig. 11-1) is quite convenient, and the tunnel cost might be \$250 million plus \$25 million for approaches, compared to \$150 million for the current Third Tunnel proposals, plus \$100 million for DPW ramp connections. A six-lane facility for bypass and through traffic provides the belt-way function that the Central Artery can never provide.

(c). The Central Artery would now be removed -- the entire elevated steel structure would be taken down. Also to

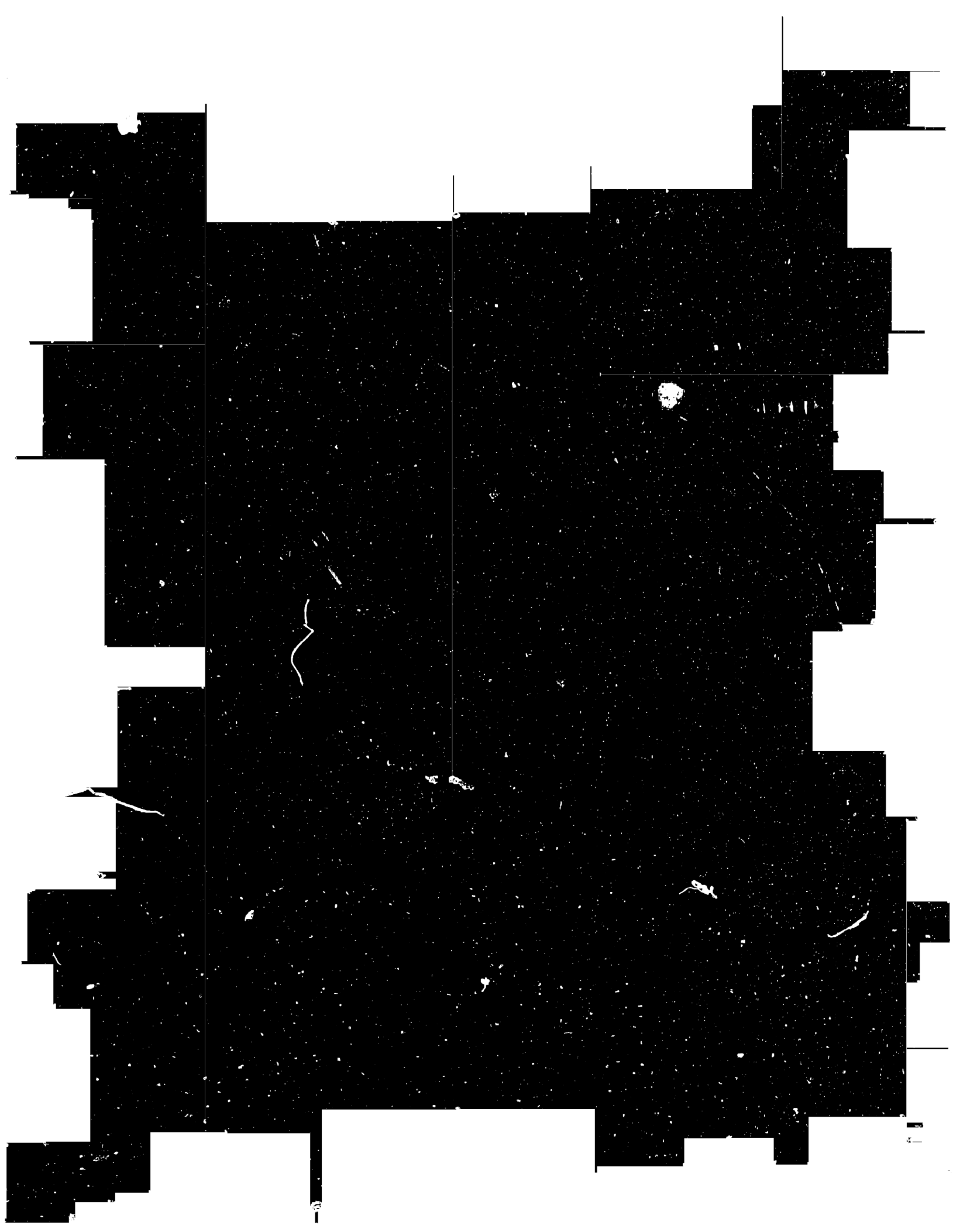


[REDACTED]

[REDACTED]

[REDACTED]





removed are the I-695/I-93 elevated structure and ramps now under construction and of such dubious operational feasibility. Since the old elevated Orange Line through Charlestown would also be removed, there would be no overhead structures in the Charlestown area. The Central Artery function would be provided by a lower level roadway across the planned Warren Ave. Dam and following the old Central Artery ROW in a low-speed, boulevard manner. Special zoning would be necessary to protect consequent areas of the North End vulnerable to overdevelopment.

- (d). There would be no Leverett Circle Bridge; instead at-grade streets would distribute traffic from the Warren Ave. Dam around to Storrow Drive (although Storrow Drive traffic must be set at much lower levels than today). The existing plans of the BRA for Rutherford Avenue would be entirely scratched, with the previous radial expressway concept (in the same corridor as I-93) being replaced by a major circumferential connection between the Mystic Bridge (and Warren Ave. Dam) and the new Prison Point Bridge, using a 4-lane limited access facility bypassing City Square Charlestown and using two existing underpasses under the Charlestown Bridge. The project and the land reclamation should be the responsibility of the MDC, although the BRA can help in maintaining some of the historical aspects of

Charlestown, as part of its Prologue 1976 program.

(e). I-93 would be torn up all the way back to the Medford line.

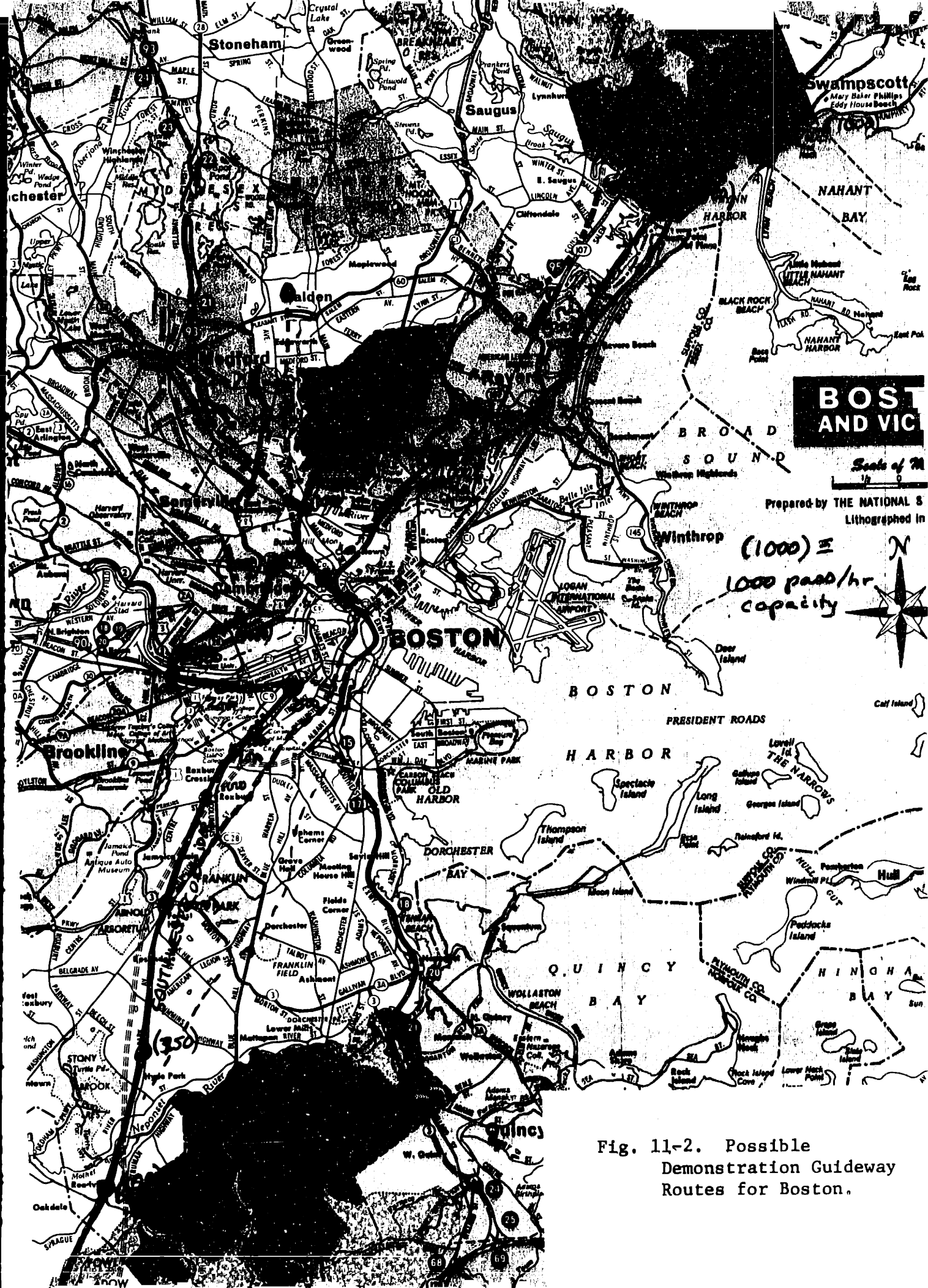
From Stoneham south, the road would be cut back to three lanes each way and would maintain its good connections to the Mystic Valley Parkway, but thereafter would be two lanes depressed (with cantilevered access roads partly in the airspace) in each direction replacing the current wall of Chinese Wall fill along Mystic Avenue. Thereafter, one lane peels off into the Sullivan Square parking garage and one continues through Sullivan Square and onto Rutherford Avenue (a 2-lane each way facility connecting into the Prison Point Bridge by a trumpet intersection). The Community College and Shopping Center plans of the BRA in Charlestown would be shelved.

(f). Plans for permanently widening the Southeast Expressway would be forgotten; the Dewey Square tunnel would be used for local traffic and vehicles seeking access to the existing tunnels. The connection from Dewey Square to Dock Square would be made by a 4- to 6-lane depressed roadway with cantilevered service roads similar to new I-93, with provision for future guideway links on either side (below grade). Thus, harbor tunnel traffic would not become tangled in Government Center traffic in the Haymarket Sq. section.

(g). Crosstown traffic through Cambridge is very difficult, except for cars using Memorial Drive, and truck traffic along River St., Western Ave. and Prospect St. is very heavy and bothersome. Cambridge has staunchly fought the Inner Belt, and for good reason, but the crosstown traffic movement can be aided by the construction of a 4-lane through-traffic-only roadway along the Grand Junction railroad tracks behind MIT -- an express road with no exist and no service roads, depressed with partially cantilevered railroad tracks at grade. The 40-mph facility could be done without taking any buildings, requires rebuilding an MDC bridge on Memorial Drive at BU Bridge, and a short at-grade crossing of Main St. and Broadway in order to get over the Subway tunnel, while Main St. and Broadway would be diverted into underpasses. The railroad bridge under the BU bridge would be rebuilt, for 4-lanes, railroad track plus 2 guideway lanes. The roadway would connect to the Turnpike as a spur behind the National Guard Armory and thus permit sharp restrictions on Turnpike exit flows trying to get onto Storrow Drive, Memorial Drive and the Cross-Cambridge truck traffic. In fact, through-trucks could be banned from Cambridge streets. (Note : trucks are 8.7% of the vehicles in the state, but comprise 15% of the ADT and 5-10% of the peak hour volumes).

GUIDEWAY routes can now be considered in terms of the above transit and highway program. The general demonstration route is shown in Fig. 11-2, with two main radials and a half-circumferential. Possible future extensions are shown in dotted lines. Initially, purely automated buses would be run and then dual-mode buses, so that stations are emphasized initially, with demountable entrances and exits provided mainly for low-volume convenience and emergencies. Approximate station locations and capacities are shown in Fig. 11-2, and are probably fairly conservative, although they provide a physical restriction against trying to saturate the guideway too quickly. Of the 24 initial stations, two would be major complexes servicing very busy commuter areas, Back Bay station and North Station. The currently deserted Back Bay station complex is an ideal location for service to both Copley Square and residential areas to the South. The guideway station at North Station could have spur tracks stopping at the current rail yards, under the old Central Artery either at the old Boston Garden or at Haymarket, or via the Accolon Way flyover to the Haymarket Station, connecting to the Green Line Lechmere Trolley and using the old Orange Line station access facilities. Thus there might be three small stations rather than one large one.

Of all the transit lines, the best candidate for conversion to dual-mode is the Orange Line, at both ends. The current elevated



BOSTON AND VICINITY

Scale of 1" = 1000 feet

Prepared by THE NATIONAL BUREAU OF TRANSPORTATION
Lithographed in U.S.A.

(1000) ±
1000 pass/hr
capacity



Fig. 11-2. Possible Demonstration Guideway Routes for Boston.

lines are badly deteriorated and ugly, but the new alignments are a grotesque parody of what transit service really should be. Therefore, a future guideway link can be extended the entire length of the Orange Line, connecting with the original guideway at Forest Hills. The station along the Central Artery at North Station can either be extended and dropped below grade to follow the depressed roadway between Dock Square and Dewey Square (thence either to South Station or out the Southeast Expressway, using some of the excessive lanes), or share the same tunnel with the converted Orange Line and then spur tunneling to the Dock Sq./Dewey Sq. connector road. Near Neponset Circle, a spur guideway can follow the railroad track to Mattapan Square and relieve the need for trolleys on this segment of the Ashmont Line. A further connection to the Dorchester Penn Central tracks via the Blue Hill Avenue median for 1/2 mile can be made using an elevated single post structure down the widest section of the Avenue, but good aesthetic design would be essential in this case.

To the North, the guideway can be extended out I-93 to further reduce the regular traffic impact from this facility, and can parallel the Mystic River Bridge -- but low enough to have two stations serving Charlestown residents -- and thereafter a loop around to the airport, with community stations in Chelsea and East Boston, as well as the airport.

The demonstration guideway should be built with the Southwest link opened first to Back Bay station. Thereafter, the line is extended under the Prudential Center complex (using either railroad airspace or a Turnpike Lane) and thereafter around the BU Bridge by Peter Fuller's , thence curving under the bridge to join the Cambridge crosstown/railroad bridge structure, at grade. The guideway would rise to cross Mass. Avenue in Cambridge as an elevated span or could drop to follow the roadway underpass, thereafter coming back to grade at Main and Broadway. The guideway would continue out under the McGrath-O'Brien overpass and through the rail yards elevated into Boston. Again, aesthetics are more important here than expected, because of MDC plans to develop the open space potential of the waterfront behind the new dam.

The link to the north would branch across the railroad yards and either follow the old MBTA Orange Line to Everett or use the overdesigned underpass at Sullivan Square. In Everett the guideway would pick up the railroad ROW and would have stops in Chelsea and Revere as it follows the tracks all the way to Lynn and Salem, with a large station for the GE plant in Lynn. For some reason, the Northeast line is not as glamorous as the Southwest, but because of bridge, tunnel and Central Artery congestion, the Northern segment may become the most needed. A second guideway could parallel existing I-95 and Route 1 north.

Clearly, a demonstration system will have details and subtleties which need extensive study in order to obtain some sense of the practicality, community reaction, cost, etc. It might be possible at this point to make a cost estimate for the demonstration guideway, but it could be more misleading than useful. Both links comprise about a 35-mile system, with 24 stations, so the cost is somewhere in the \$100 million range, maybe with ± 50 to 100% accuracy depending upon research developments and geography, as well as economics and politics.

The full-scale analysis of Boston's transportation needs should begin with the descriptive mobility nodes and links:

- * pedestrian shelter and sidewalks, ramps
- * cab station and waiting shelter
- * local bus station
- * parking garage (manual and automated) and access ramps
- * dual-mode station and pedestrian/vehicle access ramps
- * Central bus terminals
- * Transit stations & train stations
- * Mode mixers or combinations of the above.

Similarly, within the city and its environs there should be descriptive mobility regions, in order to avoid modal conflict:

- * pedestrian only
- * pedestrian plus conveyors, bicycles.
- * vehicles subject to limitations : small bus, scooters, delivery trucks, no parking on street or for longer than 1 hour.

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- * vehicles subject to limitations : small bus, scooters, delivery trucks, no parking on street or for longer than 1 hour.

- * Design-limited streets : minimal through traffic; cars and doubleparking permitted but not encouraged; residential and small shops
- * Regulation limited autoways : trucks and buses prohibited
- * Arterials : local traffic; limited access; closed access.
- * Transit arterials : Rail transit; busways; dual-mode
- * Mixed arterials and streets
- * Primary truck routes.

CHAPTER 12. CONCLUSIONS

At the end of such a lengthy thesis, it is difficult to reach a brief set of conclusions, but the effort will be made. The time is ripe in every sense except funding for major guideway development, so that every step of demonstration guideway development must be geared towards good, efficient research on a lean budget but with clear emphasis on exceptional maintainability as a valuable investment and on an avoidance of costly and ugly monument building. This technical and design effort must be complemented with a sound pre-demonstration strategy of financial planning and developing public and private support, while seeking directly to contact, persuade and mollify those groups most likely to be in opposition. The staged structure for the public and private corporations outlined in Chapter 10 seems a reasonable and quite practical method of developing a new system in a period of transportation crisis compounded by governmental & industrial budgetary woes and a taxpayers' revolt. The demonstration guideway discussed in Chapter 11. involves minimum displacement and is fairly well coordinated with a meaningful highway and transit plan for Boston. The heavy emphasis on maintenance and service is entirely consistent with our growing service economy, "consumer consciousness" and the transportation debacles of the past, esp. railroads and mass transit.

The major technical problems appear to be those of assuring good reliability of the arm and follower in switching, inspecting vehicles at entrances (and handling rejects), and keeping vehicle conversion costs sufficiently low while holding good standards of reliability. The human/guideway system interface may pose many unpredictable problems which will need to be worked out in the demonstration phase. Ten years from now, there might be an even greater public revolt against new technology, so that a technically feasible guideway may fail politically. Planners must avoid the errors of the space agency who so failed to perceive their own impacts, the changing priorities of society, of being unable to plan or to provide essential public services other than tweaking the national ego. In sum, the lack of substantive spinoff of either hardware or managerial techniques from the space program, as well as the inability to plan and to provide basic skills, makes the space program and the National Space and Aeronautics Administration one of the worst investments this nation has ever made -- right down to the unemployed space engineers who are now a burden on the economy and are so over-involved in an irrelevant, inhuman speciality that they appear quite incapable of making any major positive contribution to urban transportation problems, and may have a negative effect if thrust into the urban design sphere by well-meaning urban officials.

Conflict and concern over dual-mode must be expected and

should be faced forthrightly, and not avoided by hiding behind statutory requirements, perfunctory semi-public hearings, or thick-skinned stubbornness, as has characterized numerous highway, redevelopment and transit planning processes over the years. The eventual penalties for such avoidance are many -- poor service planning and monument building, as well as final public revolt. By August 1969, 66 major urban disputes over highway construction could be identified¹ which were causing the delay of 277 miles of highway construction worth \$3 billion. Cambridge, Mass., is a singularly significant example of a city declaring "No Highways" virtually from citizen to city councilor and city manager. Confrontation is not the worst thing that can happen -- there can be a lack of confrontation which yields only friction and a festering sore. Union problems with dual-mode must be discussed at the grass-roots level, man-to-man, without fancy speeches and formal contacts between dignitaries, since the modern union leadership is losing contact with the workers in many cases, from transport workers to police, as the concept of service personnel unionization exceed in growth the concept of union leadership of these personnel.

More should have been said in the thesis about community contacts and design techniques, of user representation on guideway policy boards, of planned or unplanned projects with significant land use and transportation impact (esp. new office buildings) and

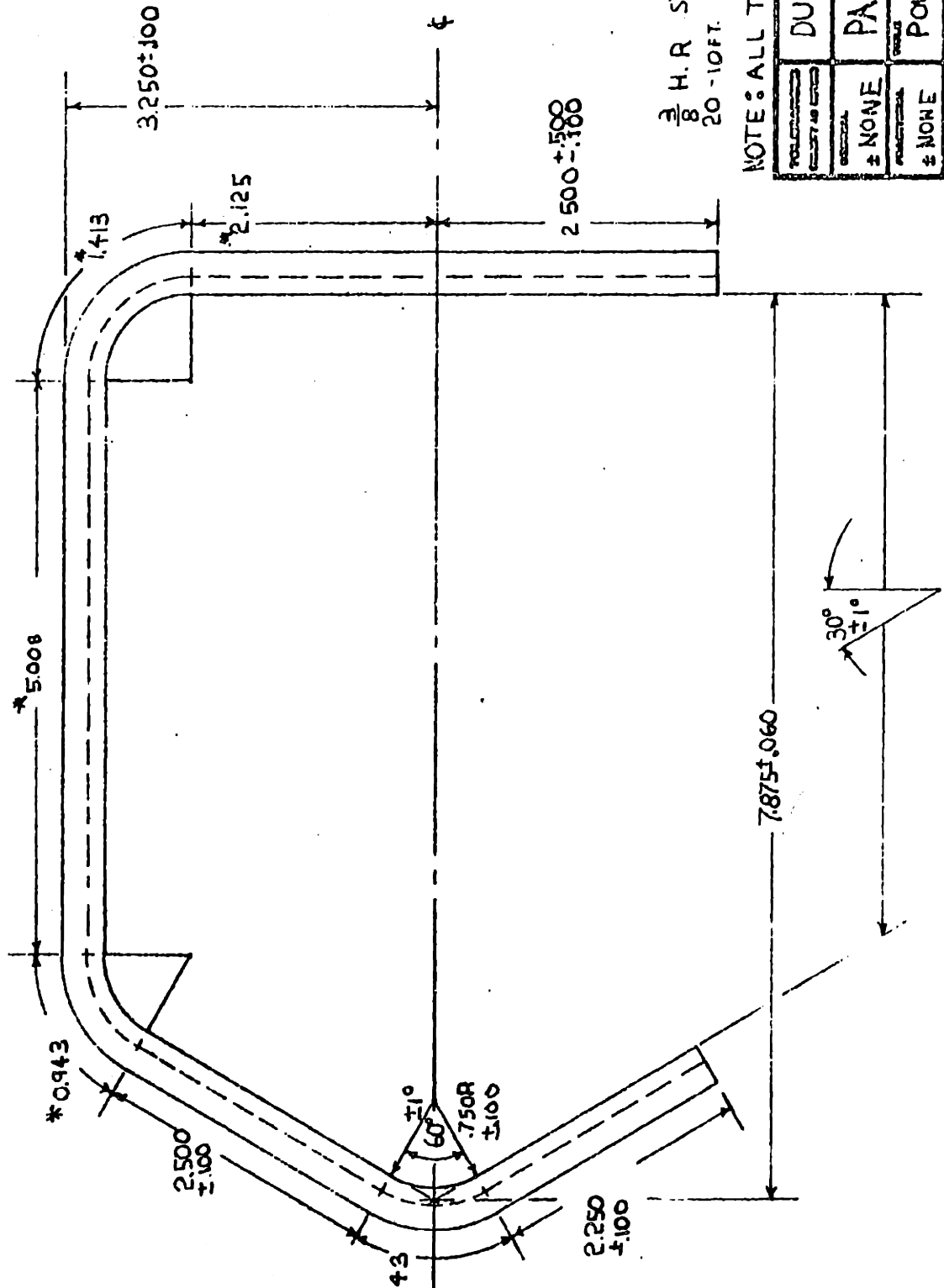
connections to Logan Airport, as well as the relation of dual-mode in the Southwest Corridor to Intercity HSGT or rail travel to New York. The future of Logan Airport may quite literally be tied up in the factor of noise and will be dependent upon the railroad development of train service to New York. Probably, the low-cost but unglamorous option of improving the rail roadbed and trains for 100 to 150 mph service will be chosen by budget conscious officials, and air shuttle service will decline rapidly. A dual-mode connection to the new University of Massachusetts extension at Columbia Point has not been included, although it might be an obvious answer to the current plans for a 7,000-car garage (complementing 15,000 students, 2000 faculty and thousands of service personnel) spilling its contents onto the already congested and bottlenecked Morrissey Blvd. However, it does not seem at all wise to have a university at this location in the first place, particularly one with no housing, so that there is some question of the value of dual-mode service to an undesirable facility.

The next steps seem reasonably clear -- further analyses of possible demonstration routes in Boston, contacts for the assembly of a company consortium to begin Stage I, and contacts with transit and highway officials to shelve plans for the construction of unwise or unworkable transportation facilities.

APPENDIX A. GUIDERAIL DRAWINGS

(drawn by William Zimmerman
and William Hall)

NEUTRAL AXIS
(4" AT ON RADIUS)



$\frac{3}{8}$ H. R. STEEL

20' 10" FT. PIECES REQUIRED (SEE DWG. PR-9)

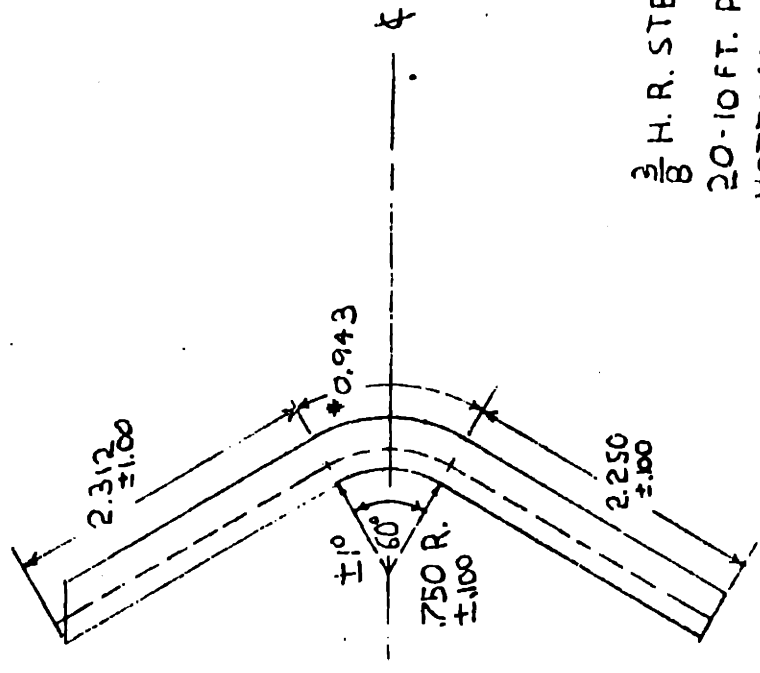
NOTE: ALL TOLERANCES FROM ϕ

DUAL-MODE GUIDEWAY	
TOLEANCES EXCEPT AS NOTED	CONTROL BY NAME HALL
REVISIONS	QUANTITY
± NONE	PART # 1010 FULL
± NONE	POWER RAIL SECTION (OUTER)
± NONE	5 SEA68
PR-2-1010	PR-2-1010

Fig. A-3. Power Rail Section (Outer)

NEUTRAL AXIS
(.4T ON RADIUS)

DATE	BY	REVISION RECORD	AUTH. OR. CR.



- 530 -

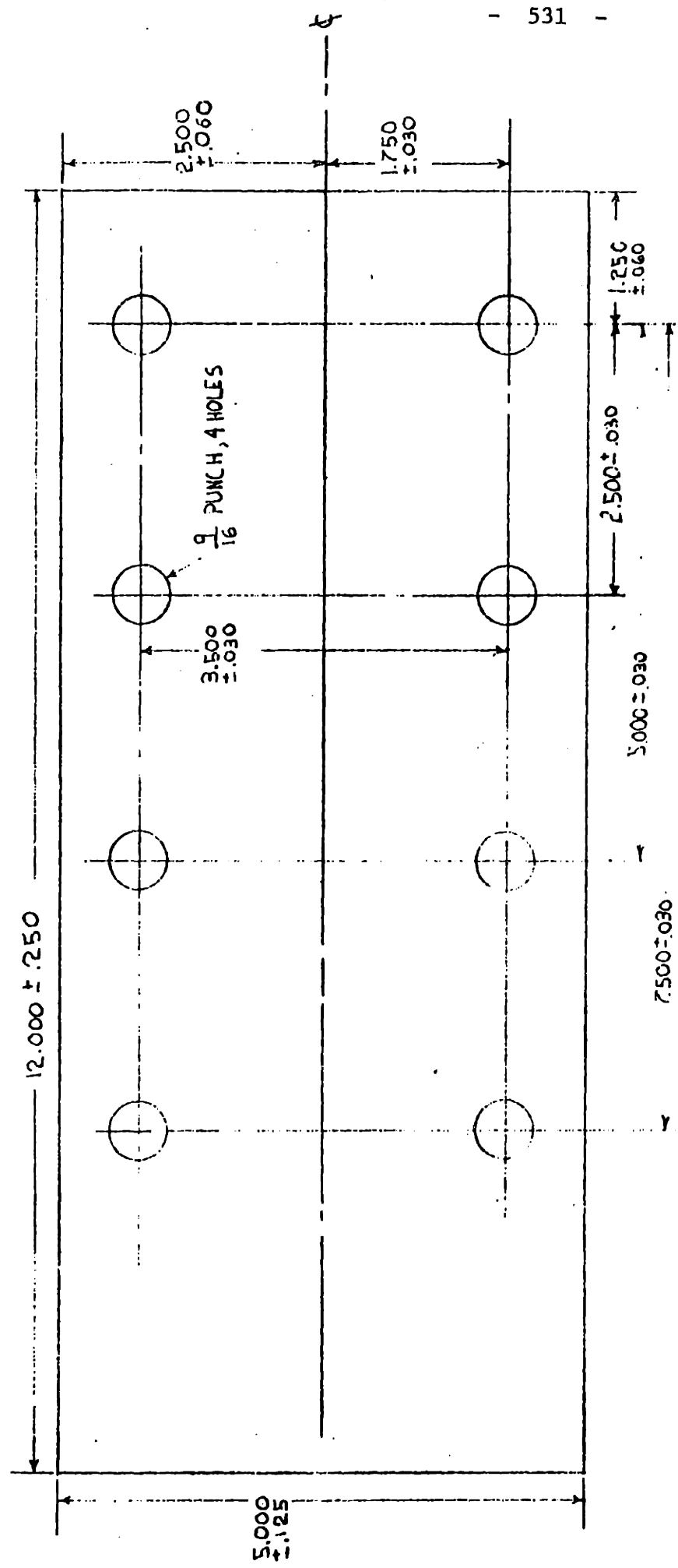
2.312
.943
2.250
5.505

$\frac{3}{8}$ H. R. STEEL, $5\frac{1}{2}$ " STOCK
20-10 FT. PIECES REQUIRED (SEE DWG PR-9)
NOTE: ALL TOLERANCES FROM ϕ

TOLERANCES UNLESS OTHERWISE SPECIFIED	DUAL-MODE GUIDEWAY	
FINISH	PART # 1020	SCALE FULL
FUNCTIONAL	POWER RAIL SECTION (INNER)	
ASSEMBLY	5 SEPT 66	PR-3 1020
DESIGNED BY	DESIGNED BY	APPROVED BY

Fig. A-4. Power Rail Section (Inner)

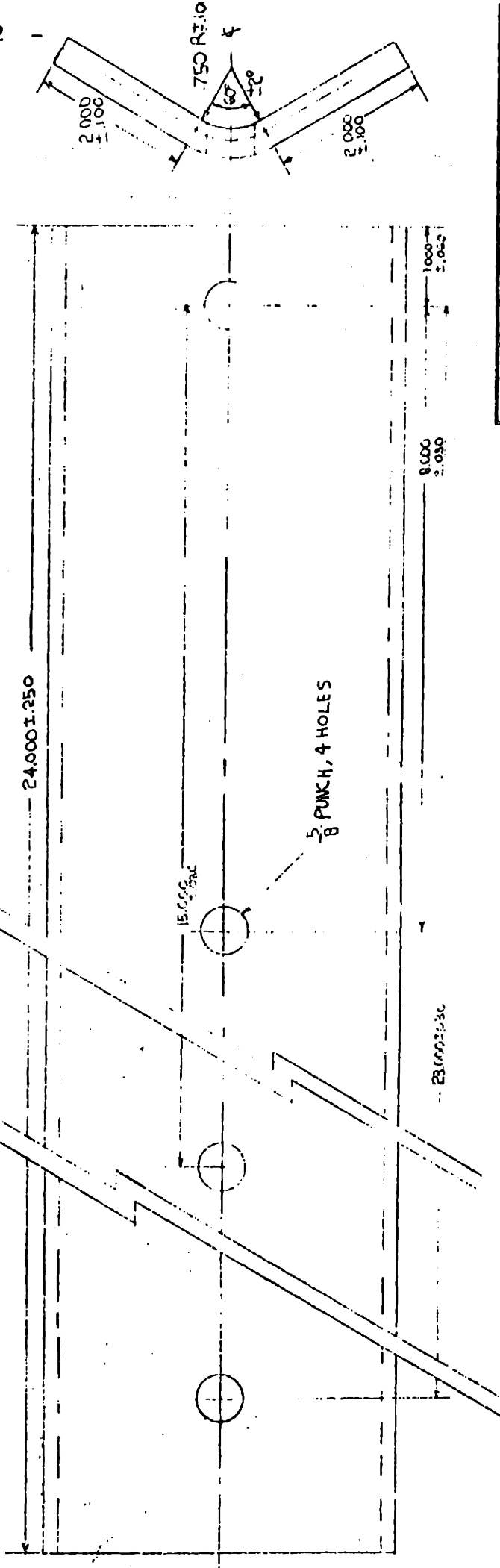
DATE	BY	REVISION RECORD	AUTH.	DR.	CR.



TOLERANCES UNLESS OTHERWISE SPECIFIED	DUAL-MODE GUIDEWAY		DESIGNED BY W. E. HALL
GENERAL	PART # 1030	SCALE FULL	APPROVED BY
FINISH	POWER RAIL JOINT PLATE (FLAT)		
QUANTITY	5 SEPT 65	REV. NO.	DATE
± NONE	PR-4-1030	REVISED BY	REV. NO.

$\frac{3}{8}$ STEEL, 5" STOCK
21 PIECES REQUIRED

Fig. A-5. Power Rail Joint Plate (Flat)

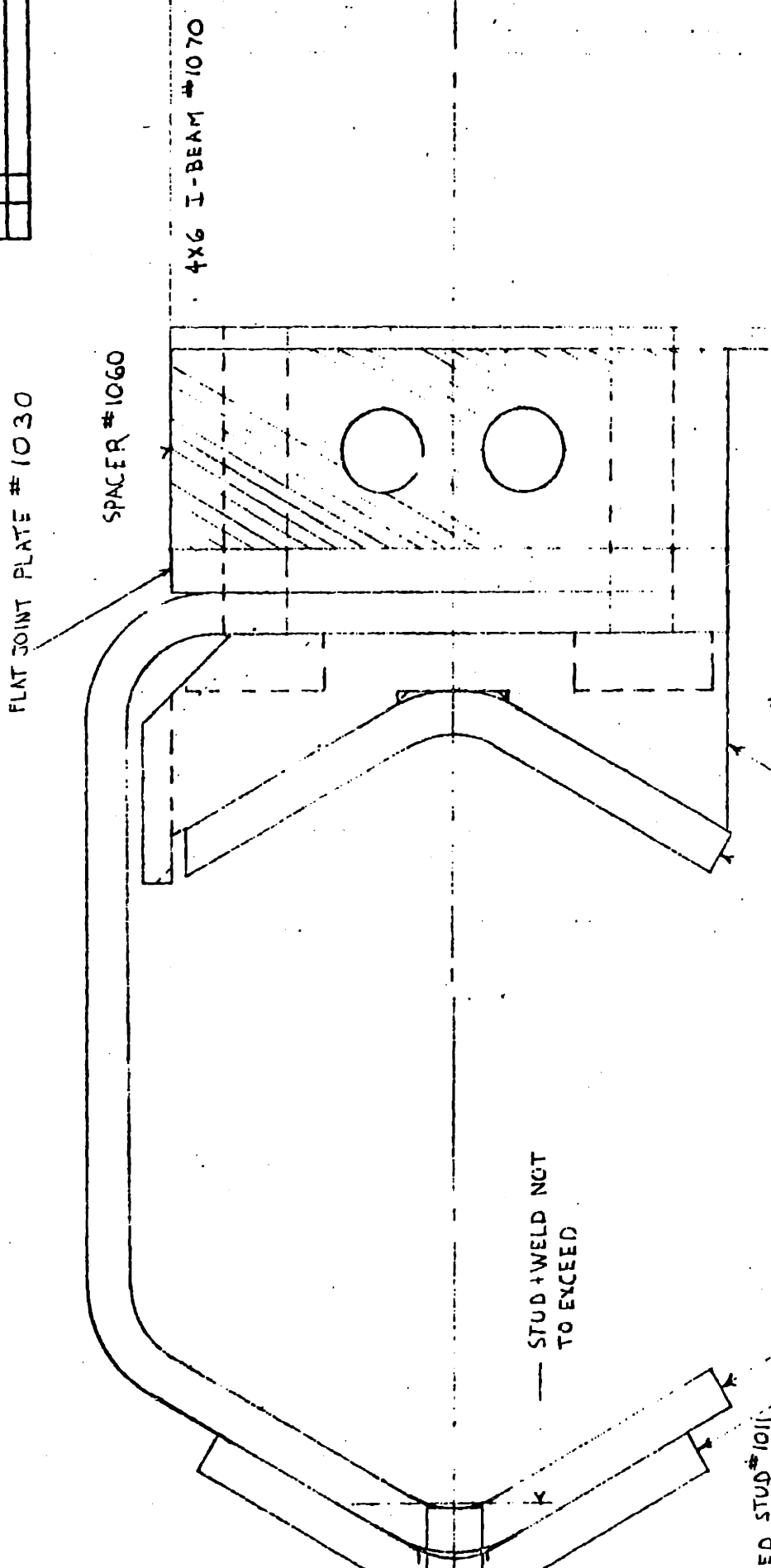


3/8 STEEL, 5" STOCK
 21 PIECES REQUIRED

DUAL-MODE GUIDEWAY	
PART# 1040	FULL
POWER RAIL JOINT PLATE (CONTOUR)	

Fig. A-6. Power Rail Joint Plate (Contour)

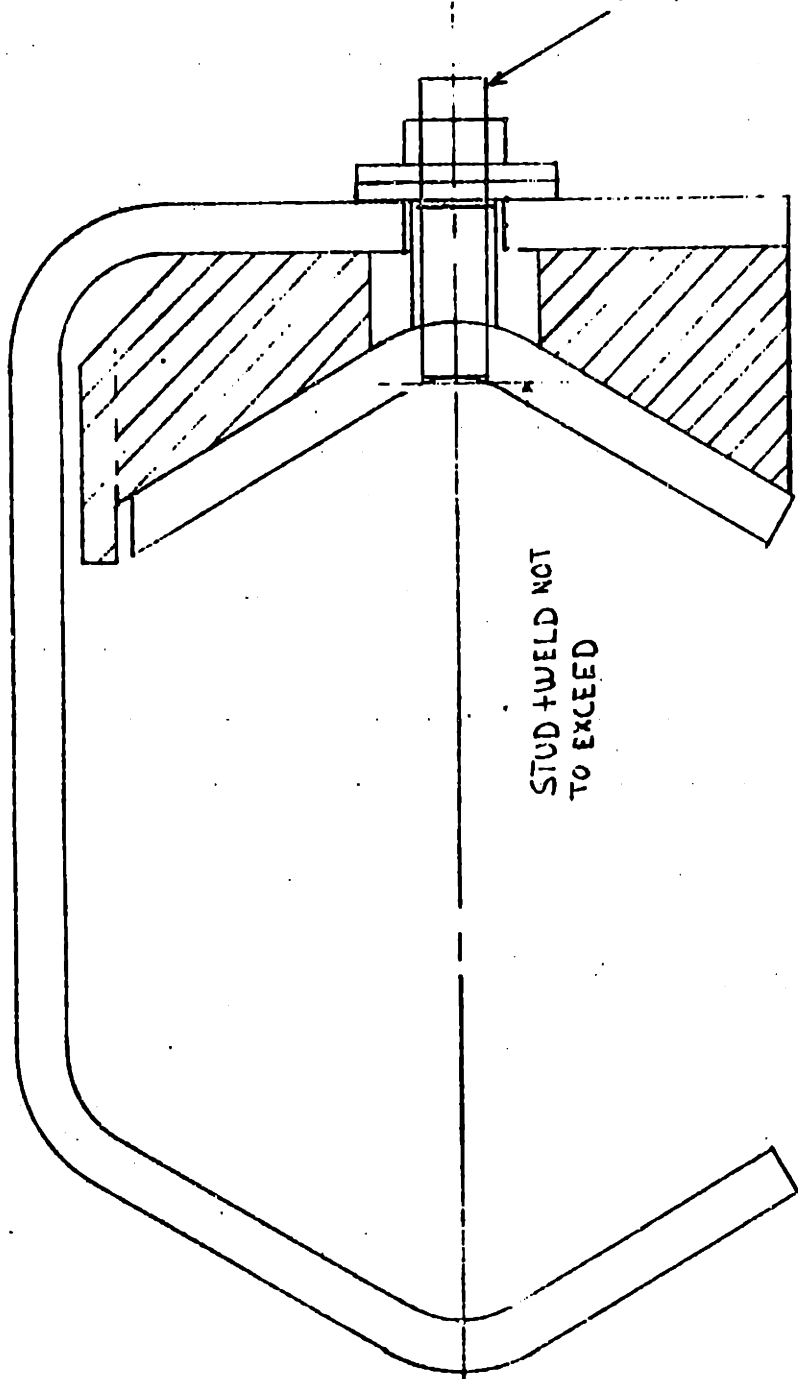
DATE	BY	REVISION RECORD	AUTH.	DR.	CL.



TOLERANCES UNLESS OTHERWISE SPECIFIED		DUAL-MODE GUIDEWAY	
DECIMAL	± NONE	PART # 1011	SCALE FULL
FRACTIONAL	± NONE	DRAWN BY A.F. HALL	
ANGULAR	± NONE	APPROVED BY	
TITLE		DATE	DRAWING NUMBER
POWER RAIL SECTION - JOINT STUD		5 SEPT 66	PR 6 - 1011

Fig. A-7. Power Rail Section - Joint Stud.

DATE	BY	REVISION RECORD	AUTH.	DR.	CL.



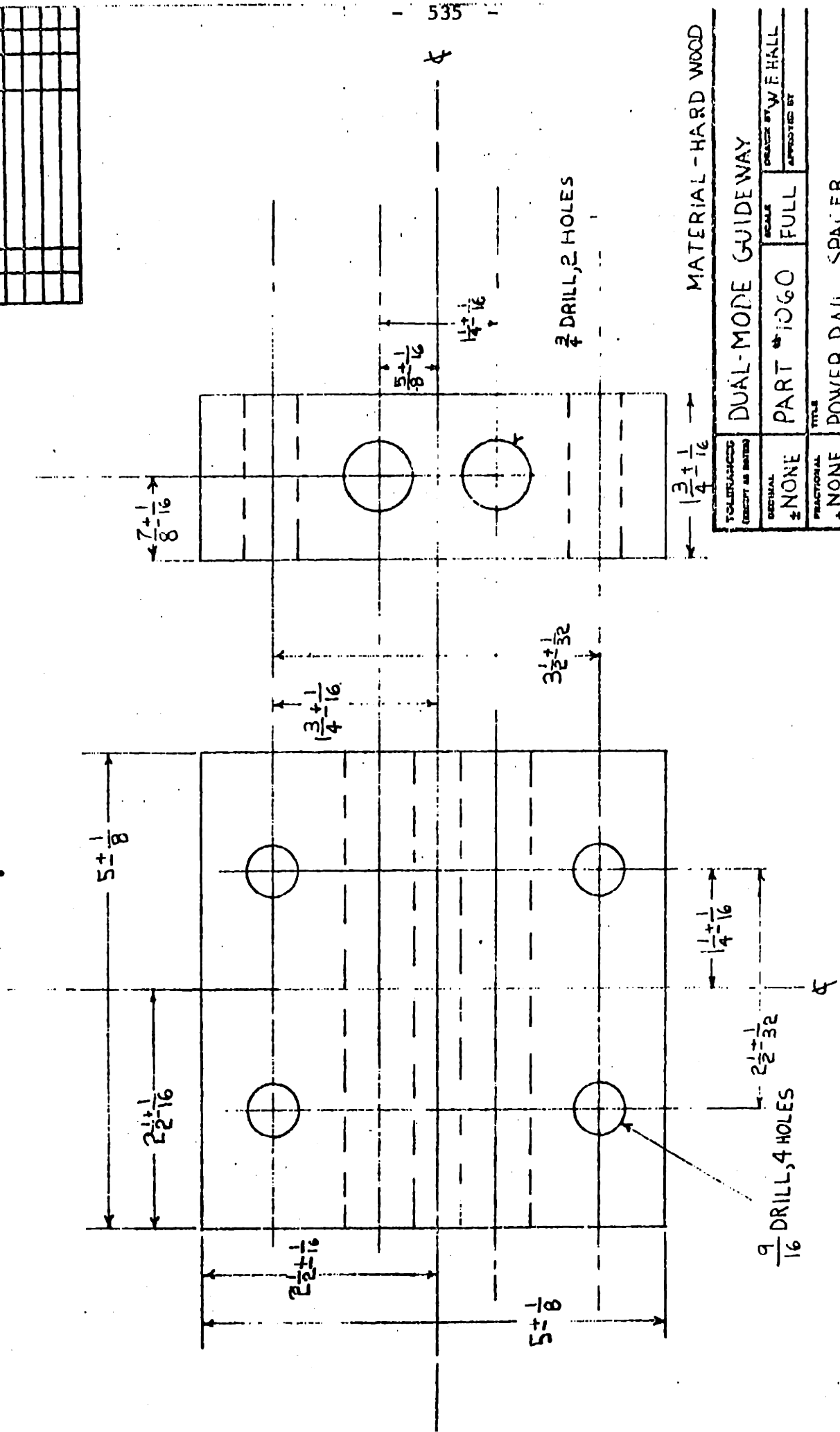
NOTE: ALL ITEMS LISTED, ON CENTER (A) ±.030

- 1/2 x 1 3/4 WELDED STUD. #1021
- 1/2 ID x 5/8 OD x 3/4 INSULATING SLEEVE #1021A
- 1/2 x 1 1/2 x 1/8 FIBER WASHER #1021B
- 1/2 x 1 1/2 x 1/8 STEEL WASHER + NUT #1021C

TOLERANCES UNLESS OTHERWISE SPECIFIED	DUAL-MODE GUIDEWAY	
GENERAL ± NONE	PART # 1021	SCALE FULL
FUNCTIONAL ± NONE	DRAWN BY W.F. HALL	
ANGULAR ± NONE	APPROVED BY	
TITLE POWER RAIL - INSULATED STUD		
DATE 5 SEPT 68	QUANTITY ORDERED	SEE SPECIFICATIONS
5 SEPT 68	PR-7-1021	500

Fig. A-8. Power Rail -- Insulated Stud

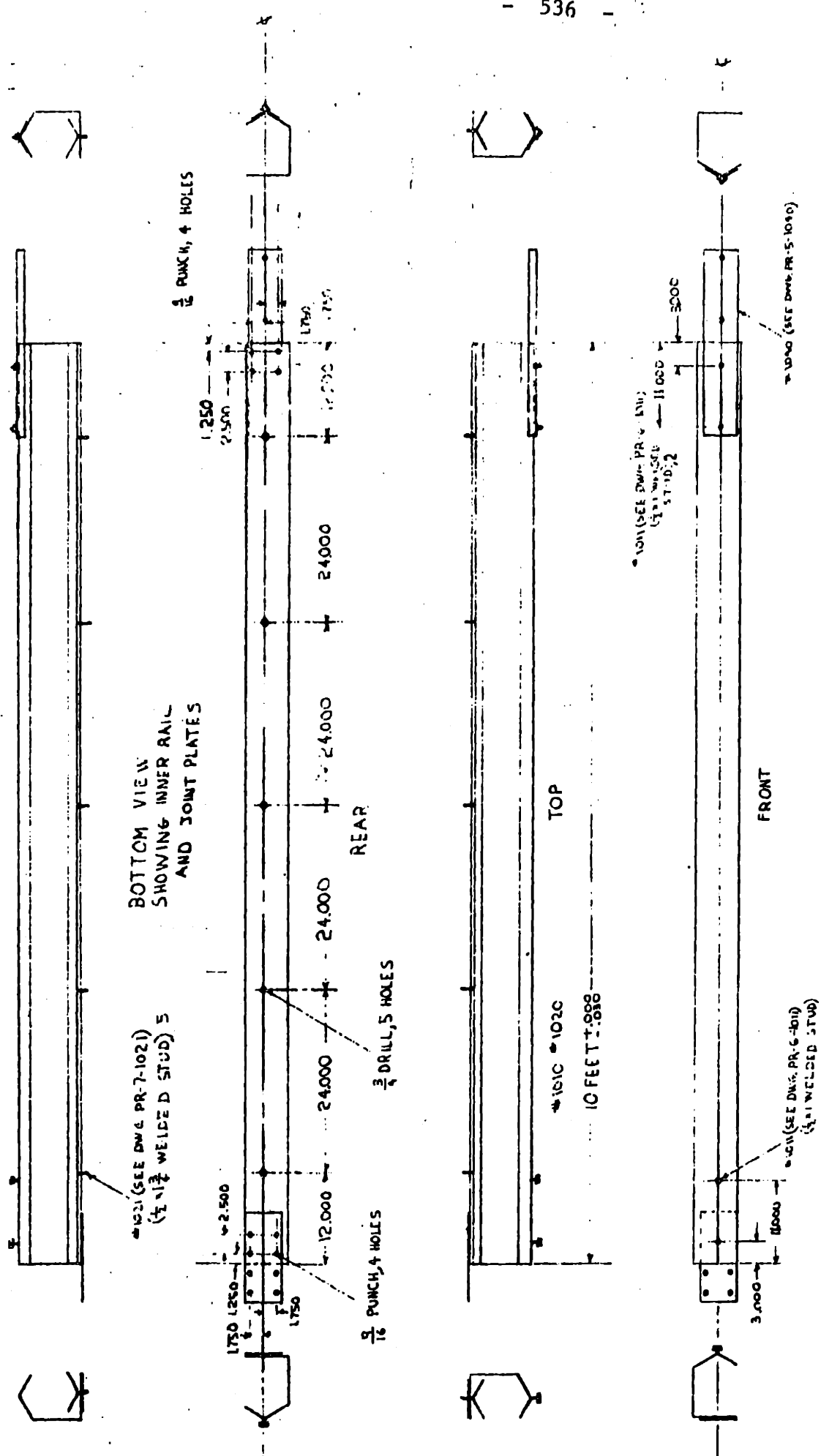
DATE	BY	REVISION	RECORD	AUTH.	DR.	CL.



TOLERANCES (UNLESS OTHERWISE SPECIFIED)	DUAL-MODE GUIDEWAY	SCALE	APPROVED BY
DECIMAL ± NONE	PART # 1060	FULL	BRUCE BY W F HALL
FRACTIONAL ± NONE	TITLE POWER RAIL SPACER		APPROVED BY
ANGULAR ± NONE	DATE 6 SEPT 68	DRAWING NUMBER PR-8-1060	DATE 9-2-68

Fig. A-9. Power Rail Spacer

NOTE: STUDS + HOLES ARE IN REFERENCE TO ENDS NOT TO ALLOW FOR MISALIGNMENT DURING
 (b) TO ALLOW STAGGERING OF INNER RAIL (220) FOR 4 FEET
 (c) TO ALLOW INTERCHANGING OF CORNER OF OUTER RAIL (310)



- NOTE: ALL STUDS MUST BE SHIPPED WITH NUTS FLUSH WITH OUTER END.
- NOTE: STUDS MAY EXCEED SPECIFIED LENGTH

Fig. A-10. Power Rail Assembly

DUAL-MODE GUIDEWAY			
QUANTITY IN DRAWING	PART NO	SCALE	DATE
1050	1010	1:210	10/11/61
DESIGNED BY	CHECKED BY		
NONF	PR-4-1010		
DATE	PROJECT		
10/11/61	PR-4-1010		

APPENDIX B. PROTOTYPE FOLLOWER DRAWINGS

(Basic design by Robert Tanner;
drawn and built by Philip Davis)

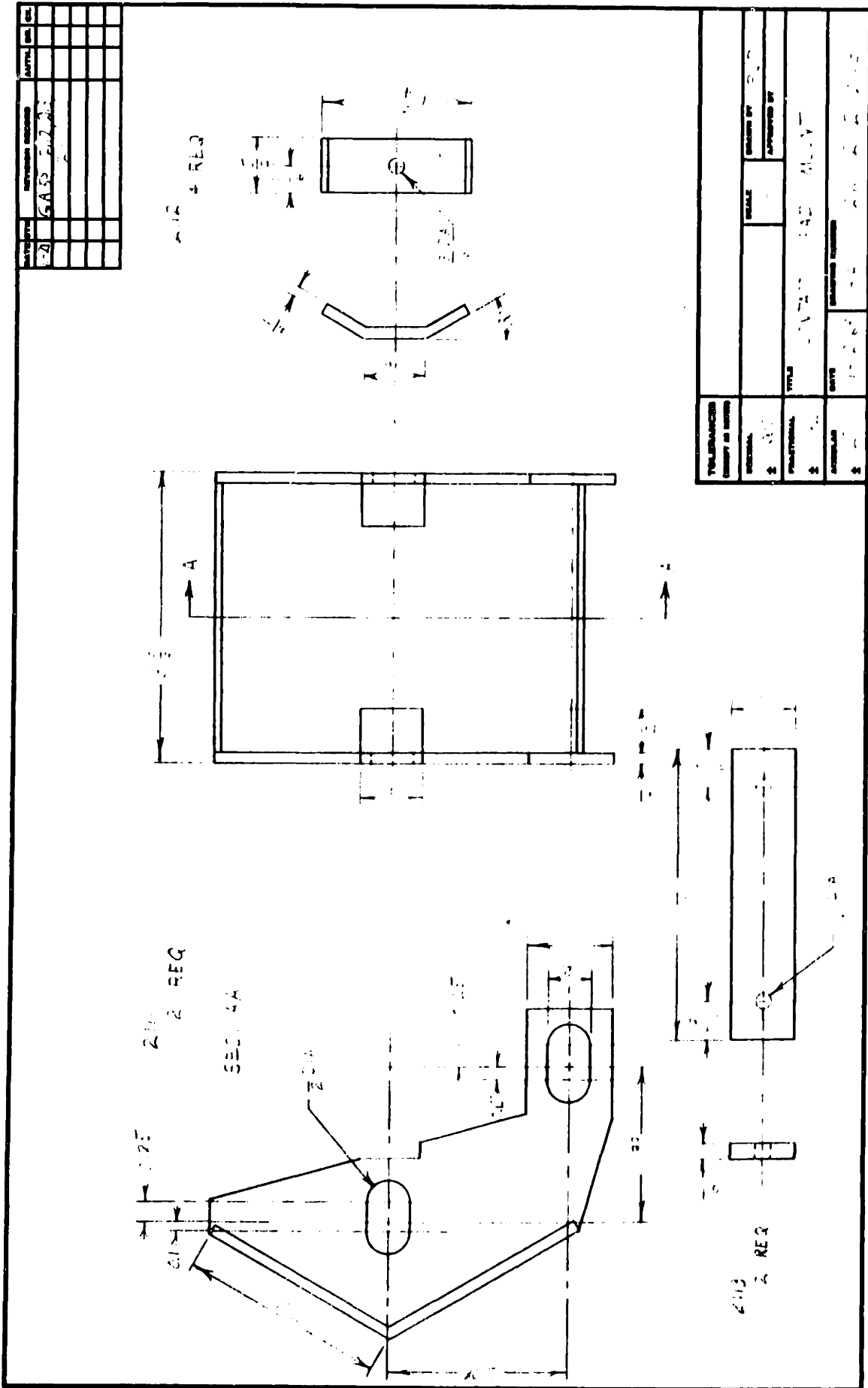


Fig. B-1. Contact Pad Mount.

APPENDIX C

BRANCHING RAMPS

As noted in Chapter 5, non-simultaneous accelerations can lead to variations in headway. On deceleration ramps, the headways tend to decrease, and fan-out ramps may be necessary to thin out the flow for high volume exits. In the interests of system safety, the maximum permissible flow along any ramp segment between two switches will be constant and will correspond to a maximum design flow density ρ_{\max} which might be in the range 0.8 to 0.95. The theoretical flow capacity Q_{\max} is still defined by $\frac{V(t)}{d_s}$. The degree of flow saturation (the branching criterion) λ , at any point along the guideway \bar{s} is defined as

$$\lambda = \frac{\rho(s)}{\rho_{\max}} \leq 1.0 \quad (C.1)$$

At the beginning of the exit, the flow saturation will be λ_1 , and this value will determine the number and length of the branching ramps.

If N is the number of lanes, $\frac{\lambda_1}{N(s)}$ is an increasing staircase function for acceleration and a decreasing function for deceleration (Fig. C-1). For the case of constant average headway (no flow compression at low speeds), the first lane saturation occurs at a speed of

$$V_1 = \frac{V_o \lambda_i}{1.0} \quad (C.2)$$

and generally

$$V_N = \frac{V_o \lambda_i}{N} \quad (C.3)$$

If the final velocity at the station or exit is V_e , the total number of branch lanes N_f is the nearest integer $\geq V_f/V_e$, so

$$N_f \geq \frac{V_o \lambda_i}{V_e} \quad (C.4)$$

shown in Fig. C-2.

The procedure for calculating the ramp geometry at exits, given the exit flow Q_e and ρ_{max} , and λ_i , plus V_o and V_e is to obtain λ_i and integer N_f . For example, given $Q_e = 3250$ vph, $\rho_{max} = 0.8$, $V_o = 60$ mph and $V_e = 10$ mph, $\lambda_i = 0.4$ and $N_f = 2.1$ so that three lanes would be required. Total ramp length, including 150 ft. for initial high speed queuing, is 820 ft. for 0.3G max deceleration braking.

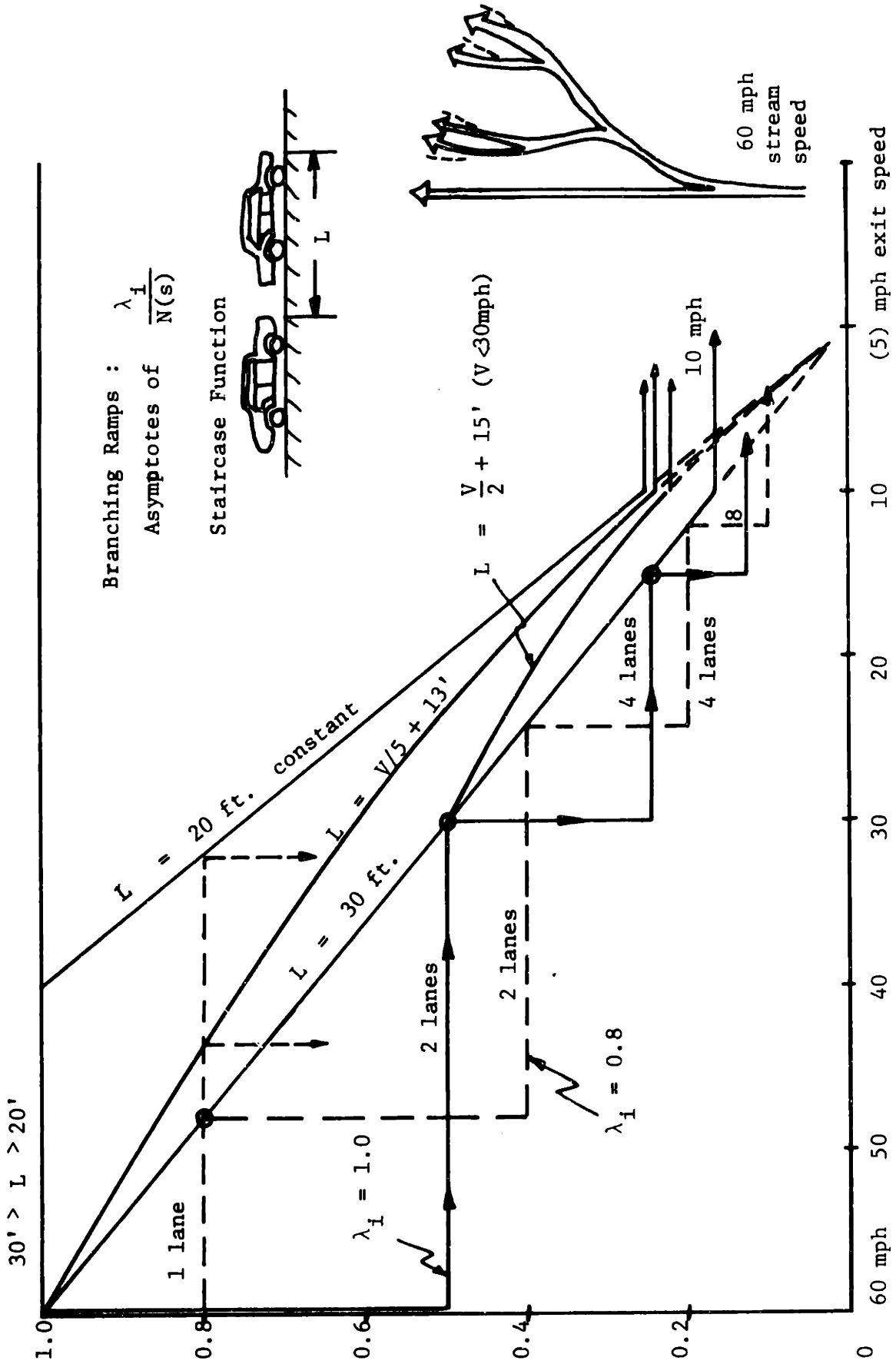


Fig. C-1. Branching Ramps : Staircase Function

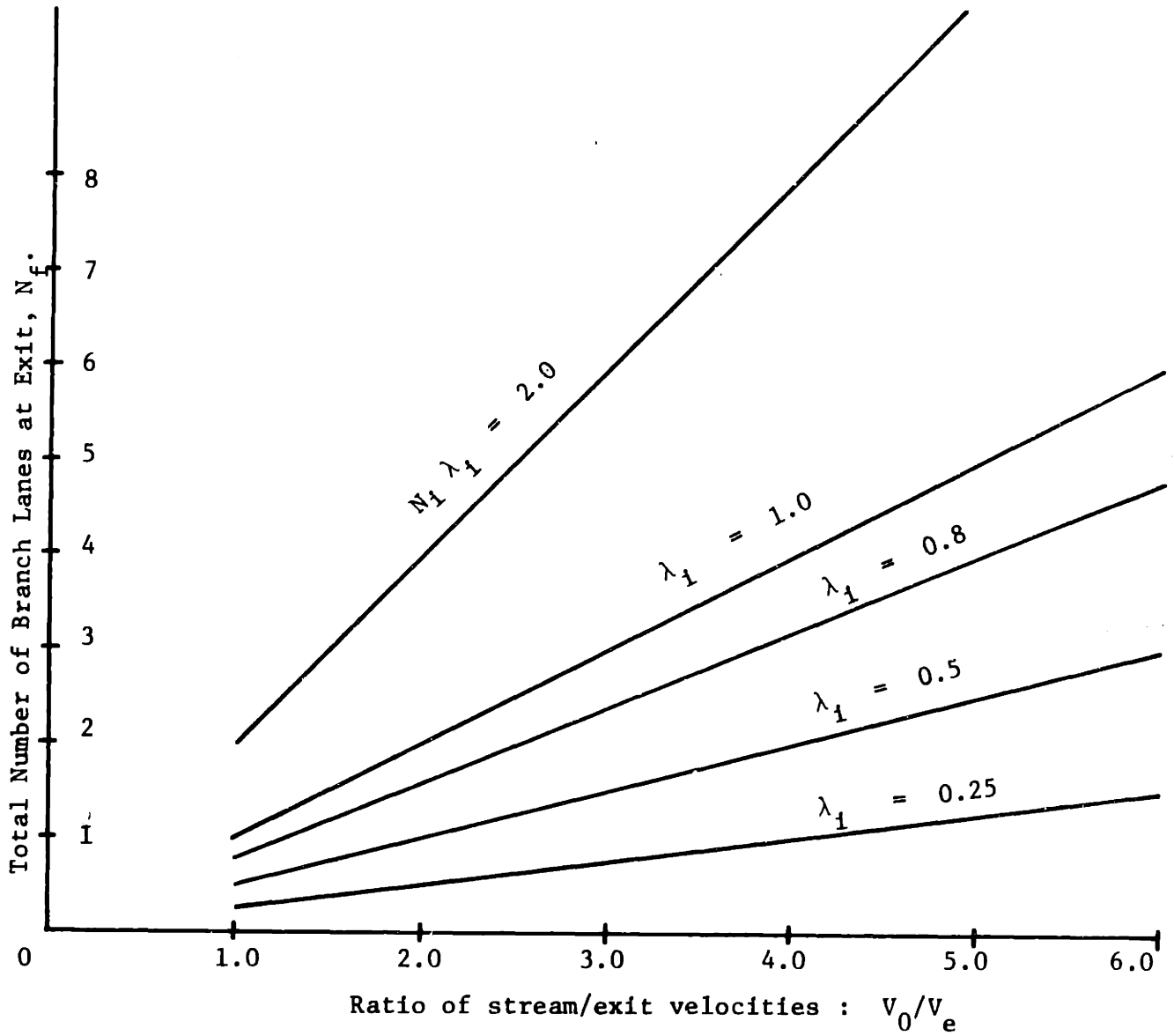


Fig. C-2a. Total Number of Branch Lanes.

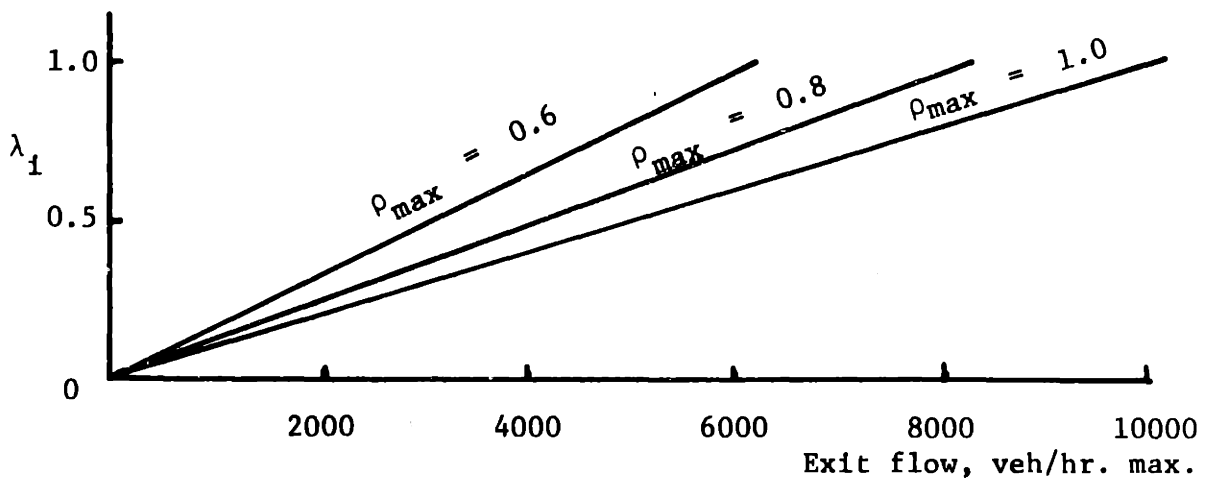


Fig. C-2b. Ramp Flows & Lane Saturation

APPENDIX D

DUAL-MODE BUS OPERATIONS
ON INTERCITY ROUTES

While dual-mode autos have limited value in a rural setting, because of the expense of the guideway and the low cost of land, the adaptation of the dual-mode concept to high speed intercity buses may be a practical spin-off. Fairly large buses, possibly using the same guideway as cars but not necessarily, would pick up their passengers at convenient terminals and stops at various locations, enter the guideway, and in tandem with two or three buses going the same direction, be hitched together and accelerate to cruising speeds of 120 to 150 mph along the grade-separated right-of-way. Railroad air space could be used, with the guideway elevated to avoid crossing accidents and reduce the threat of vandalism. The buses would shuttle back and forth between adjacent cities, for example in the Boston-Washington corridor, and the off-line station concept of dual-mode can be used to permit a mix of local and through traffic. If the buses had walk-through capability, passengers could leave the leading "express" buses and walk into the rear bus which then drops off and stops at the station.

The hitched buses provides a motive redundancy which means that any bus train will tend to keep itself going until the next exit.

For increased stability, lateral guidance arms for skid prevention can be located at the rear of each bus, so that buses are effectively anchored in yaw at all four corners.

A 125 cruising speed on the guideway translates into an under two-hour line haul trip between Boston and Washington, with half-hour of traffic or more at either end. If the buses were paired and operated at one-minute headways, a two-way capacity of 9,600 pass/hr. is attainable. The implications of such a guideway for trucking operations, especially at night, would be quite considerable. If the cost of soundproofing airplanes and airports or of improving the Penn Central tracks and setting up good management prove to be overwhelming problems, a dual-mode link (instead of a TACV line) in the Eastern Seaboard corridor is a reasonable possibility.

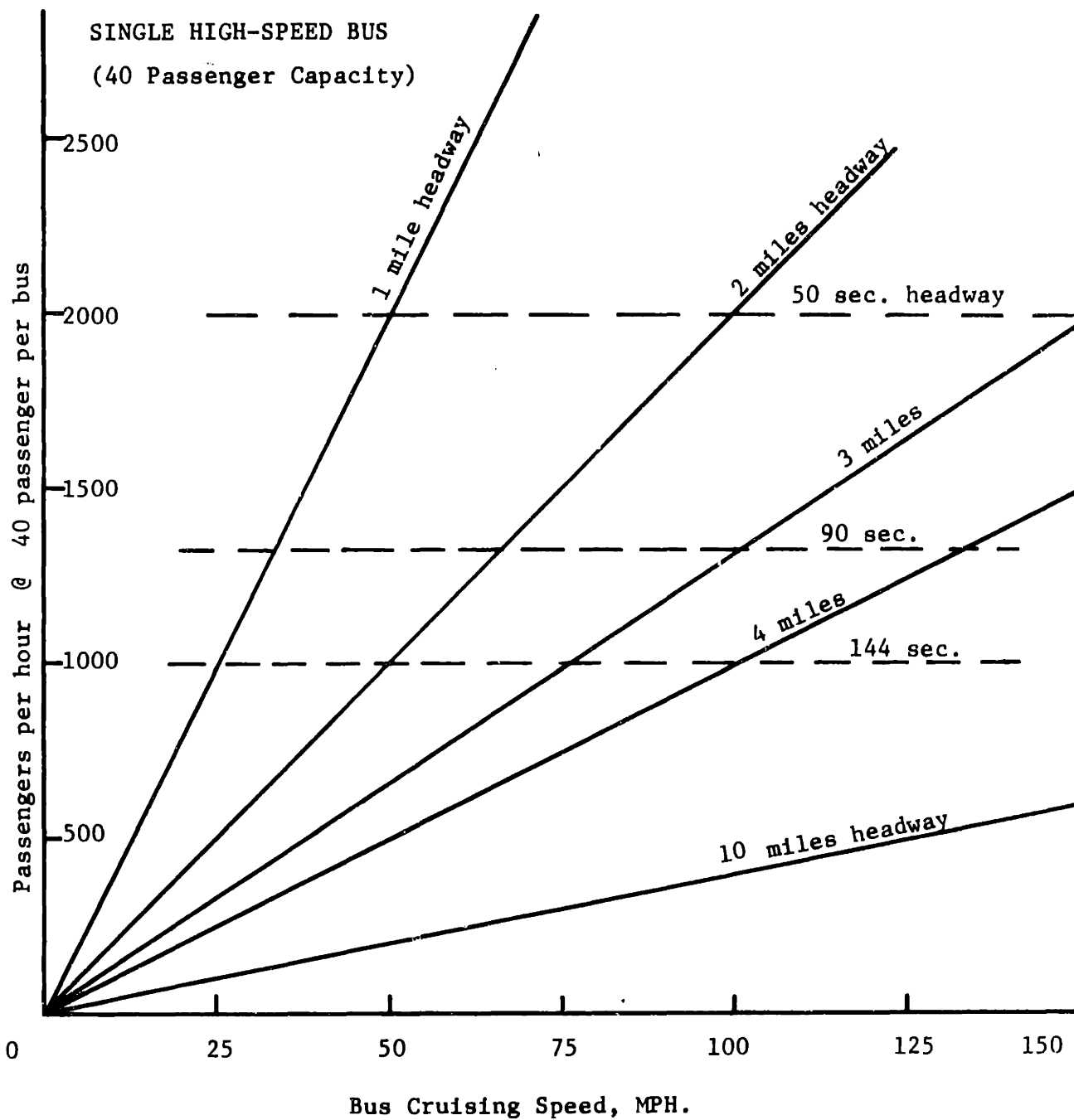


Fig. D-1. Intercity Dual-Mode Bus : Capacity and Headway Relations

APPENDIX E

GUIDANCE ARM OPTIONS

A more inclusive list of guidance options than that presented in Chapter 2 is :

1. Support of both the front and rear wheels on a pallet or piggyback flatcar, which themselves need to be powered & guided.
2. Similarly, pallet support under the front wheels only.
3. Steel wheels inside regular wheels, like Urbmobile.
4. Hitching cars together via a bumper hitch.
5. Regular wheels running in grooves or channels in the road
6. Radio-controlled steering or buried cable follower
7. Cable car
8. Single raised rail in roadway, or concrete ridge
9. Roadbed slot and ventral arms underneath the car.
10. Lateral Guidance arms and guiderails
11. Monorail : around a beam or in a channel
12. Overhead wire and slider
13. A large trough

For various structural and design reasons, all choices were selectively eliminated, leaving the lateral guidance arm the best choice by far.

APPENDIX F

DEMONSTRATION GUIDANCE AND POWER SYSTEM

The test vehicle has been a 1967 Mustang, 6-cylinder hardtop, with 3-speed transmission, power steering and a 3.2 : 1 rear axle. It was acquired in July 1968, from the Ford Motor Company. For guidance, a simple single-pivot arm was attached to 1/4 inch steel reinforcing plates welded to the cowl bulkhead. Arm extendability is achieved through an inactive 2.5-in. bore hydraulic cylinder incorporated into the arm. Coil springs of net $K = 300\text{lbs./in.}$ are located on both sides of the piston to filter lateral guidance forces.

The guidance arm terminates in a non-articulated follower, which is inserted in a simple chute at the beginning of the 200-ft. guiderail. To save costs, only one side of the guiderail and one arm were constructed. A convertible top motor raises and lowers the arm from rail height position to storage position within the fender. The modified fibreglas fender has two flaps to cover the arm in its stored position. The rail, disassembled in Summer 1970, was supported every 10 feet by surplus highway guardrail posts. It was broached by a specially designed device employing two files to remove the scale, rust and smooth over the joints. The roadbed surface was crushed gravel.

The first vehicle tests were made using the ICE power, with clutch and accelerator control, while the steering wheel was allowed to caster freely. Speeds of up to 25 mph have been obtained in the short 200-ft. distance.

The entrance chute has been supplemented by a roadway positioning beam for the right front wheel. Initially, aiming the car proved difficult and took some training, but more experience and the curbing soon permitted the driver to move slowly but non-stop onto the guideway, even though the arm was on the right side, out of sight.

The Mustang has been modified to incorporate electric motor drive, with speeds up to 15 - 20 mph on the guideway. A diesel starter motor (24 VDC, 6-in, diameter, 16-in. long, rated at 10 HP) is mounted on the back of the rear axle assembly and is powered initially by batteries to check motor performance, with the intent being eventually to take in power through the test rail. The driveshaft is extended out the rear end of the differential and is connected to the electric motor by a one-way clutch and chain drive with a reduction ration of 14 : 32. The motor speed at 20 mph (for a 3.20 axle ratio) is 2040 rpm.

The total weight of the motor assembly is 80 lbs., which compares to an unsprung weight of over 300 lbs. For preliminary tests four 6-volt batteries are arranged transversely over the rear axle hump. An incremental voltage system employing eight SCR's for acceleration and 4 solenoids for braking has successfully undergone tests, and the modified axle is functioning reliably.

Modifications to the car include rerouting the muffler and replacing the main gas tank with an auxiliary unit. A stabilizing

strut to limit rear axle windup was been incorporated, but otherwise springs and shocks are stock equipment.

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