CALIFORNIA PATH PROGRAM
INSTITUTE OF TRANSPORTATION STUDIES
UNIVERSITY OF CALIFORNIA, BERKELEY

Studies of Road Infrastructure Requirements for Small Innovative Vehicles

William L. Garrison

UCB-ITS-PRR-93-16

This work was performed as part of the California PATH Program of the University of California, in cooperation with the State of California Business, Transportation, and Housing Agency, Department of Transportation; and the United States Department Transportation, Federal Highway Administration.

NOVEMBER 1993

ISSN 1055- 1425

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

STUDIES OF ROAD INFRASTRUCTURE REQUIREMENTS FOR SMALL INNOVATIVE VEHICLES

ABSTRACT

Phase 1 of this study of the road infrastructure requirements for small innovative passenger vehicles sought to scope the benefits and costs associated with the introduction of such vehicles. It also sought to identify the ways vehicles might be introduced and the road modifications that might be required or desired if such vehicles were to appear in vehicle fleets. Two small vehicles were considered: a high performance, 500 to 700 pound, 1 + occupant, narrow car that might serve as a commuter car and a low performance, golf cart-like vehicle that might be used for neighborhood range travel. Either of these vehicles might be used to access transit facilities and serve as a station car.

Analyses of benefits for the commuter vehicle indicate that it might increase the mobility of households, aid highway agency provision of cost effective capacity increases, and provide generally dispersed benefits associated with reduced urban congestion and consumption of petroleum fuels. The commuter vehicle could be an ultra-low-emission car. But because ultra-low-emission vehicles will be required in California whether the commuter car is marketed or not, its availability would have little impact on reducing emissions from automobiles.

Road infrastructure modifications for the commuter car include restriping, provision of special lanes including outrider lanes on structures, and flyovers. Increases in parking facility capacity could be achieved by restriping. These modifications could sharply increase capacity and could be achieved incrementally at low cost.

Golf carts are already in use, as are small utility vehicles of similar size. The wider use of these or similar vehicles appears to turn on provision of road facilities for them. Peachtree City, GA illustrates how such facilities can be provided in a new community. The provision of facilities in old neighborhoods poses a more difficult problem. Designs were developed suggesting how facilities might be provided. Neighborhood cars might increase local scale mobility and might aid in improving the quality of local environments.

Wider use of neighborhood cars could be aided by improved facility design concepts and the development of standards. More needs to be known about the market for, and potential uses of, commuter cars, as well as about associated road designs. Start-up production costs and market risk may be a barrier to marketing commuter cars.

The work reported has not rejected the notion that small vehicles might offer opportunities for transportation system improvements. That's not the same a proving that the notion is viable. That kind of proof will be found at the end of rounds of inquiry when vehicles appear on the market. So although the report contains many observations that have a findings character, small vehicle opportunities remain a subject for study and testing.

STUDIES OF ROAD INFRASTRUCTURE REQUIREMENTS FOR SMALL INNOVATIVE VEHICLES

1. INTRODUCTION

This is the Final Report of Phase I studies of road infrastructure requirements for small innovative highway vehicles. The adoption of such vehicles turns on answers to questions about improved mobility and reduced energy use and air pollution, as well as questions about regulatory constraints, vehicle producers' decisions, and the suitability of the highway infrastructure. Modifications to highways may be required before consumers will purchase and use innovative vehicles or they may be desired if such vehicles are widely used. For this reason, stress in this Report is on highway modification questions. Preliminary estimates of benefits and costs are presented, some "ball park" and some relatively refined. There is also stress on what has been learned about the problem of introducing innovative vehicles or novelties into the highway system.

Project reports previously published provide statements of approaches and findings, and these provide the basis for the present report which strives for clarification-stocktaking objectives. Reports previously published should be consulted for details of the work (1, 2, 3, 4, 5; see also 6).[1]

Clarification-stocktaking objectives are appropriate at this time because rounds of work have been completed that addressed fuzzy questions. Work sought to clarify those questions. Some things have been learned about the importance and substance of benefit-cost questions. Some things have been learned about the technical problems of introducing innovative vehicles into the highway system. At this point in the stream of work, this report strives to say what is known now about the small innovative vehicle opportunity and how it might be grasped.

The findings to be presented will say that small innovative vehicles promise decreases in congestion, improvements in mobility, and reductions in energy use. Impacts on air pollution depend on the type of vehicle and its uses. Important caveats bear on those findings, especially uncertainties about changes in vehicles and road facilities, markets and market penetration, changes in travel, and safety. These will be noted.

Because the innovative vehicle concept is novel and the term can mean many things, the concept will be presented along with some definitions prior to discussing motives for the work, sketching the research approach, and identifying the topics and findings to be covered in this Report. To provide a partial summary of findings, and to prepare the reader for the discussion to follow, some questions and answers about innovative vehicles will be treated at

---

'Arabic numbers refer to references. They are listed at the end of this Report.

the end of this introductory section.

1.1. The Innovative Vehicle Concept

This study was triggered by General Motors Corporation (GM) investigations of the feasibility of marketing a relatively inexpensive single occupant, high performance, fuel efficient vehicle.* Known as the Lean Machine, a prototype of the vehicle has been on display in Florida for some years, where it has received a high level of visitor interest (Figure 1). The vehicle is about 9 feet long and 3 feet wide. Production versions would weigh about 500 to 700 pounds empty, offer high acceleration, achieve 100-150 mpg depending on accessories, and cost from $5,000 to $8,000.

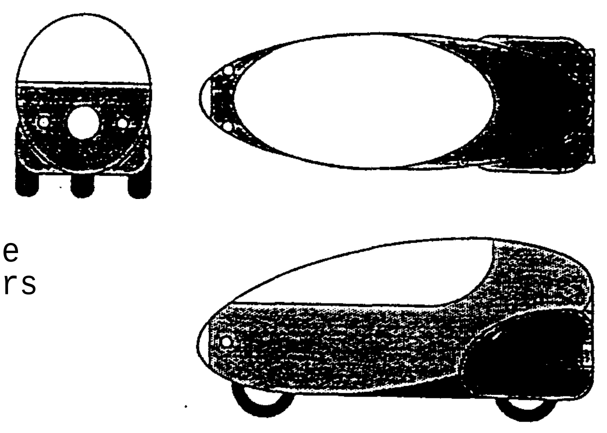

Figure 1: Example of a Possible Commuter Car: The General Motors Lean Machine.

Examination of the vehicle concept suggested that it might hold the potential for congestion relief. Narrower than conventional vehicles and achieving stability by leaning, it would reduce requirements for road space. For example, if the number of

*Appendix A provides a partial history of the project and identifies participants.

vehicles in the traffic stream warrants, 12 foot lanes could be striped to form two 6 foot lanes and thus increase road capacity. One conventional parking space might be converted to two spaces.

As studies were undertaken and plans for additional studies unfolded, the innovative vehicle concept widened to considerations of the travel functions to be served. It was recognized that the Lean Machine or some competitive design might serve single person trips when high performance, including capability for relatively long trips, is desired. For this reason, the vehicle began to be described as a commuter car. Urban highways are congested during commuting hours, and most commuting is in single occupancy vehicles. Later in the study, however, discussions with potential vehicle purchasers and users revealed that the commuter car label may be too limiting, for individuals imagined a richer set of functions for the vehicle. They also called for room for an occasional passenger.

The consideration of functions led to parallel investigations of a vehicle that might be used for neighborhood range travel: a neighborhood car, which might also serve for access to transit facilities, i.e., a station car (Figure 2). Such a vehicle would not require high performance, including long range, and might be a simple electric vehicle. The golf cart is illustrative of such a vehicle. Modifying the road infrastructure for neighborhood range travel raises a different set of issues than those for the commuter car, of course.

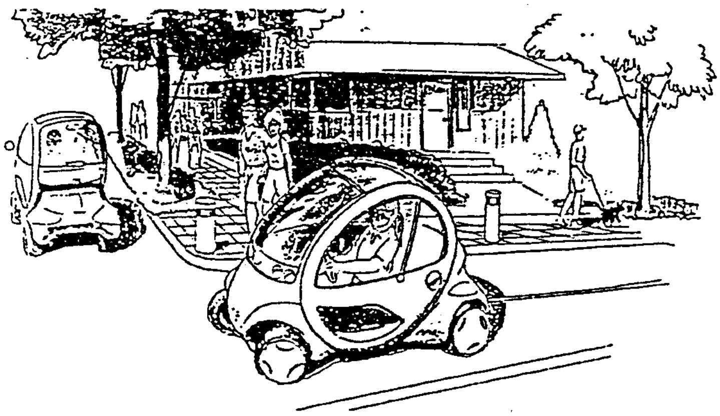

Figure 2: Neighborhood Car Concept Developed by the Trans-2 Corporation.

In short, the work to be reviewed in this Report first focused on a particular proposed vehicle, the Lean Machine. As work progressed, focus widened to classes of vehicles that might be introduced to serve a range of travel purposes in varied environments. The result of this changing focus appears in the shifts in terminology and the scope of the work to be reviewed in this Report.

1.2. Definitions

Definitions before proceeding: What is an innovative vehicle: What is road infrastructure? There are many techniques for doing most anything. An innovation is a technique for doing something that finds a market. In this very general sense, all highway vehicles are innovative. They involve techniques for moving passengers or goods and are marketed. The notion of "innovative vehicle" used in this work is less general. Concern here is with vehicles that are sufficiently different from conventional vehicles that road infrastructure changes may be required or desired before they can be used successfully. This rules out many new vehicles, such as the passenger van which has had recent market success but has required no changes in roads. The high level of automation imagined, in some IVHS concepts may require changes in highways. Although aspects of the findings from this work may have inferences for the implementation of IVHS technologies, these were not considered in the work to be reviewed. Concern has been with vehicles that are waiting-in-the-wings, so to speak, and vehicles whose benefits flow from their small size. As a practical matter, this means light weight vehicles that might be inexpensive to own and operate and lessen congestion, energy consumption, and air pollution.[3]

Because different vehicle concepts have inferences for different classes of roads, concern is with all classes of public roads. Roads are not the only physical facilities used by vehicles, of course. There are driveways, parking garages, filling stations, etc., and innovative vehicles may place requirements on such facilities. Battery powered electric vehicles, for example, require charging facilities. On occasion, there will be reference to such extensions of the road infrastructure.

1.3. Motivation

It was stated that the studies were triggered by GM's interest in the prospects for a novel small vehicle, the Lean Machine. The

[3]Larger/heavier trucks also meet the criterion because they do not match present road designs very well. They will be mentioned in the last section of this report.

broad motivation for the study was much wider than that, and the Lean Machine served as a promising case in point. As is widely known, a variety of initiatives are underway to improve highway system services and more are under discussion: for example, provision of HOV lanes, exhaust emissions and fuel economy regulations, development of IVHS technologies, shifts in the loci and structure of planning and project initiation, safety regulation, development of toll roads, and congestion pricing. In part, the innovative vehicle concept may be thought of as augmenting these initiatives.

Innovative vehicles may have a "have your cake and eat it too" character. There is the promise of improved mobility from reduced congestion and lowered costs of vehicles and travel. Light weight promises fuel efficiency and, provided state-of-the-art emission controls are used, reduced emissions. The question of whether innovative vehicles might augment or supplement today's initiatives seemed worth exploring.

There is an even broader somewhat more abstract motivation for the work. It builds on a broad observation about the highway system. The physical designs, traffic protocols, funding arrangements, and other attributes of the present highway system accommodate present vehicle types. System development responding to social needs may be viewed as constrained by structural rigidities: vehicles have to fit roads and uses, roads are designed for vehicles and their uses, and users make choices in light of available roads and vehicles. This makes radical change very difficult. The difficulty is illustrated by the problem of forging and implementing policies to achieve further sharp reductions in vehicle energy use.

Because of the "things have to fit" character of the highway system, improvements that might be obtained by introducing novelties, such as innovative vehicles, may require coordinated system adjustments. On reflection, rigidities that block novel development opportunities characterize many large systems. It is also true that many large systems, such as communications systems where cellular phones and other new services have been introduced, illustrate how novelties may energize developments.

1.4. Analysis Approach

How were the issues bearing on the assessment of the small vehicles concept and also on the introduction of innovative vehicles identified and analyzed? The approach was to mimic the ways products and services are conceived and introduced to markets, for the concept isn't viable unless there are ways to introduce innovative vehicles in markets. As already discussed, the constrained character of decision-making by manufacturers, travelers, and road suppliers poses unconventional product introduction problems. Innovative vehicles are sufficiently different from conventional vehicles that imagination has be stretched, not just for vehicles, but also for roads and travel.

Striving for imagination stretching, the analysis focused on how markets might be identified and established. Markets are created when there is interaction of demand and supply. Aided by knowledge of markets for their products and of their production capabilities, suppliers develop new products or improve old ones. They evaluate possible offerings on many dimensions: risk, manufacturability, profitability, loss of markets for existing products, competitiveness, etc. They then may or may not offer products to markets. Consumers find out about products through advertising or word-of-mouth and express their preferences through purchases.

Figure 3 displays how the analysis mimicked supply and demand and product introduction processes. The analysis proceeded in a learning way, and it is convenient to describe it as a set of steps or rounds. Round 1 began when the concept was introduced and sharpened. Next, actors on the demand and supply sides reacted to the concept. Based on what was learned from their reactions, the concept was further sharpened. As the process proceeded, benefit-cost measures were refined and there was monitoring for barriers or "show stoppers." Analyses not yet made would follow the same pattern, as would succeeding steps in introducing vehicles to markets.

The process shown in Figure 3 is not as neatly structured as the Figure implies, and that is also true of the activities within the process. The process ran somewhat differently in the neighborhood car and commuter car cases. It is described as if there are separate roles for actors on the market and supply sides, and that is only partly true. Early in the process of examining the commuter car, the researchers made simple cost calculations and trip comparisons to infer how the market might respond to the concept, and the concept was partly brought to potential purchasers later in'the work when structured interviews were undertaken.

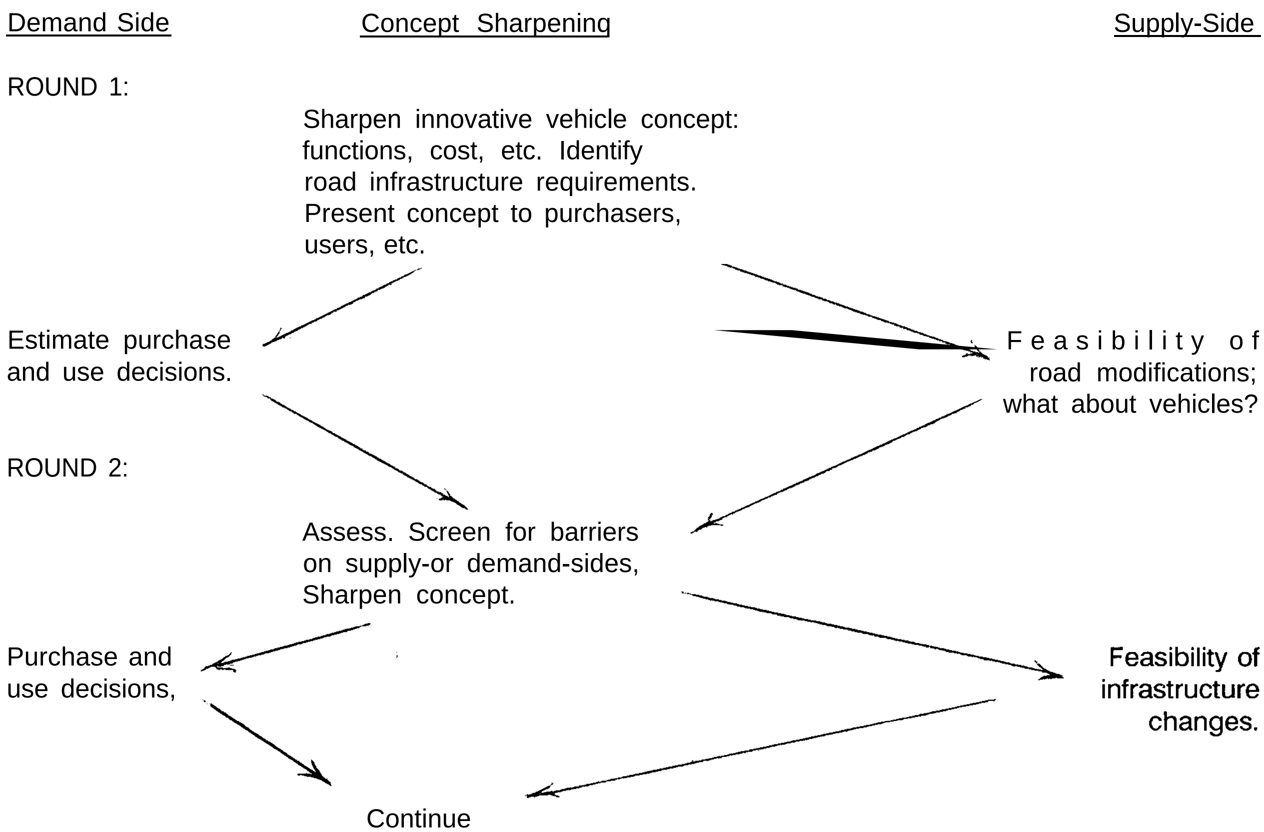

Figure 3: Interacting Supply and Demand

1.5. About Findings So Far

Would it be feasible to introduce commuter and neighborhood vehicles into the highway system? Would such vehicles improve mobility and aid in managing congestion, environmental, and energy problems? Yes.

But that yes is subject to strong caveats. The overriding unknown stems from limits to what can be done with questions of this type using "paper and pencil" analysis. Market acceptance is the ultimate test of new products and services, and final answers of the feasibility and benefit questions will not be known until small innovative vehicles and associated road infrastructures are tested in markets.

If that is the case, why answer the questions, yes? The work accomplished so far can be described a "reality check," to use a current expression, and a series of questions have been answered, yes. Yes is in the sense, "From what has been learned so far, yes seems to be the case." The questions include:

> From the points of view of travel needs and vehicles used, might households find small vehicles attractive purchase and use options?
>
> If small vehicles are increasingly used, can cost effective modifications of road infrastructure be made to accommodate the vehicles?
>
> Can modifications of road infrastructure be made in an incremental, step by step fashion tuned to increased numbers of small vehicles?
>
> Would actors involved with providing roads and streets and community scale political decision makers welcome the use of small vehicles and support infrastructure modifications?
>
> Are there broad social and economic benefits that might induce public policy favoring the use of small vehicles?

Two other questions where the yes answer is qualified were identified. For these questions, the qualification is one of perception. Reasons were not found saying that the answer would not be, yes. Rather, there is concern that actors would not accept that answer. The questions are:

Would small vehicles be safe?

Would manufacturers produce small vehicles?

With respect to safety, small vehicles are perceived to be less safe than large ones, and the bases for that perception are the physics of collisions and accident experiences, The small car concept discussed here imagines small vehicles on roads tailored for them. Even so, the perception carried over from experience with vehicles operating in mixed traffic may be a barrier to the development of small car systems.

With respect to vehicle production, manufacturers are already producing or planning to produce small vehicles with neighborhood car characteristics. Excepting the motorcycle, there is no commuter car prototype-like vehicle being marketed. Perceptions of risk, market size, and other considerations may be a barrier to vehicle production.

A final point needs to be made about the findings from the work. It has do with unexpected effects.

The highway system is large and provides a complex set of services. It has a high level of interrelations with other transportation modes, as well as with production and consumption systems. For these reasons, and because of the difficulty of completely understanding complex systems, unexpected effects may occur if small vehicles and infrastructure modifications are introduced. There is the unanswerable question of the nature of unexpected effects.

However there is a question that can be addressed:

> Would the development pathway triggered by the introduction of small vehicles and modified roads be sufficiently flexible so that it could track on changing technologies and markets, as well as changes in the environments of transportation?

A question asked and answered yes earlier asked if incremental road adjustments could be made as the as small vehicles entered the vehicle fleet. That earlier question partly answers the present question.

1.6. To Follow

The questions just discussed will be treated in the sections to follow. Section 2, beginning below, will provide a broad brush overview of the findings about commuter cars and, using a similar style, Section 3 will discuss neighborhood vehicles. In both sections, the objective is clarification of the opportunities that innovative vehicles may present, as well as the adjustments in road infrastructure that may be required.

Section 4 provides a short summary (or stocktaking) of thinking about the vehicles and the roads they might require. As stated, the work is in mid-stride, and this section addresses the question, How do we see it now? In addressing that question, the discussion will revisit the questions just discussed.

The final sections provide perspectives on safety issues and broadly-scoped modifications to the highway system.

2. COMMUTER VEHICLES IN THE HOUSEHOLD AND ON THE ROAD

The discussion in this section focuses on the benefits and costs associated with the commuter car and the road facilities required or desired for it. It begins with a sketch of the role of the vehicle in serving household travel needs. The next part of the discussion examines how roads might be modified to accommodate the vehicle and its uses. The section closes with an examination of benefits and costs measured at aggregate levels: energy savings, air pollution reduction, and congestion reduction. The first two parts of the discussion are general, the last part focuses on California and, for congestion relief measures, the San Francisco Bay and the Los Angeles areas.

The logic of the presentation is this: Benefits will not be achieved unless individuals, households, and other organizations find it worthwhile to purchase and use commuter vehicles. At the same time, the attractiveness of the commuter vehicle to these potential purchasers and users may turn on the ways roads are modified to accommodate it. Road modifications raise the question of the benefits and costs to highway agencies. Would highway agencies find modifications an attractive alternative? The attractiveness of vehicles to consumers and highway suppliers provides perspectives for applying broad measures of benefits and costs.

2.1. Households and the Commuter Car[4]

Some of the properties of small innovative vehicles say that they would be socially desirable. They would enlarge the choices available to consumers and do so at lower costs compared to most conventional vehicles, thus increasing consumer surplus. Congestion should be reduced. Air pollution and energy consumption are of concern, and small innovative vehicles would be parsimonious in energy consumption with a corresponding reduction of emissions.

With respect to socially undesirable results from the adoption and use of small cars, there is the question of safety (a topic to be treated in the last section of this report). Also, if driving is made easier through reduced congestion and lowered per mile cost, then annual passenger vehicle miles of travel (VMT) may increase. Some regard increases in VMT as undesirable in any circumstances. In the main, that concern is addressed to conventional vehicles where increased VMT increases fuel consumption, congestion, and emissions. To the extent that small vehicles substitute for larger vehicles for existing travel, fuel consumption, congestions and emissions would be reduced. If small vehicles trigger additional travel, the negative effects of that travel should be modest.

2.1.1. Affordability and Usability:

The notion that households might find the commuter car an attractive purchase and use option had elements of affordability

[4]The discussion in this subsection is drawn largely from references 1 and 2.

and usability. Households differ in size, financial resources, and number of licensed drivers, as well as stage in the family life cycle and living, consumption, and working styles. About 58 percent of U. S. households own two or more vehicles, and that's about 54 million households. (Table 1) Today, the average cost of a new car is about $17,500. Estimating the purchase cost of the commuter vehicle to be about one half (or less) the average cost of a conventional automobile, some multi-car households might find it desirable to substitute one or two commuter vehicles for a conventional car (or passenger van or pick up truck).

TABLE 1: PERCENTAGE DISTRIBUTION OF HOUSEHOLDS BY NUMBER OF LICENSED DRIVERS AND NUMBER OF VEHICLES, 1990 (7)

Number of Licensed	Number of Vehicles				Million
Drivers	0	1	2	3 or more	Households
None	61.9	18.0	14.1	6.0	9.3
One	6.3	59.4	24.5	9.7	37.4
Two	.9	16.6	61.3	21.3	38.0
Three or More	1.1	5.0	24.2	69.7	8.5

Big numbers are involved. There were about 130 million automobiles in use in 1990, and annual sales were running at about 9 million. If the commuter car were to capture 5 percent of annual sales, almost one half million commuter cars would be added to the automobile fleet annually. But considering the large number of automobiles in the fleet and their survival rate (the medium age of automobiles in the fleet is about 6.5 years), it would take time for the fleet to change composition.

Consumers consider operating cost along with initial purchase cost when acquiring new or used vehicles, and when those costs are added they run about $.27 per mile for a large car, $20.8 for a compact car, and $.14 for the Lean Machine version of the commuter car.[5] These cost calculations were made in a way not to favor the Lean Machine, and assume that the maintenance, accessories, tires, and insurance costs for the Lean Machine are not much lower than those for conventional vehicles. Overall, vehicles are about 10 percent of consumer expenditures and motor fuels about 4 percent.

There is the purchase decision, and there is the use decision. As stated, the innovative vehicle was termed the commuter car because of the characteristics of commuting trips. In 1990, 91 percent of these were by automobile, and the percentage has been increasing. Vehicle occupancy is relatively low. Trips are relatively long, and many commuting trips take place during the hours when highways tend to be congested (Figure 4).

As Figure 4 indicates, there are many noncommuting trips that are often single person trips, and the commuter car might serve well for these trips. In addition, discussions with fleet managers indicate the possibility of the commuter car as an attractive alternative for many of the duties performed by fleet vehicles.

So far, the commuter car has been treated as another vehicle in the stock of vehicles available to households. The presumption is that if households choose the vehicle, there is improved mobility for the household in terms of lower ownership and operation costs and, perhaps, easier scheduling of trips if more

[5] These costs are from the estimating procedure used in Reference 1. A life cycle, net present value analysis presented in Reference 5 yields $.36 per mile for a conventional car and $.23 for a commuter car, a 36 percent savings for the commuter car.

vehicles are available to the household.

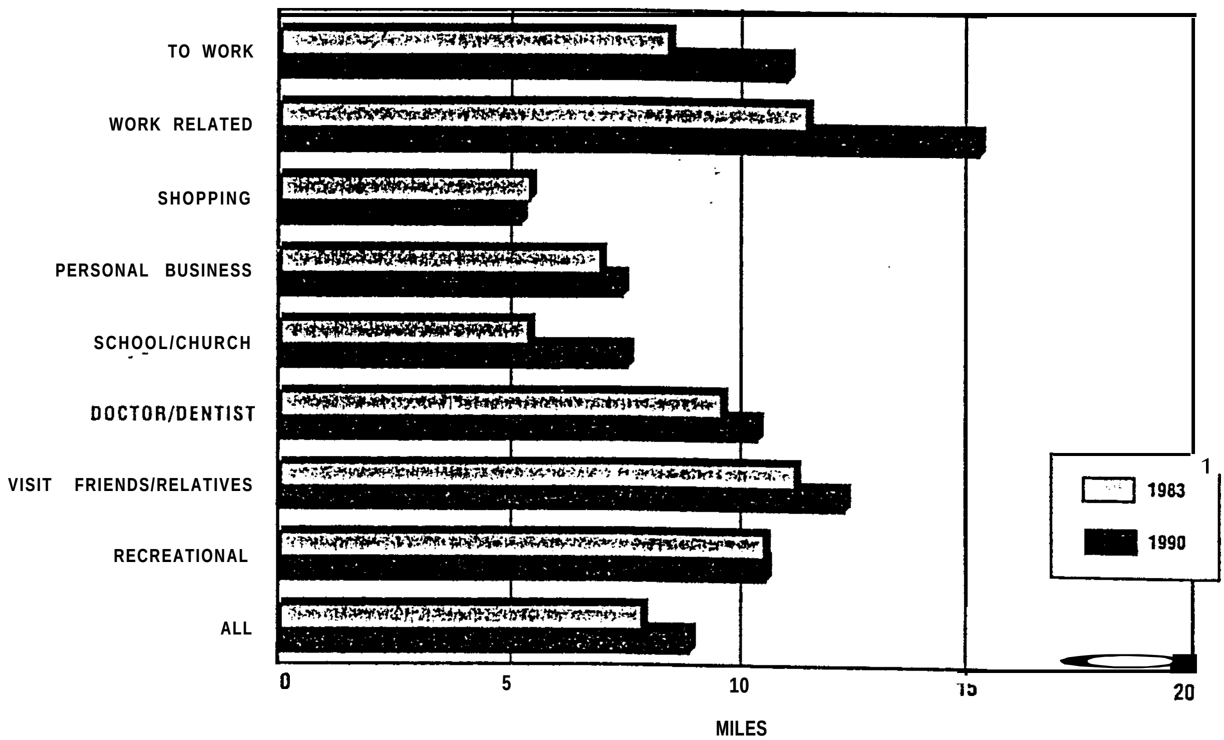

Figure 4: Vehicle Trip Length Trends: 1983-1990.
(As reported in Reference 8)

2.1.2. Eased Trip Making:

Improved mobility may also be obtained because of eased trip making. To illustrate this point, suppose a trip is made by a commuter car at a point in time when there are a number of such vehicles in use. The driver might leave the home base and drive on neighborhood streets to an arterial street. When traffic queues at lights, there may be openings between conventional vehicles so that commuter cars can move toward the heads of queues. Use of HOV lanes for access to freeways and for travel along freeways may allow the vehicle to avoid congestion delays. Where HOV lanes are not available, there might be special lanes and/or entrance and exit flyovers for commuter car use. If traffic is relatively free flowing, the commuter car might occupy a lane as a conventional car does. At congested places, there might be narrow lanes specially marked for commuter cars. At the trip end, the car might be parked at reduced cost in specially marked stalls in small spaces.

The HOV lane part of the trip would be quite similar if the small vehicle user were one of the first to use commuter cars. But early-on there would be absence of road facilities specially configured for small vehicles; special parking spaces might be marked fairly quickly although they might be few in number. Even so, the user might find it relatively easy to pass through congested areas by passing slow moving larger vehicles using the lane space available and find parking areas, just as motorcycles do.

Travel benefits to commuter car operators should increase as the population of those vehicles increases. It should be mentioned that there should also be benefits to users of conventional cars as drivers switch to commuter cars and leave more room for conventional vehicles. Interestingly, if commuter cars were increasingly substituted for conventional cars for single or occasional 1 + vehicle occupancy trips, the efficiency of conventional cars would increase as their occupancy increased. A conventional car with four passengers, for instance, would achieve passenger miles per gallon approaching the energy efficiency of the commuter vehicle.

The point of these examples is that there might be mobility gains for commuter car users from less frustrating and costly travel. For the Lean Machine version of the commuter car, the ride might be more comfortable and "fun." That's because the vehicle leans when cornering and is very maneuverable. A bicycle-like ride results; the driver does not tend to slide on the seat when cornering.

2.1.3. Vehicle Availability:

Commuter vehicles must be manufactured and available on the market if consumers are to have choices and grasp benefits. The discussion so far does not answer questions a potential manufacturer might ask: 1. What should the vehicle be like? 2. What will be the annual sales? 3. Would sales of commuter vehicles decrease sales of conventional vehicles? 4. Will modifications be made to roads that would improve the attractiveness of the vehicle?

Questions 1, 3, and 4 will be treated in later sections of this report.

Considering annual sales, the observation was made that large numbers are involved when the existing fleet of automobiles and annual sales are described. It was further stated that some percentage of annual sales, say, 5 percent, would represent a sizable market for a potential vehicle manufacturer. For example, at current levels of annual new car sales in the U.S., 5 percent of the market would represent between 400 and 500 thousand vehicles. Data are available on the number of automobiles in households, the socio-economic characteristics of households, and trip making. Using these data, "if, then" estimates of overall market size would permit refinement of gross magnitudes. For example, if households with two or more commuters purchases one vehicle, then the gross market would be....... Simple calculations of this type support the "large numbers" view of the market. For comparison with the 400-500 thousand sales mentioned, some 1990 sales (in thousands) were: Mustang, 124; Cavalier 307; Chevrolet/Geo, 128; Taurus, 313; and Mazda Minta 34 (9).

It must quickly be said that the conclusion "comparisons suggest 5 percent of the market would make manufacturing a near-certainty" cannot be drawn. Among other things, potential manufacturers must consider achieving economies of scale both in assembly and the production of parts. In particular, the commuting vehicle may be sufficiently different from existing vehicles to limit the communality of parts between it and conventional vehicles. There may be other manufacturability problems that differ from those of conventional vehicles.

Although there is much discussion in the literature of flexible manufacturing, the loosening of requirements for scale in manufacturing, and carefully engineering manufacturing process for specific products, there is no escaping potential manufacturers' needs for information about markets. Two ways to derive market information may be considered. The first involves market partitioning as suggested by the discussion of magnitudes above.

The second is to use formal choice analysis to make estimates of vehicle purchasing and trip making choices. This may involve the evaluation of results from test markets (consumers' revealed choices). An alternative is to investigate consumer reactions to imaginary product offerings obtained from well designed experiments where potential purchasers and users are given information on vehicles (consumers' stated preferences).

The results of studies of travel using conventional cars say things that appear obvious at first glance: for instance, travel decreases as fuel price increases and increases as income increases, new cars are driven more per year than old ones, and the higher the price of new cars the less old cars are scrapped. However, a virtue of these studies is that they go beyond the obvious and provide elasticities in the form: a 1 percent increase (decrease) in x yields a y percent increase (decrease) in z. The drawback is that elasticities apply to small changes in current conditions and extrapolation of information on conventional cars to the commuter car is not warranted.

Is there a conclusion from this discussion of vehicle availability to potential purchasers? Not really, so we will return to this topic toward the end of this report. As stated, availability turns on whether manufacturers will produce products. The market size that would attract manufactures partly turns on manufacturability questions on which we have no information. Ignoring costs and prices, commuter car-type products could be produced, of course. The issue is that of the balance among market sizes, the costs of production for markets of varied sizes, and product prices and consumer choices.

2.2. Road Facilities for Commuter Cars[6]

To this point it has been said that commuter cars in the urban traffic mix portend overall benefits and that individual purchasers and users might be motivated by the benefits they obtain. There are questions not yet treated about the highway infrastructure: How easily could it be adapted to serve commuter vehicles, What would be the benefit-cost situation?

2.2.1. The Commuter Car in Traffic:

Length Doesn't Matter So Much: There are costless benefits to traffic flow because the commuter car is relatively short compared to conventional vehicles, say 9 feet compared to 18 feet. The reduced length of the commuter vehicle says that a given length of highway can accommodate more vehicles, whether traffic is free flowing or lined in queues at traffic signals or at congested points. In addition, more cars can also be handled because it has been observed that drivers accept shorter than average spacing when following small vehicles (Table 2). Capacity increases when traffic is free flowing are estimated to be from 8 to 15 percent, and at intersections, from 6 to 20 percent. Capacity increase depends on velocity, and that is why some analysts report ranges of increases. (The last two entries in the Table were calculated for the Lean Machine. See Reference 2 for the sources of the data shown in the Table).

The percentage increases shown are obtained when extreme cases are compared: traffic is composed either of all large cars or of

[6] This discussion is based on Reference 2.

small cars. That not being the case and with mixed traffic, capacity increases would be lower than those shown.

TABLE 2: ESTIMATES OF THE EFFECT OF VEHICLE LENGTH ON ROAD CAPACITY

Standard Car Length (feet)	Small Car Length (feet)	Small Car Capacity Increase Percent
16	12	a
la	14	a
18	12	10-15*
20	10	10-15 15-20*
18	9	6-11*
la	9	9-13
18	9	18*

*At intersections.

Congestion is measured in time units of delay; and the cost of congestion is estimated by multiplying delay-time by a monetary value. One estimate of the cost of annual congestion delay for 1987 in Los Angeles during hours of peak travel yields 8 billion dollars (about $700 per capita and $1,000 per vehicle). So if shorter headway resulting from increased numbers of commuter vehicles reduced delay by, say, 2 percent, the overall savings would be quite sizable, about 160 million dollars per year. But those aggregate savings would be shared by all highway users and not just by those purchasing and using small vehicles, and savings would be small on a per vehicle basis (about $20).

Width Matters Very Much: The width of the commuter car matters much more than its length. The Lean Machine version of the commuter car is about three feet in width, suggesting that it could operate on relatively narrow lanes. Just how narrow is unknown, but at very low speeds small vehicles would require from one half to one foot of clearance. A lane 6 feet in width should accommodate the vehicle at moderate speeds and width greater than 6 feet would be required at higher speeds. These assumptions, which seem reasonable especially if a vehicle is highly maneuverable as is the Lean Machine, suggest three things. 1. In "stop-and-go" congestion the commuter car could maneuver past stopped or slow moving vehicles, as motorcycles and bicycles do. 2. For access-and-egress to freeways and in areas of recurrent congestion where speeds are relatively low, commuter vehicles could travel side-by-side on existing lanes and/or special lanes for commuter cars could be either newly constructed or created by striping 12 foot lanes. 3. At intermediate speeds some side-by-side travel could be expected, as is suggested by the ways motorcycles operate. 4. The extra foot or so of clearance and lane width that might be required for higher speeds is not a matter of concern. Higher speeds occur when traffic is free flowing. Under those conditions, there is room for commuter cars on conventional lanes.[7]

A modern highway lane on a multilane facility can accommodate about 2,000 conventional passenger vehicles per hour (vph). Suppose Lean Machine type commuter cars begin to appear on such a lane. One possibility is that Lean Machines travel in single file. In this case, there is modest increased capacity of the lane as the

---

[7]An "almost four lane carriageways" scheme has been discussed in Germany. Lanes 4.2 meters wide (about 14 feet) are proposed. In rush hour traffic, trucks and busses would operate using the entire width of the lane. Conventional automobiles would travel side-by-side. Work has suggested that such lane occupancy is suited for short strips of road, lengths up to 800 meters. See Reference 10, p. 303.

fraction of Lean Machines increases, for the capacity increase to 2260 vph is only due to the shorter length of Lean Machines. Another possibility is that Lean Machines are paired at random, say, just as they happen to join the traffic stream, and drivers move side-by-side in a happenstance-joining way. A third possibility is that drivers of Lean Machines rearrange their positions in traffic to form pairs of vehicles. In the random-paired and rearranged-paired cases the capacity of the lane increases to 4520 vph as the percentage of Lean Machines in the traffic stream reaches 100 percent (Figure 5).

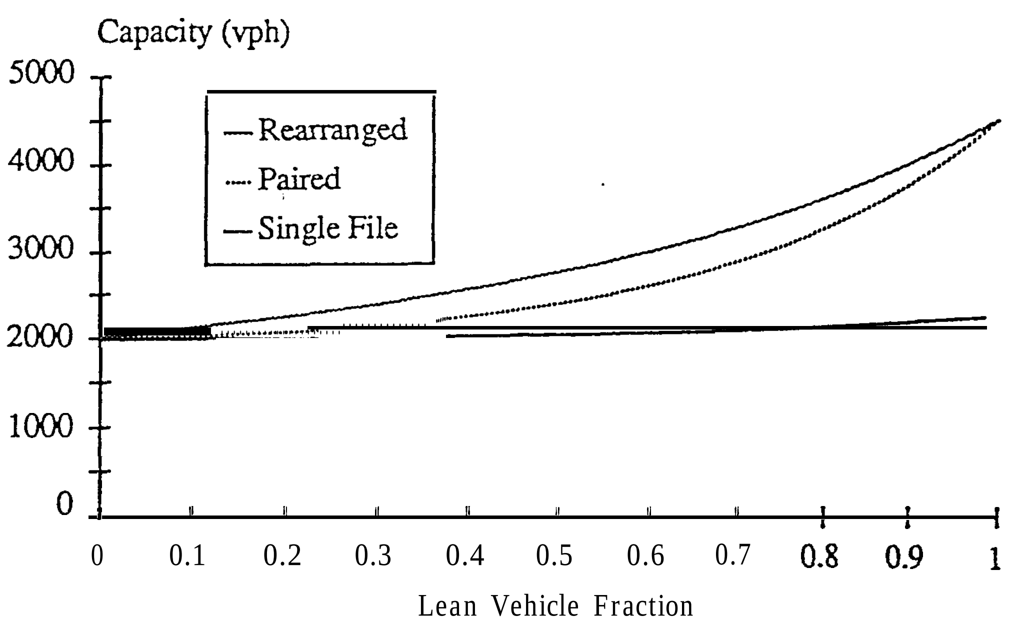

Figure 5: Capacity of a Lane of Multilane Highway as a Function of the Fraction of Commuter Vehicles in the Traffic Stream.

<u>Height; Frontal Area:</u> A vehicle used primarily for one person need only be wide enough to accommodate that person, and a 3 foot

width should be more than ample. A vehicle with a corresponding tread width of about 3 feet containing a person sitting upright would have a relatively high center of gravity and tip-over would be of concern. Because curves on roads are not superelevated to the degree that would be desired for such high center of gravity vehicles, solutions are to lean the vehicle or to have the driver sit on a very low seat. In the latter case, the vehicle would not be very tall and may not be adequately visible when in traffic. Vehicle access and egress may be awkward.

The commuter vehicle is imagined as a high performance vehicle, so aerodynamic drag is a consideration. To reduce aerodynamic drag, modern conventional automobiles have rounded shapes, and commuter vehicles would also have rounded shapes. To determine drag, the coefficient of friction is multiplied by the frontal area of the vehicle. The small frontal area of a commuter car such as the lean machine plays a major role in drag reduction and fuel efficiency gains.

2.2.2 Implementing Road Modifications:

In California, there are programs to relieve congestion by the construction of HOV lanes at bottlenecks, and those might be used by commuter vehicles, with side-by-side driving where appropriate. If the number of commuter vehicles warrants, a narrow lane might be constructed or a conventional lane striped for side-by-side driving. On arterial streets as well as freeways, flyovers might be constructed. There are a large number of single options and combinations of options (Figures 6 and 7).

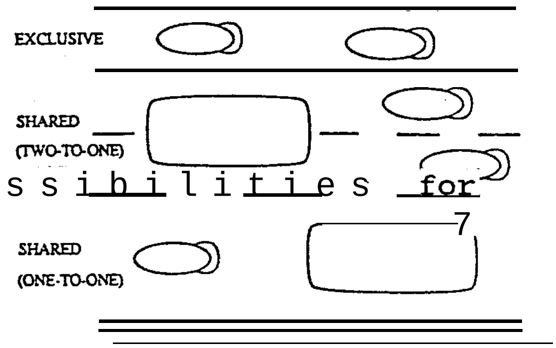

Figure 6:' Illustrating Possibilities for Accommodating Commuter Cars.

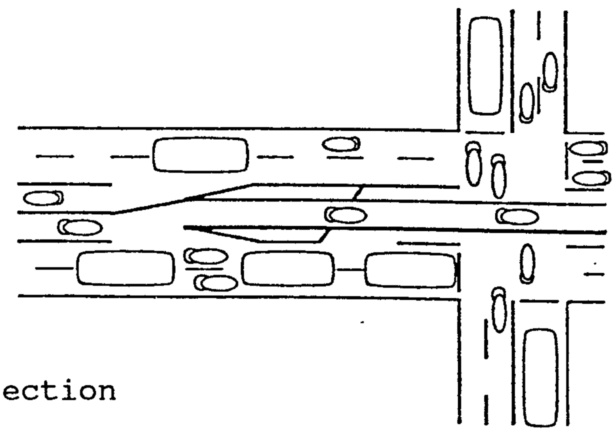

Figure 7: A Flyover at an Intersection

These are options for treating bottlenecks, places where there is recurring congestion. As a rule-of-thumb, however, about one half of the congestion in urban areas occurs at recurrent bottlenecks, and the remainder is incident generated--by accidents, disabled vehicles, emergency road repair, flooding, etc. (Incidents may occur at recurrent bottlenecks, of course.) Highway agencies attempt to reduce congestion caused by incidents by fast response to accidents, providing information to drivers who may be able to select alternative routes, etc. The ability of commuting cars to maneuver through narrow spaces might be another way to dampen incident-caused congestion.

Returning to bottleneck situations, whatever the option or combination of options chosen to serve commuter vehicles, agency costs are reduced compared to the costs of constructing facilities for conventional vehicles. That's partly because the narrow width of the conventional vehicle reduces construction cost and follow-on maintenance costs by about one half: e.g., two six foot lanes provide twice (and a little more) the capacity of a twelve foot lane. The light "footprint" of a commuter vehicle and its maneuverable should offer additional cost savings through reduced requirements for bridge and pavement strengths and the vehicle's acceptance of sharp curves.

Parking: The "two will fit in the space for one conventional car" on a highway lane observation holds for parking. Spaces in existing parking structures could be restriped as demand for commuter car spaces increased (Figure 8). Also, there might be small, currently unusable spaces, that could be used for parking. Similar restriping strategies could be used for curb parking. Because of the ease of increasing parking capacity, managers of parking facilities would be expected to modify facilities quickly.

Highway Modifications Cost Effective and Relatively Easy: How easy would it be to adapt highways to increasing numbers of commuter vehicles? The early highway experience says that adaptation is practical. Turn of the century highways were revamped for use by automobiles and trucks at the beginning of the automobile era. Those were innovative vehicles in the sense that the concept is used here because they were sufficiently different from wagons and buggies to require modification of road infrastructure. Similar to the situation today, the early roads were good enough so that motorized vehicles could begin to be used and their'markets explored.

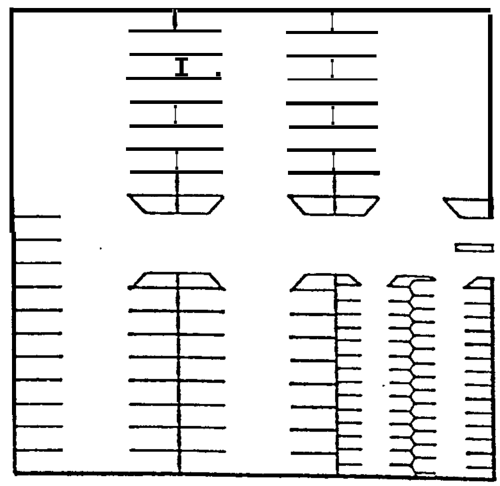

Figure 8: A Parking Lot With a Section Restriped for Small Vehicles.

Also similar to today's situation, the network of turn of the century highways was extensive for it served the settled areas. The early problem wasn't so much that of expanding the mileage. (Expanded mileage since the turn of the century has resulted from expanded settlement and, to a lesser extent, expanded capacity for intercity travel.) Pneumatic tires and increased velocity raised dust when displacing fine materials on road surfaces; they damaged road surfaces. Dust and the destruction of road surfaces increased the need for pavements. The better roads of the time were high in the center to provide drainage. Low velocity buggies and wagons occupied the middle of the road except when passing. Where traffic permitted, they would move to the inside of curves when curving, e.g., moving to the left side of the road when making a left turn.

There were many sharp curves. These and other geometric and structural features of early highways required new approaches to road design and engineering when high velocity motorized travel grew.

In addition to adjusting road technology, there were requirements for changes in fiscal and institutional arrangements. Prior to motorization, most roads were local in every way: uses, financing, control, design, etc. Longer distance travel and the concentration of travel on routes called for a shift from local responsibility and authority to mixed local, state, and federal roles.

Some Concerns: The paragraphs above suggest that business as usual would implement road modifications for the accommodation of commuter cars. That's true, but there are some points of concern. For one thing, the procedures for sizing the capacity of today's improvements and determining what those improvements should be may not apply very well. Today, the locations of bottlenecks are known and there is a toolbox of tested physical designs or policies from which to select ways to ease congestion. Techniques are available so that network flows may be balanced, and this enables sizing the capacities of proposed actions. Extending further, there is experience with preparing environmental impact statements, assigning project and program priorities, and determining appropriate funding responsibilities.

Though certainly applicable, today's tools, procedures, and experiences may not apply very well to the commuter car situations because of lack of experience with appropriate highway improvements (e.g., simple flyovers), the possibility that improvements will need to be made as demand emerges (today, improvements are made to catch up with demand), and the complex ways that purchase and use decisions about commuter vehicles might affect network flows (vehicle drivers might select routes and vehicles for travel differently from drivers of conventional cars).[8] Methods for cost assignment to commuter versus conventional vehicles and, perhaps, among communities served would need to be developed.

2.3. California's Benefits and Costs[9]

The magnitude of net benefits turns on market penetration: how many commuter cars are purchased and how they are used. The timing of the stream of benefits turns on when vehicles might appear on the market and the time it takes for the market to saturate. Time to market saturation varies widely among products. It took about 70 years for sales of automobiles in the U. S. to stabilize at about 10 million per year: digital watches achieved market saturation in a much shorter period of time. In the case of the commuter car, time to market saturation may be accelerated or decelerated by the pace at which road improvements are made to accommodate the vehicle. The market estimates to be discussed that

[8]The development of an approach to sequencing road improvements is discussed in Reference 2. The approach combines benefit-cost analysis as used for transportation projects with precedent diagrams used in construction engineering.

[9]This subsection draws largely on reference 5.

road modifications are made in tandem with vehicle market penetration.

2.3.1. Estimating Market Size:

Estimates of market size were made using three different procedures. Method 1, a preliminary market survey estimate, estimated the potential market using preliminary survey information about potential purchasers and relating that to travel and demographic information about California drivers. The vehicle was assumed to appeal to residents who commute using cars or trucks.

It was assumed that because the vehicle appeals to educated young families, the 25 to 44 year old population was the most likely market segment. Surveys indicated that drivers older than 45 would not be attracted to the vehicle because of their presumably higher income and lower sensitivity to operating costs. Younger drivers typically have only a single car available, and it was assumed that the limited interior space of the commuter vehicle would discourage its purchase and use. Sixty seven percent of California residents age 16 or older commute to work by car or truck. This percentage was applied to the number of 25 to 45 year old drivers. This yielded a conservative estimate because the percentage of commuters in that age range is probably higher that it is for the 16 years or older **age** range.

Market survey information from EPCOT where the vehicle is on display indicates interest in the vehicle by about 55 percent of the target population, and that percentage was taken to be the maximum market penetration. In order to bound minimum penetration, 20 percent was used as the minimum penetration.

The second method used (method 2, California sales estimate) relied on sales data and information on the demographic characteristics of new car purchasers. Roughly, about a million new cars are sold in California annually; 810,113 cars were produced for sale in California in 1992. Data at the national level on new car buyers indicate that about 43 percent of purchasers were in the 25 to 44 years age group. To capture economy minded members of that age group, potential buyers were assumed to be households with medium annual incomes of less that $50,000.

A high estimate was obtained by using the EPCOT survey information, that is, about 55 percent of the buying group would purchase the vehicle. A low estimate was obtained by again using 20 percent as the minimum market penetration.

The final method (method 3, market segmentation estimate) used knowledge of the automobile market and of the attributes of the commuter vehicle that appeal to consumers: high fuel economy, low initial cost, sporty handling and performance, and access to preferential lanes and parking.

First, the 1992 sales of fuel efficient cars in California were assessed--cars that obtain an average fuel economy greater than 37.5 miles per gallon. The sales of these vehicles, the Geo Metro, Suzuki Swift, Honda Civic, Daihatsu Charade, and Ford Festiva, were about 4.2 percent of total sales during 1992 (in all, 21,360 vehicles). For this vehicle count and calculation, 4-door versions of the vehicles were excluded. The assumption was that purchasers of 4-door vehicles may not be interested in a commuter vehicle with its limited carrying capacity. With a fuel consumption of about 120 mpg, the commuter car is very competitive compared to these vehicles, and it was assumed that 50 percent of fuel economy minded consumers would select the commuter vehicle if it was on the market. Fifteen percent was taken to be a conservative, low estimate.

The second consideration was initial low cost. The medium price of automobiles sold in 1990 was $15,560, and 7 percent of the cars purchased that year were priced below $10,000. Assuming that the commuter vehicle would sell for about $8,000, 16 automobiles were identified that sell in that price range. Several of these were fuel efficient cars previously treated, and to avoid double counting, these were removed from the list. To obtain a minimum estimate of sales, it was assumed that commuter vehicle would capture about 10 percent of the low cost market. Including the attractiveness of fuel economy as previously considered yielded a high estimate of 50 percent of the market for commuter vehicles.

From a performance point of view, the commuter car may be competitive with sporty cars and motorcycles. It was assumed that the commuter vehicle could capture from 5 to 30 percent of the motorcycle market. Twenty four low and moderately priced sporty vehicles were identified, and it was assumed that the commuter car would capture from 1 to 10 percent of this market segment.

The fourth attribute of interest to consumers is access to preferential lanes and parking. Purchase of a special vehicle to take advantage of this attribute would depend on the vehicles available to households. Of California households in 1990, 8.9 percent had no vehicles, 33.2 had one vehicle, and 57.9 percent had two or more vehicles. It was assumed that if a low level of road infrastructure improvements was made, only 1 percent of the households with no or one vehicle would purchase commuter cars and about 5 percent of households with two or more vehicles would do so. Assuming a higher level of road modifications, these numbers were assumed to climb to 5 and 25 percent.

In summary, three methods were used to estimate the commuter car market:

Method 1, a preliminary market survey estimate.
Method 2, a California sales estimate.
Method 3, a market segmentation estimate.

The technical approach used in making estimates can be described as filtering. For instance, in the first method the first filter was the number of licensed drivers between 25 to 44 years of age, the second was the percentage of the population that commutes by car or truck, and the third was the percentage of the driving population that expressed interested in the vehicle. Demographic, vehicle population and sales, and general characteristics of drivers data were from industry and state and federal government sources. The filtering process also used survey data. As mentioned, some of the survey data were from EPCOT where the Lean Machine is on display. Information was also available from (survey) clinics held with representative commuters. The researchers observed the clinics, but did not have available the detailed analysis produced from the clinics. For this reason, the researchers used general impressions that were consistent from clinic to clinic.

The government and industry data used in the analysis may be used to replicate the analysis using different purchaser decision assumptions. In this sense, the approach could be reproduced by other researchers who might augment readily available data with new information.

3.3.2. The Size of the Market:

Table 3 presents a summary of the estimates obtained using the three estimating methods. Method 1 gave the lower estimates. It considered college educated drivers in the 25 to 44 age group and ignored potential buyers in other age groups. Method 2 included all households with median incomes less than $50,000 and gave somewhat higher estimates. Method 3 yielded the higher estimates. Unlike methods 1 and 2, it considered the effects of road improvements on purchases, multi-car households, and vehicle attributes that are competitive against attributes of vehicles already on the market.

The low estimate from method 1 and the high estimate for method 2 were used to estimate the benefits to be treated shortly. With respect to market saturation, a linear growth of the market was assumed for method 1, with time to saturation of 15 years. For the high estimate from method 2, constant sales were estimated for the first five years. It was assumed that road infrastructure improvements would begin to phase in at about that time and accelerate sales. Beginning in the sixth year, it was assumed that 40 percent of commuter car buyers would purchase it instead of an alternative new car, and 60 percent would purchase it instead of a used car or a motorcycle. Overall market growth was not considered. It was assumed that the total California vehicle population would remain constant at about 17 million vehicles.

Table 3: CALIFORNIA MARKET ESTIMATES FOR THE COMMUTER CAR

Estimate	Method 1	Method 2	Method 3	Average
		Annual Sales		
High	74,466	101,544	144,277	106,762
Low	27,078	36,925	28,834	30,946
Mean	50,772	69,236	86,556	68,854
		Vehicle Population at Market Saturation		
High	893,592	1,218,528	1,731,324	1,281,148
Low	324,936	443,100	346,008	371,348
Mean	609,264	830,814	1,038,666	826,248

Figure 9 shows the projections of the cumulative commuter car population. As stated, the projection methods used assume a stable car population in California, and also assume that new car sale are stable and that commuter cars compete with new cars. For these reasons, there would be a reduction in conventional new car sales as commuter cars phase into the fleet of cars. Once the commuter car market is saturated, new car sales would rebound because commuter car sales would take on a replacement rather than market growth character.

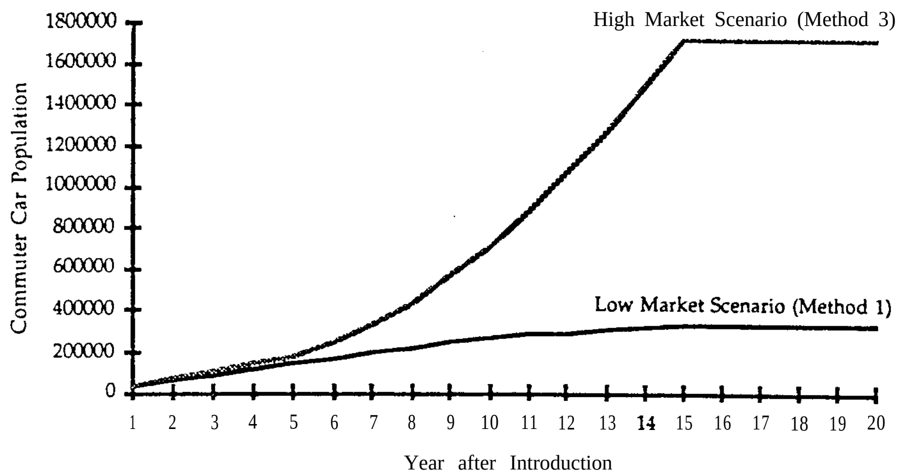

Figure 9: Estimated Commuter Car Population

2.3.3. Benefits:

Using the market size estimates just discussed, benefits in three categories were estimated.

Energy Use: About 13 billion gallons of petroleum fuels were used for transportation in California in 1991, and if adopted and used, the commuter car would reduce consumption.[10] To calculate the reduction in consumption, the commuter car is assumed to achieve 120 mpg although fuel efficiency of about 150 mpg might be achieved. The commuter car would be competing against a fleet that is increasing in fuel efficiency, so CARB estimates of fleet fuel efficiency for years 1993, 2000, 2005, and 2010 were used when calculating fuel savings. (Table 4) That is, baseline estimates were made using CARB projections and savings from the use of commuter vehicles were calculated from the baseline.

[10] It is assumed that the commuter car would use gasoline. It could be designed to use alternative fuels such as methanol.

Table 4: CALIFORNIA AIR RESOURCES BOARD PROJECTIONS OF FLEET AVERAGE FUEL ECONOMY

Calendar Year	Year After Commuter Car Introduced	Economy (mpg)
1993	1	23.73
2000	8	26.86
2005	13	28.48
2010	18	29.19

Figure 10 projects fuelconsumption in California for the baseline case and for the high and low market penetration estimates for the commuter car. Figure 11 indicates the cumulative savings in expenditures for gasoline, assuming a stable gasoline price of $1.35 per gallon. For the calculations shown in Figures 10 and 11, annual vehicle mileage is assumed to be 10,000 miles. Cumulative savings range from $4.1 billion for the high market penetration estimate and $1.4 billion for the low estimate.

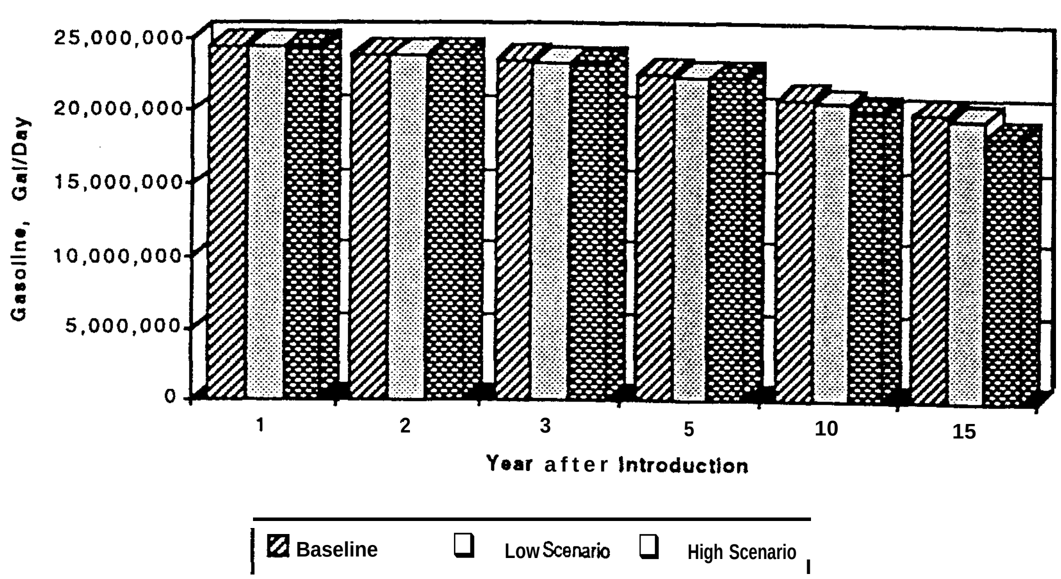

Figure 10: Comparison of Annual Fuel Consumption

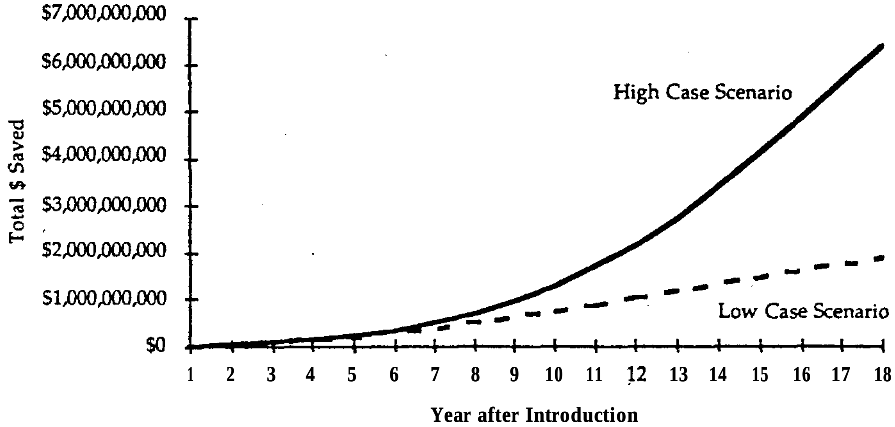

Figure 11: Cumulative Savings in Expenditures for Fuel

<u>Emissions Reductions:</u> During the period in which the commuter car might be introduced, pollutant emissions from new vehicles will continue to be reduced sharply because of the phase-in of new California emissions standards. This drives the baseline case for calculating emissions reductions from the introduction of commuter vehicles. The reductions called for and represented in the baseline case are so great that the commuter vehicle will have little effect on emissions, in spite of its having potential as a low-emissions vehicle.

The State has recognized classes of vehicles:

Transitional low-emission vehicles
Low-emission vehicles
Ultra-low-emission vehicles
Zero-emission vehicles

and manufacturers have flexibility in producing mixes of vehicles as long as their sales mixes meet fleet average standards.

The small engine of the commuter car together with advanced fuel control and exhaust after treatment would likely enable its classification as an ultra-low emissions vehicle. Again, producers have some flexibility in the product mix as long as their fleets meet standards. So, roughly, a manufacturer could sell a transitional low-emission vehicle for each commuter car sold. Because of this trade-off and for other reasons, market penetration by commuter cars would have little impact on future emissions. If a manufacturer didn't market commuter cars, it would have to market other low emission vehicles to meet standards.

Two points should be mentioned. In areas of the nation where standards are less strict than in California, commuter cars might make more of a contribution to emissions reductions. The commuter car might be an effective alternative for achieving lower emissions from conventional vehicles, and this might motivate manufacturers to produce and market commuter vehicles.

Decreases in Congestion: California's larger cities are congested, and the benefit question is the extent to which increased numbers of commuter vehicles in the traffic stream might reduce congestion. As has been discussed, commuter vehicles might reduce congestion: 1. mildly because its small size and maneuverability would enable it to thread through traffic where velocity is low, 2. more significantly if lanes are restriped enabling gaining a lane as one lane is converted to two lanes, and 3. also more significantly if special lanes, flyovers, and other facilities are constructed.

The Los Angeles and San Francisco Bay Areas were used as case studies to examine the ability of the commuter car to improve traffic flow. Although there is debate about the ways congestion is measured, by any measure, these are truly congested metropolitan areas. The Federal Highway Administration regards areas that have 13,000 and above daily vehicle miles of travel (DVMT) per freeway lane as congested. The Los Angeles area leads the nation by this measure with 17,946 DVMT, followed by the Bay Area's 16,285 DVMT. In descending order, other cities with above 13,000 DVMT are Houston, Atlanta, Phoenix, Seattle-Everett, and Dallas (11). About 8.1 and 3.7 million vehicles, respectively, are registered in the Los Angeles and the Bay Areas.

About 67 percent of California residents commuted to work by car or truck in 1990, as already stated, and about 30 percent of commute trips occur during the peak morning commute hour. Assuming that 60 percent of the population of commuter cars would be used during the peak commute hour, with a split in the Los Angeles and Bay Areas corresponding to the split in the vehicle populations, the fractions of commuter cars in the traffic stream were then calculated (Table 5).

Table 5: FRACTION OF COMMUTER CARS BY SELECTED YEARS OF MARKET PENETRATION

Year After Introduction	Fraction Los Angeles	Bay Area
	High Estimate	
5	.024	.028
10	.096	.112
15	.232	.270
	Low Estimate	
5	.020	.023
10	.036	.041
15	.049	.051

The Bay Area could have a fraction of commuter cars of .27 by year 15 with a corresponding increase of vehicle throughput during congested periods of up to 34 per cent. The .23 fraction in Los

Angeles suggests about a 29 percent increase in throughput. These increases assume that needed adjustments in road infrastructure are made and that the average operating speed is 30 mph.

These are aggregated calculations. It is reasonable to assume that road improvements will be made at the more congested places, and that there would be marked improvements at such places.

2.4. Perspectives on Benefits

As stated in the introduction to this section, one question is that of whether benefits would accrue to decision makers in ways that would energize the adoption and use of commuter cars. The answer to that question seems to be yes. The availability of commuter vehicles would enable households to improve their mobility while reducing costs. Highway agencies would reduce their costs when providing capacity increases. Overall, there would be savings in energy consumption and reductions in congestion, The emission of pollutants would not be increased, and commuter vehicle might play a role as an ultra-low-emissions vehicle. If it were to prove to be an attractive purchase and use option, it might accelerate the entrance of ultra-low-emissions vehicles into the vehicle fleet.

Suppliers of vehicles received only brief mention. The assumption that if there is a market, vehicles will be produced is overly simple. The costs of designing a manufacturable vehicle and creating production facilities are great. Achieving economies in management, production, and marketing requires a sizable annual market. A novel vehicle may expose producers to liability risks. These and other considerations were mentioned previously, and the issue of vehicle production will rementioned in a latter section where there will be comments on activities needed to further explore commuter vehicle possibilities.

In addition to the incidence of benefits, there is the question of preciseness: How accurate do benefit measurements need to be? The measurements of benefits obtained so far range from first approximations (e.g., energy savings) to fairly precise (e.g., increases in capacity as the number of commuter cars in a traffic stream increases"). They seem adequate enough to support the conclusion that the innovative vehicle concept is viable from a benefit point of view. The first approximation measures could be refined. For example, measurements of impacts on congestion in case study areas could be refined by examining routes one by one and considering demand elasticity and shifts in travel routes as capacity is increased.

The benefits that might flow from the adoption and use of commuter cars ought to be set in the contexts of other actions seeking benefits and of the sizes of problems. That's in part to aid in establishing priorities for public programs. For instance, 1990 federal (Clean Air Act) and California State (California Congestion Management Act) initiatives seek to increase vehicle

---

"Although not mentioned in the discussion of increased capacity, estimates were made of annual savings if capacity is increased and of costs of road modifications. These are available in Reference 2.

occupancy for the journey to work, while a commuter car initiative would likely decrease occupancy. What's the choice? Also, some problems are vast, and while commuter cars might lessen problems, they may be far from what is fully needed for problem management. Energy conservation is an example. Automobiles accounted for 39 percent of U.S. transportation energy use in 1990; about 110 billion gallons of gasoline were consumed during that year. The amount consumption might be reduced by the use of commuter cars in the Los Angeles and San Francisco Bay Areas is small compared to total consumption in California and in the nation.

Finally, a very general consideration. In the first section of this report, it was stated that commuter and neighborhood cars could be thought of as novelties--products whose introduction requires system adjustments. From that perspective, the questions can be asked: 1. Would the introduction of a variety of novelties and associated system adjustments make major contributions to increasing mobility andmanaging safety, congestion, environmental, and energy problems? 2. Might there be supporting, interactive relations among novelties? 3. Would the introduction of novelties provide pathways for reenergizing improvements in highway system services and improved productivity of system users?

The discussion of the neighborhood car in the following section may be suggestive of answers to those questions, and the questions will commented on near the end of this report.

3. SMALL VEHICLES IN NEIGHBORHOODS[12]

In addition to examining commuter vehicles, a study was made of vehicles for neighborhood range travel. The discussion to follow will overview the neighborhood vehicle opportunity touching on vehicle uses, costs, and road facilities topics.

3.1. Vehicles and Roads

Road and vehicle requirements for short range travel in residential areas are not very demanding. Low speed local travel is not demanding of acceleration capability, so a vehicle could be powered for a top speed of 20-30 miles per hour. For short distance travel, an inexpensive, within the state-of-the-art electric vehicle might serve well. Using a golf cart comparison, such a vehicle might be one fourth to one third the average cost of conventional vehicles.

A neighborhood car might have, say, a four foot tread width and seat four persons or two persons when carrying groceries or other items. Simple to operate and inexpensive to own, it might be used by persons not now operating conventional cars. for instance, elderly persons, perhaps using limited operators' licenses. For some households, the neighborhood car might augment the vehicles already available and reduce the difficulties of scheduling trips or requirements for chaffering. This image of the vehicle and its use is speculative, of course. It flows from vehicle occupancy and trip length data such as that shown previously in Figure 4.

---

[12]This section is based on Reference 4.

Many neighborhoods were designed with generous street widths, and in these cases lanes might be marked for travel by small cars. The ease of such modifications is site specific, of course. Where building lots are small and/or there are many multifamily dwellings, much street space may already be claimed for parking and curb cuts for access to garages or other off-street vehicle storage. In cases, the transition to increased numbers of neighborhood vehicles might displace some conventional vehicles and ease parking problems. The parking situation might worsen in other situations.

Designs for new neighborhoods might incorporate paths for small vehicles.

When local travel requires using arterial streets or crossing such streets, as might be the case when shopping, school, or local recreational trips are made, then there may be needs for special modifications of roads.

If the neighborhood vehicle is an electric vehicle, then battery charging facilities must be considered. Not very power demanding, the neighborhood vehicle could be recharged using an existing outlet in a garage, but with the increase in the number of vehicles in households, garage space is at a premium for many households. Curb-side outlets would require facility construction and reserving spaces at curbs. Charging opportunities when away from the home base may need to be considered.

3.2. What Do Golf Carts Say?

As stated, the neighborhood vehicle is imagined as a small, inexpensive and low power vehicle, possibly electric, that would seat up to four persons, perhaps five in a pinch. In one version, a 4 by 6 to 8 foot platform containing energy storage, propulsion, and steering mechanicals might be marketed, with dealers mounting seats, enclosures, and other items depending on customers' desires. Small wheels would be used to keep the center of gravity low and to permit easy entrance to and exit from the vehicle. The 4 foot width would permit side-by-side seating. (Tourist seating on airlines is about 20 inches in width including shared arm rests; first class, 27 inches.) Aerodynamic features would not be important because speeds would be low.

While the golf cart indicates that such a simple, low power vehicle can be manufactured and distributed at a low price relative to a conventional vehicle, the term golf cart was not used when the research began because it suggested a very restricted travel function, as well as a particular life style. But as work progressed, the golf cart was increasingly given attention because of its presence in a number of communities and the possibility of its multiple uses.

A survey of golf cart uses in 52 golf cart owning households in Canyon Lake, CA, a golf oriented community, found that golfing was the primary use of the vehicle. Put another way, only 12 percent of the households made primary use of a golf cart for trips such as shopping and joy rides. Only one of those respondents indicated golfing was not a secondary use. Survey results indicate that after being available for some years golf carts occupy a market niche defined by special environments. This seems also the case for small vehicles used to shuttle tourists at resorts and small utility vehicles used at construction sites, on some farms, in parks, and in other sequestered spaces.

This limited survey and observations about vehicle uses suggest emphasis on market niches for neighborhood vehicles.

3.3. Neighborhoods as Market Niches

Might be neighborhood environments other than golf-oriented environments in which neighborhood cars would be useful? If not, how might they be created? Should they be created?

With respect to new residential areas, there is discussion today of transit oriented and/or "pedestrian pocket" designs. This involves providing sequestered spaces for walking and conveniently located trip ends. Clusters of retail space, offices, and housing oriented to transit facilities are imagined, with each cluster not requiring more than about one quarter of a mile of walking between houses and service, office, or transit facilities. Essentially, the spatial arrangements of functions are tied to the transportation services to be used. Also, the neighborhood is to be self-contained to a considerable extent. Trip ends (stores, transit stations, etc.) are to be arranged to reduce out-of-the-community travel.

This arrange-the-land-uses design strategy could consider neighborhood cars and walking as the basic modes of travel of within neighborhoods. (Because the neighborhood car might serve those trips that are "too close to drive and too far to walk," it can be thought of as an aid-to-walking vehicle.) Neighborhood cars would increase the range over which community travel may be made from the home base and thus increase the variety of services and amenities easily available.

With respect to existing neighborhoods, there is increased attention to "taming" traffic in order to improve neighborhood quality, and the pedestrian pocket designs have that objective. Some of today's discussions of the redesign of existing neighborhoods are oriented to the "woonerven" (residential yard) concept pioneered in Holland. Essentially, this involves redesign of streets to control through traffic and to provide common yard-like spaces carved from existing streets. Vehicle access is limited, and vehicles are parked in spaces consistent with street furniture, such as benches and plantings. Streets are thought of as spaces for living rather than spaces for automobiles.

3.4. Existing Neighborhoods

Existing neighborhoods were built and designed yesterday, and their designs reflect then-current ideas about desirable urban forms. They also reflect yesterday's standards and customs for the sizing and lay-out of lots and streets, as well as household sizes, economic conditions, etc. Because existing neighborhoods are mostly built-out, change in the physical inventory of land uses and structures is slow. This condition may seem to constrain options for the retrofit of residential and commercial lots. However, the reduced street space required for neighborhood vehicles opens options for changing the uses of existing lots.

Figures 12 and 13 use the case of Emeryville, CA, to illustrate how streets might be modified and how land uses might change. One design indicates how a major arterial might be treated. The other emphasizes increased sizes of structures. Although just what creates an improved neighborhood environment has many aspects, these designs are consistent with the tame-the-automobile and improved street space trends and the trend toward increased square footage and amenities of housing. For the latter, the reasoning is that reductions in street spaces might allow expansion of the size of houses or creation of multiple units by home owners.[13]

Emeryville is an example of a neighborhood developed at the turn of the century and before. Many neighborhoods are newer, and because of the trends toward lower population densities and increased street spaces, they may offer a greater diversity of design options. In the relatively new community of Palm Desert, CA, for example, golf carts are accomodated on **combined use" local streets where speeds are limited to 25 mph or less. Lanes have been striped to reserve spaces for golf carts.

[13]Designs were also developed that increase population density. The idea is to decrease the demand for urban land and resulting urban sprawl.

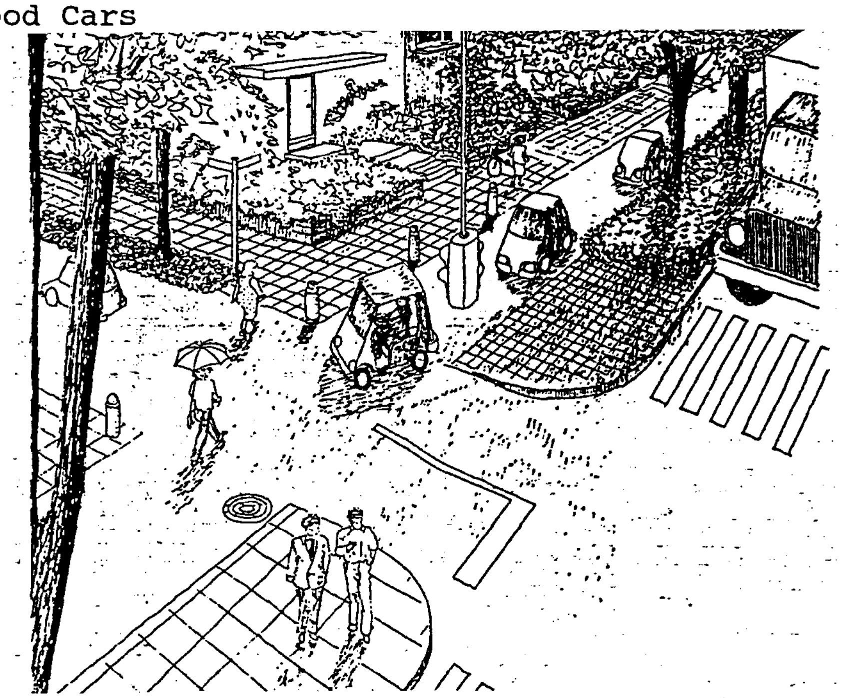

Figure 12: Separate Lanes for Small Cars Proposed for Arterial Streets in Emeryville, CA.

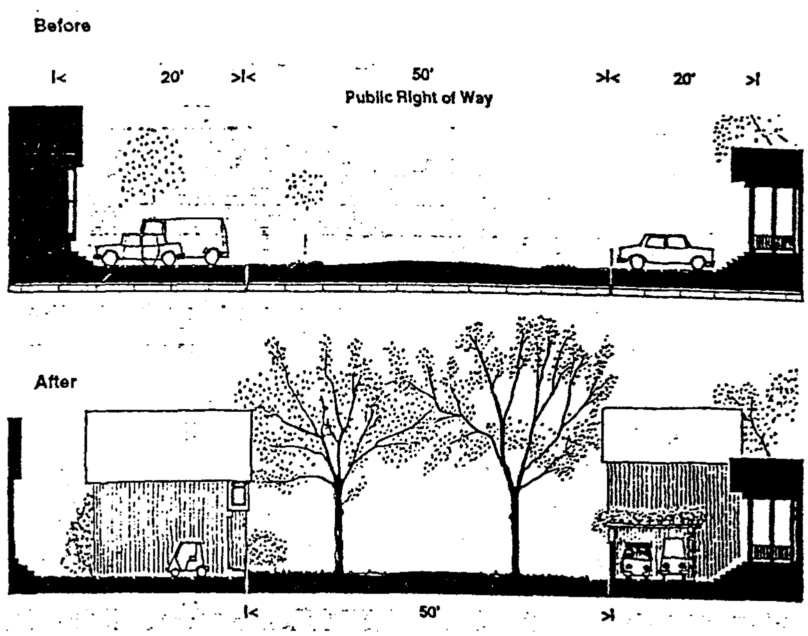

Figure 13: Reduced Need for Street Width Might Enable Increasing the Sizes of Residential Structures

3.5. **New Communities**

New community designs provide more options. One is to restrict movements of conventional vehicles by providing peripheral parking for conventional vehicles and designing access routes to residencies for small vehicles. Those access routes need to be wide enough for occasional access by conventional vehicles; they might be, say, 10 feet in width. Swan Lake, CA, has adopted this design scheme for trailer housing on small plots (Figure 14). Other options might provide for dual purpose roads. Some other schemes are shown on Figures 15 and 16.

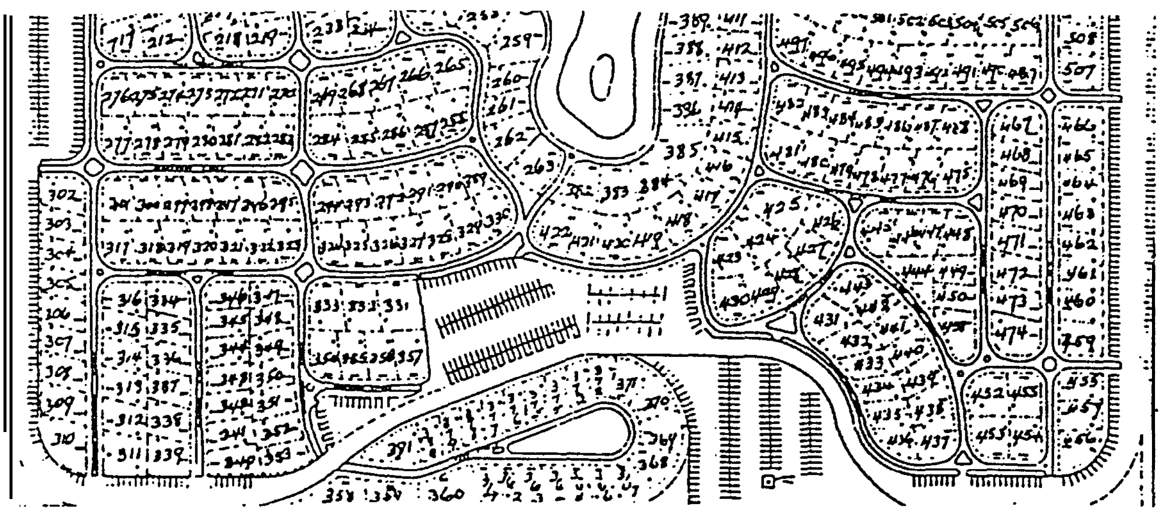

Figure 14: A Portion of the Swan Lake, CA Mobile Home Park. Large Cars Are Parked at Edges of the Development.

Peachtree City, GA, has adopted another design scheme.[14] Paths for walkers, bicycles, joggers, and golf carts are shown on

[14]We did not become aware of developments in Peachtree City until after the work reported in Reference 4 was completed. The information presented here is from the Atlanta Journal Constitution (February 14, 1987 and August 5, 1988) and from materials obtained from the Peachtree City Development Corporation (Jerry Peterson) and the City Engineer (Barry G. Amos).

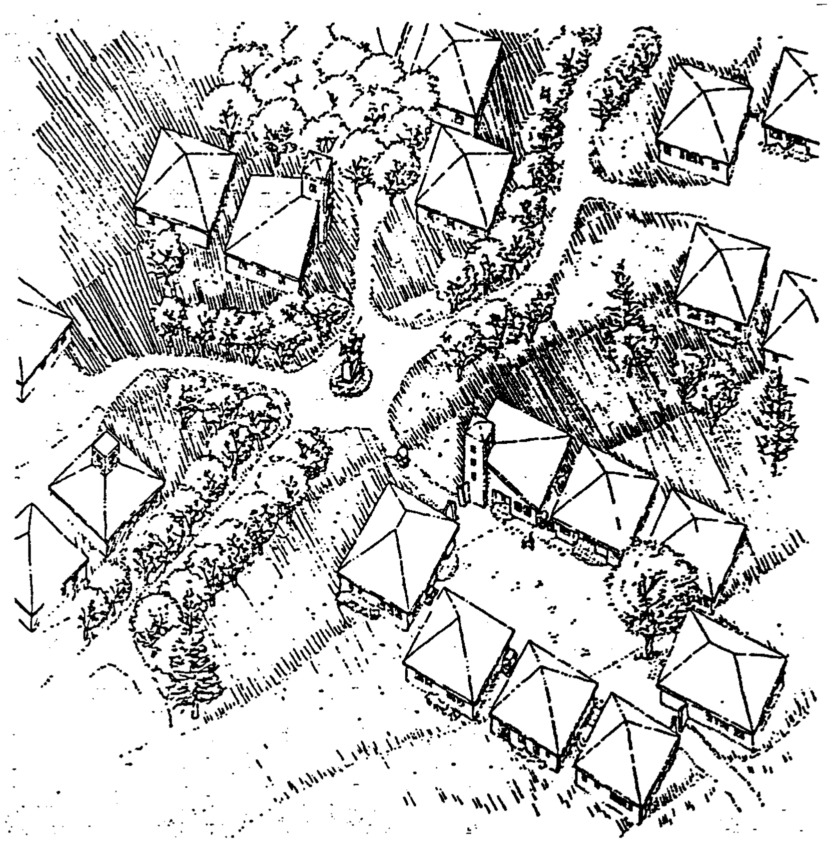

Figure 15: Houses in Clusters. Conventional Size Vehicles May Penetrate the Area When Necessary.

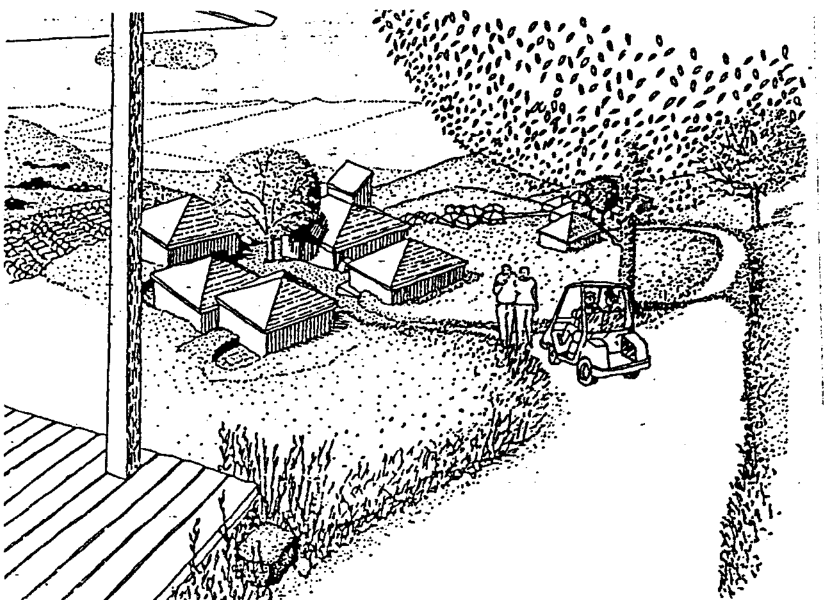

Figure 16: Lanes May Follow the Terrain.

the fragment of the Peachtree City road map (Figure 17). In this case, the paths serve as supplemental access facilities. They collect traffic from local access roads and reach throughout the community to shopping, school, religious, and recreation facilities. Shopping centers advertise, "Just a short golf cart drive away."

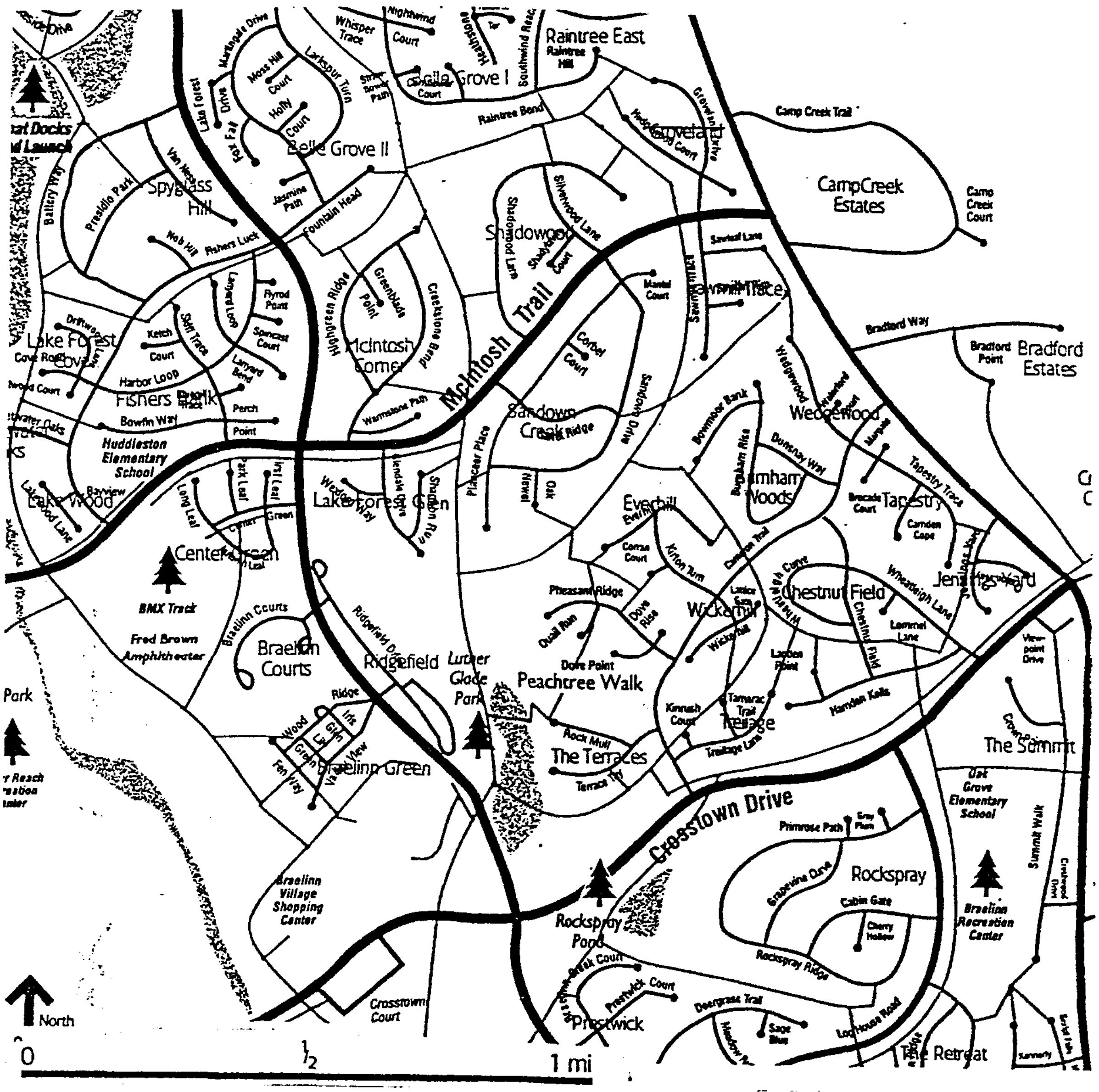

Figure 17: A Portion of the Map of Peachtree City, GA.

On Figure 17, cart paths are indicated by thin lines and are not named. In many cases, they provide "short cuts" when compared to travel on the conventional street system. In all, there are 60 miles of paths in the community, which covers about 15,000 acres, and paths are being extended as the community grows. Serving two way traffic, pavements are 8 feet wide. Undercrossings or overcrossings are provided at major streets.

Chartered in 1959, growth began in the middle 1960s and population has reached about 23,000 persons and about 7,500 households. Single family dwellings dominate. Only about 10 percent of the dwellings are condominiums or apartments, although they are being added at an increasing rate.

About one half of the households own golf carts, and about one half of these are reported to be used exclusively for nongolf purposes. A driver's license is required for operation on city streets. No license is required for operation on cart roads, although the City requires that drivers be at least 12 years of age or be accompanied by a licensed driver.

The City Engineer of Peachtree City has proposed modifications to the cart path system. The proposal identifies trails for pedestrians, connectors to connect residential streets and commercial/institutional facilities to the path system, and collectors feeding arterials. Proposed widths are, respectively, 6, 8, 10, and 12 feet. Trail use is to be restricted to pedestrians, otherwise, there is to be mixed use.

3.6. Some Questions

Uses of the golf cart and similar size vehicles indicate a market niche for neighborhood cars. One question is that of the size of the market niche. Is what is observed a fleshed out market oriented largely to special situations or are we seeing first evidence of a new transportation service? To what extent is neighborhood accessibility a driving force for the spread of neighborhood car services? What's the role of improvements in the quality of neighborhoods?

These questions have been touched on in the previous discussion, but they remain unanswered. Rather straightforward, continued observation and inquiry will further illuminate them. They are, in a sense, "wait and see what happens" questions.

There are some less sweeping questions that have less of a "wait and see" character. They turn on the presumption that has motivated this inquiry--the presumption that the availability of neighborhood vehicle service would improve mobility, neighborhood quality, etc. The test of that presumption is what the market says: what individuals and households do when the neighborhood vehicle option is available. There are important questions that bear on the availability of the option in markets.

There are questions about vehicles and vehicle operations, although at this time these seem not to be pressing. Vehicles are of simple construction and production. Manufacturers are known to be exploring designs and markets, and there is public policy interest in market prospects (see, e.g., 12). At this time, vehicles are regarded as off road (golf carts) or motorcycles," and operate under rules for such vehicles. If the population and use of such vehicles increases, however, regulatory questions may be asked and answered in ways affect vehicle cost, availability, and operations.

There are questions about facility designs and financing. Experience has begun to answer some of these questions, as the Peachtree City example illustrates. But there are other questions, such as whether mixed traffic should be permitted on paths. For instance, bicycle paths are already available in some neighborhoods, and they might provide initial facilities for neighborhood cars. Yet the California Department of Transportation **Highway Design Manual** states that "dual use by pedestrians and bicycles is undesirable" and that "all motor vehicles are prohibited," although local agencies may permit the use of paths by "mopeds" (13, Topic 1003).

Answers to these and other questions that bear on the availability of vehicles in markets are important, because, unless satisfactory answers are found, they may thwart the availability of neighborhood vehicles in markets.

---

[15] For instance, the Mini-el City, a three wheel electric vehicle manufactured by CityCom A/S in Denmark.

4. STATUS OF THE INVESTIGATIONS

The information presented so far sought to achieve clarification objectives: What are the opportunities? The short discussion to follow has stocktaking objectives: What do we know? What needs to be done? The neighborhood car will be treated first, following on the section just completed.

4.1. The Neighborhood Car Concept

The first round of analysis completed for the neighborhood car involved only a short review of the present situation. (The term "round of analysis" refers to the scheme shown in Figure 3.) It was already known that there are several manufacturers of low performance, relatively inexpensive small vehicles, of which the golf cart is an example. On the market side, there are already niche markets for golf carts and other small low performance vehicles, and information was obtained by interviewing users and community leaders in these markets. With respect to road facilities, the main missing information bearing on the concept had to do with appropriate road designs.

As the analysis moved to round 2, emphasis was given to appropriate road designs and to market niches other than those found in golfing communities. Studies were made of road width and curvature requirements and how neighborhood car facilities might be created by using existing streets.[16] To consider varied market

---

[16]And a review was made of existing local street design guidelines (4). Reference 14 provides a more extensive review.

niches, design approaches were used to suggest how road facilities might be provided in old and new communities. Neighborhood improvement (spillover) benefits were also hypothesized, benefits realized as enhanced neighborhood designs.

As was mentioned in section 3 above, the case of Peachtree City was found late in the analysis process. The case supports the notion that market niches might be increased if road facilities were made available. There is an interesting fragment of information from that case bearing on neighborhood amenities. Golf carts may be electric or gasoline powered. Recent City action has ceased licensing of gasoline powered carts because of complaints about noise and exhaust fumes.

The process just described leads to the following observations:

There are already small market niches for golf carts and small utility vehicles.

The provision of pathways for general neighborhood access increases the use of vehicles. The necessity of crossing arterial roads can be managed using under- or overpasses or intersection traffic management.

New communities may incorporate pathways in their designs. Existing communities present a more difficult design problem. Analysis suggests that redesign to include paths for neighborhood vehicles is feasible.

There is need for continued work on road facility designs. No standards are available to aid facility development.

The retrofit of road facilities in existing neighborhoods remains a topic for analysis.

Maximum market penetration observed so far is about one out of two households. Full exploration of the opportunity will require studies of a variety of cases.

Benefit questions need to be framed and explored. To an extent, the neighborhood vehicle is a complement to households' existing travel means. It also serves as a substitute for existing vehicles. Travel information needs to be obtained in order to examine compliment-substitute questions.

Used for short trips, neighborhood cars might play an important role in air pollution reduction. Again, travel information beyond that already available is needed to examine this possibility. There might be an important public policy opportunity: recognize traction battery powered neighborhood cars as zero-emission vehicles.

In summary, the neighborhood car operating at least partly on special road facilities appears to offer opportunities. Issues of market size, the nature of needed facilities, and benefits remain unexplored.

4.2. The Commuter Car Concept

There have been many small, high performance car proposals, and proposals continue to emerge.[17] At the 1993 Geneva International Auto Show, for example, BMW presented a prototype (BMW Z13) measuring about 7 feet in length and 5 feet in width. Seating a driver and two passengers staggered on each side of and partly behind the driver, the vehicle was reported to be designed to save money, reduce energy use, and reduce congestion. From time-to-time, such small vehicles have been described as city, depression, or mini cars. Some have found markets, especially outside of the United States.

These efforts were known when the commuter car analysis began,

[17] Proposals are reviewed in References 2 and 6. Reference 4 contains a discussion suggesting why previous proposals have had limited viability.

and round 1 of the analysis sought to position the commuter vehicle relative to these experiences. (Again, rounds of analysis are shown on Figure 3 in the introductory section of this report.) It was judged that the proposals and experiences just discussed might not apply to the Lean Machine. Previous proposals were for small conventional cars, and while unsuccessful small cars offered economies in comparison to conventional cars, the small cars did not fare well on dimensions of ride quality, interior space, value of fuel efficiency, crash worthiness, etc. That's what the market seemed to be saying. The trend toward larger cars in Europe, in spite of relatively expensive fuel, seems to be supporting this conclusion.

It was felt that the Lean Machine might have a different market response because it is sufficiently different from conventional cars to be judged on a different set of dimensions. An obvious dimension is ride quality. Reference is not to smoothness and noise and vibration control when passing over surfaces of varied quality. Rather, reference is to the Lean Machine's ability to lean, and thus provide comfortable cornering and, and because cornering is comfortable and because of the short wheel base of the vehicle, high maneuverability.

As stressed, it was felt that the availability of appropriate road facilities was important.

With respect to markets, it was clear that the Lean Machine would not be a substitute for the general purpose conventional automobile. It would be a special purpose vehicle that augments household fleets or agency fleets. To explore this notion and community attitudes about the accommodation of small vehicles on facilities, local public works managers, politicians, and traffic engineers were interviewed. One conclusion was that information on possible facility modifications was needed. This motivated the work on striping of lanes and other highway modifications to accommodate the commuter vehicle.

Not mentioned in section 2 was work on "how to design" in order to augment the "what to design" question. Indeed, how to design was given a higher priority than what to design. That was partly because answers to the "what" question would depend on how the system is used and the experiences of users and highway traffic and facility managers. For example, while it has been assumed that a 6 foot wide lane would accommodate a three foot wide vehicle at low and moderate speeds, that assumption must be verified by experiences. Also, selection among facility improvements, say, flyovers versus special turning lanes at intersections, would depend on experience and site specific problems.

Today's "how to design knowledge" evolved over the decades as the highway system evolved. There was large scale experience as the interstate was designed and constructed, and the result is well developed capability to treat topics such as the capacity of proposed major freeway links. Design procedures for fine detail capacity or safety improvements exist and are becoming increasingly important as attention goes to incremental improvements in the existing system. The design methods investigations undertaken for the commuter vehicle sought to improve existing procedures and to deal with a gradual cost effective transition from today's situation to what would be needed if commuter vehicles were increasingly used.

Once this preliminary work was completed, work advanced to what may be thought of as round 2 of the investigations. On the supply-side, planners and local road agency managers were recontacted, this time with questions focused on implementation. Reactions stressedmainlythetime-consuming, information-demanding character of the transportation planning process.[18] On the demand-side, interviews were held with potential purchasers and users. Also during this round of work, investigations of congestion, energy saving, and pollution management benefits were undertaken.

Based on these experiences, the situation with respect to the commuter vehicle summarizes in this way:

> While it had been thought that modifications of roads to accommodate commuter vehicles might be required before the deployment of vehicles begins, this does not seem to be the case. It appears that incremental cost effective road modifications may be made as the number of commuter vehicles increases.
>
> However, the long lead times for projects and the complexity of the planning and programming process are of concern.
>
> Design, funding, and other protocols bearing on the highway system have evolved over a long period of time; they represent a consensus. For instance, responding to requests, the Intermodal Surface Transportation Enhancement Act of 1991 set aside federal funds for "transportation enhancement" projects--small projects that are "over and above" existing projects. Criteria for allocation have been established, and money is

[18]Reference 3 discusses this work.

"spoken for," in a sense. A new initiative, such as the commuter car initiative, may face turf battles.

As discussed, vehicle width and performance attributes are critical. These attributes appear necessary to achieve efficient modifications of the highway infrastructure and to achieve reduced congestion.

Because of small size and high performance attributes, commuter vehicles require innovative designs. A major barrier to the appearance of vehicles in markets is the risk that must be taken by vehicle manufacturers if they attempt to produce and market such designs.

The risk exists in part because markets can only be crudely estimated, and estimates can only be honed once the product is on the market.

However, it should pointed out that the California market estimates are suggestive of a sizable market. The low estimates range around 30,000 vehicles per year, which suggests a national market of about 300,000 vehicle per year

Experience with vehicles and their uses is also required before necessary or desired road modifications can be precisely identified. For this reason, it would be useful to procure a selection of vehicles and observe lane keeping, parking, curving, and other aspects of vehicle use that bear on road designs.

To aid in managing risk, a government role may be desirable. If commuter cars are successful, the benefits may be large and widely dispersed, yet risk taking manufacturers may suffer a period of negative returns while product designs are refined and there is learning by users and road facility providers.

At this time, it appears desirable to fashion a coalition of private sector and government actors and introduce vehicles to markets. Well designed demonstrations should develop information on demand and benefits, as well as on desired/required road modifications.

In short, commuter car investigations promise opportunities. But richer understandings of opportunities and implementation requirements will require experience with vehicles and their uses.

5. SAFETY; SWEEPING CHANGES IN ROAD INFRASTRUCTURE

From a technical point of view, how safe would small vehicles be? Regardless of the answer to the technical question, would consumers perceive them as safe? How might consumers' perceptions of safety affect their purchase and use decisions? Would the provision of special road facilities change the safety equation? Consumers perceptions of safety have not been investigated. Only partial answers to the other questions are available.

5.1. NHTSA's FMVSS

If safe means meeting National Highway Traffic Safety Administration's (NHTSA) Federal Motor Vehicle Safety Standards (FMVSS), then the commuter car could be a safe vehicle, and meeting NHTSA standards is the intent for the Lean Machine. It could be framed with roll cage construction, there is crush space available in the front of the vehicle, and required lights, mirrors, overturn fuel shut off devices, seat belts, air bags, etc., supplied.[19] The neighborhood car, as it has been imagined, would not meet NHTSA's FMVSS for conventional vehicles. It would be technically possible to meet those standards, but at a cost that might reduce the attractiveness of the vehicle to consumers. (Perhaps at some time in the future inexpensive, lightweight aluminum- and polymer-

---

[19]Commuter cars could be treated as motorcycles and subject to less stringent regulations that passenger cars. The Wagner W-18 K5, manufactured in Switzerland, has a motorcycle character--two wheels with two outrider wheels that lower at low velocity. Seating two persons in tandem, it is 145 inches long and is powered by a 1,000 cc BMW motorcycle engine.

intensive materials might change this situation.)

The failure of the neighborhood vehicle to meet NHTSA standards is not a "show stopper," at least so far as market introduction is concerned. The four wheel golf cart is regarded as a recreational vehicle and escapes federal attention, although state regulations require that golf carts be registered and have lights and rear view mirrors if they are operated on mixed traffic city streets. For the time being and while experience is gained, the neighborhood vehicle could be regarded as a golf cart-like vehicle. Another possibility, which also holds for the Lean Machine, is to produce a 3 wheel vehicle and consider it a motorcycle and subject to the less restrictive standards applied to motorcycles. (There is requirement for wearing a helmet, which consumers may find onerous.) NHTSA is developing standards for electric vehicles, and special standards for neighborhood vehicles could be established as part of that process. Another option would be for NHTSA to leave setting standards for neighborhood car-like vehicles to the states more or less as the situation is now. This would recognize variations among the states in possible market niches, road environments, and vehicle designs.

NHTSA's FMVSS are mainly set to protect vehicle occupants in the so-called second collision: the collision of occupants with steering wheels, dashboards, intruding materials, etc. The standards apply to all conventional cars. They ask for a minimum level of crash worthiness performance when a vehicle is subjected to collision forces. But even though a small, light weight vehicle may meet minimum levels of performance, light weight vehicles are disadvantaged in collisions with heavier vehicles. This is elementary physics: the momentum of heavier vehicles dominate that of much lighter weight vehicles.

Short length and narrow tread vehicles may not perform well when running off the paved road onto shoulders and through ditches. Break-away signs, light stands, and other structures designed for heavier vehicles may not be forgiving of light weight vehicles. (The weight of automobiles is tending downward, and there has been attention to these topics (see, e.g., References 15, 16).

Visibility of small cars is also of concern. The experience with motorcycles indicates that small vehicle are often not seen by drivers of other vehicles. There is also the matter of distance judgement. If a small car has the same outline as a large one, it may be judged as farther away that it actually is. This is thought to be a factor in the closer headway accepted when small cars are in traffic streams. To improve visibility, motorcycles use headlights at all times. The use of poles and flags, as some bicyclists do, might be helpful.

5.2. Improving Safety

There is much more to safety than NHTSA standards and vehicle size. NHTSA roles extend beyond the FMVSS, and there are roles for law enforcement, the courts, vehicle manufacturers, road facility providers, drivers licensing and training agencies, and traffic engineers, as well as public interest safety organizations and different levels of government. Much has been accomplished.

One measure of safety is fatalities per 100 million vehicle miles, an exposure measure. On this measure, safety has improved by a factor of 12 since the early days of the automobile (Table 6). Safety increased sharply during the 1930s and 40s, slowing subsequently, although percentage reductions in fatalities remain dramatic. Essentially, the process of achieving safety improvements was realized by a (reverse) J-shaped curve. Similar curves hold for other nations, and the U.S. compares very favorably with other automobilized nations.

Table 6: DEATH RATES PER 100,000,000 MOTOR VEHICLE MILES (17)

Year	Rate
1913-17 average	18.20
1928-32 average	15.60
1938-42 average	11.49
1950	7.07
1960	5.31
1970	4.88
1980	3.50
1990	2.18

The lowering of fatality rates was achieved in many ways.[20] Traffic ordinances and their enforcement by police and the courts were well established the 1920s. Improvements in road facilities were making contributions by the 1930s, and the 1930s saw a swell of public concern, in part caused by the publicity given to fatalities and injuries by Readers Disest. Results included

[20] No broad treatment of the evolution and effectiveness of safety programs appears to be available in spite of the importance of the topic and the large literature it has generated. Partial analyses are available, such as the review of traffic safety in Reference 18 and analyses of the regulation of the automobile in References 19 and 20.

drivers licensing and education programs. Insurance companies, the National Safety Council, and the American Automobile Association played important roles in developing these programs. The federal government increased its involvement in the 1960s, and the Highway Traffic Safety Act of 1966 provided federal funding to states that developed and implemented highway safety programs. The Act of 1970 created NHTSA and its programs.

Actions have addressed:

Drivers and pedestrians: education, licensing, safety campaigns, control of substance abuse, etc.

Facilities: designs (sight distance, road surfaces, grade separation), structures adjacent to roads, signs, etc.

Vehicles: lighting, strength, bumper height and resistance to crash damage, etc.

Operating rules: traffic ordinances, traffic engineering and signing, etc.

As would be expected, the most promising actions were pursued first. This is surely the reason why the absolute decrease of the fatality rate was rapid in the early days of the auto and has slowed subsequently (This is especially marked when fatalities per x members of the population is calculated. This measure reached a peak at about 1940.)

5.3. Would Specialized Roads and Vehicles Improve Safety?

Suppose the highway system gradually changes its form. Increasingly, roads would be redesigned to accommodate specialized vehicles such as neighborhood and commuter cars. Larger/heavier trucks would increasingly have their own lanes. Other types of vehicles would emerge and also operate on facilities specially redesigned for them, IVHS vehicles and facilities, for example. Matching the vehicles and facilities would be appropriate driver training and licensing and traffic engineering and control.

Such a change of form would surely improve safety for, compared to the present situation, it would provide better matches among drivers, vehicles, and road facilities and for tailoring designs and controls to situations. Vehicle-to-vehicle weight differences would decrease, as would differences in vehicle velocities, braking performance, etc., in streams of traffic.[21] Facilities could be better matched to their environments, neighborhoods, corridors, etc., and pedestrian control would be simplified.

Interestingly, a study of the accident involvement of small cars in Japan reports that while these cars are involved in a disproportional (more than expected) number of accidents fatalities are lower than expected (21). (The small cars are K-cars with engine displacements of 550 cc or less.) The reasons appear to include the operation of the vehicles at low speeds in urban areas, the lower speed limits in those areas, and the caution exercised by

---

[21] Vehicles involved in a collision are subject to the Newtonian laws on the conservation of momentum and the conservation of energy; the masses and pre collision velocities of vehicles are of concern. There is less energy to be dissipated if vehicles are lightweight compared to the situation when both vehicles are heavy. This, together with considerations of size and crush space availability, argues for separation of lightweight vehicle from heavy ones. The question of the alignment of masses and velocities argues for vehicles moving at more or less the same velocities in sequestered lanes.

small car drivers. Perhaps these findings are saying that small cars are relatively safe when operated in suitable environments.

The situation seems to be this. Actions have been taken to improve the safety of the highway system, and, as Table 6 indicates, returns from actions have been diminishing. Tailoring or redesign of vehicles and roadways along the lines suggested by commuter and neighborhood cars might make old safety enhancement actions more productive and/or offer options for new actions.

This is not a claim that safety problems would be "solved." Demographic and educational trends bear on safety. Attitudes, acceptance of risk, and substance abuse would not be controlled by vehicle and highway designs.

The notion that highways ought to be specialized to vehicles and their uses is not a new one. A proposal presented to a world conference on roads during the first decade of the century involved side-by-side facilities for trucks, walking, autos, and horse drawn vehicles. The proposal was rejected because of the extensive requirement for right-of-way and questions about how intersections would be designed. The first objection would not apply to specialization suggested here, for it seeks to use existing right-of-way more effectively. Intersections would pose problems. But they are offset somewhat by extensive experience in intersection design since the 1920s and the light weight of neighborhood and commuter vehicles.

Specialized passenger cars provide an opening wedge for improvements in highway services. Larger/heavier trucks provide a second wedge. The efficiencies to be gained from larger/heavier trucks are well known (see, e.g., 22, 23, 23). Large truck acceleration and deceleration rates are not compatible with those of passenger cars, and per mile of travel they are over represented in fatal accidents. As a result, there have been various proposals for specialized passenger car only facilities, as well as for truck facilities (25). Such proposals are not new. The Congress debated a truck only regional road system in the 1930s, a proposal said to be supported by Henry Ford. Earlier, an editorial in the 1928 edition of Roads and Streets said, "....nothing seems more certain then that many special highways will be constructed for motor trucking."

Perhaps the evolution of specialized facilities for neighborhood and commuter cars and for larger/heavier trucks might be complementary. Complementary might also be true as special facilities emerge accommodating IVHS technologies.

REFERENCES

1. William L. Garrison and Mark E. Pitstick. Lean Machines: Preliminary Investigations. UCB-ITS-PRR-90-4, 1990.

2. Mark E. Pitstick and William L. Garrison. Restructuring the Automobile/Highway System for Lean Vehicles: The Scaled Precedence Activity Network (SPAN) Approach. UCB-ITS-PRR-91-7, 1991.

3. Booz Allen & Hamilton. Study of Road Infrastructure Requirements for Innovative Vehicles. 1992.

4. Peter C. Bosselmann, Daniel Cullinane, William L. Garrison, and Carl M. Maxey. Small Cars in Neighborhoods. UCB-ITS-PRR-93-2, 1992.

5. Booz Allen & Hamilton. Benefit and Cost Impacts of Implementing Commuter Cars in California. 1993.

6. William L. Garrison and Mark E. Pitstick. Lean Vehicles: Strategies for Introduction Emphasizing Adjustments to Parking and Road Facilities. SAE Technical Paper 901485, 1990.

7. Patricia S. Hu and J. Young. Summary of Travel Trends. 1990 Personal Travel Survey. Federal Highway Administration. 1992.

8. Alan E. Pisarski. Travel Behavioral Issues in the 1990s. Federal Highway Administration. 1992.

9. Automotive News, May 29, 1991.

10. Hartmut H. Topp. "Traffic Safety, Usability and Streetscape Effects of New Design Principles for Major Urban Roads," Transportation, 16 (1990), pp. 297-310.

11. United States General Accounting Office. Traffic Congestion: Trends, Measurements, and Effects. 1989.

12. OECD. The Urban Electric Vehicle: Policy Options, Technological Trends, and Market Prospects (Proceedings of a Conference), Paris: 1992.

13. California Department of Transportation. Bighway Design Manual, 1990.

13. Michael Southworth and Eran Ben-Joseph. Regulated Streets: The Evolution of Standards for Suburban Residential Streets. UCB-ITS-WR-93-9. 1993.

15. F. M. Council et al. Safe Geometric Design for Minicars. Federal Highway Administration. 1988.

16. National Highway Traffic Administration, Small Car Safety in the 1980s. U. S. Department of Transportation, 1980.

17. Motor Vehicle Manufacturer's Association. Facts and Figures (various issues).

18. James L. Foley, Jr., "Traffic Safety Retrospective," ITT Journal, July 1991, pp. 61-64.

19. John D. Graham. Auto Safety: Assessing America's Performance. Auburn House Publishing Company, 1989.

20. Joel W. Eastman. Styling vs. Safety: The American Automobile Industry and the Development of Automobile Safety, 1900-1966. University Press of America, 1984.

21. F. T. Sparrow. "Accident Involvement and Injury Rates for Small Cars in Japan," Accident Analysis and Prevention, 17 (1985), pp. 409-418.

22. Robley Winfrey et al. Economics of the Maximum Limits of Motor Vehicle Dimensions and Weights. Federal Highway Administration. 1968.

23. Kenneth Small, Clifford Winston, and Carol Evans. Road Work: A New Highway Pricing and Investment Policy. The Brookings Institution. 1989.

24. Youssef M. Fawaz. Alternative Truck/Highway Combinations: An Exploration of Opportunities for Major Productivity Gains in the Truck-Highway System. UCB-ITS-DS-93-3. 1993.

24. Bruce N. Janson and Anji Rathi. "Economic Feasibility of Exclusive Vehicle Facilities," Transportation Research Record 1305, 1991, pp. 201-214.

APPENDIX A: BRIEF HISTORY OF THE RESEARCH

Work on innovative vehicle and road infrastructure concepts began in July 1989. It was decided that Phase 1 of the research would proceed in a "paper and pencil" style, and focus on the viability of concepts. It was planned that Phase 2 would involve demonstration type investigations. Phase 1 has been completed.

Tasks Accomplished

Formation of Coalition: At the time the work was initiated, General Motors (GM) was defining work on the marketing and manufacturing feasibility of a vehicle it had designed a decade before. This vehicle, termed the Lean Machine, had been on display at EXPO in Florida and interest in purchasing had been expressed by visitors who examined the vehicle. Booz Allen & Hamilton (BAH) had been working with GM, and it had proposed work for GM on safety, market analysis, and business planning topics.

The GM-BAH association offered a context for exploration of the commuter car concept, and our work proceeded in association with GM and BAH. GM allocated resources for in-house work, as well as support for BAH work. Work at Berkeley (Institute of Transportation Studies, University of California, Berkeley) began using the Lean Machine as a case at point. A working coalition was formed. While the results of some of the BAH work funded by GM was proprietary, there was a high level of sharing of information about approaches and results.

BAH waived its fee on the work supported by Caltrans through the Berkeley-based research. As put by a BAH manager, BAH wanted to be counted in at the birth of a new concept and product.

Start-up: The first months of work at Berkeley were exploratory and directed to the development of a research plan.[22] Researchers visited cities and agencies to determine interest in the innovative vehicle concept and to identify potential sites for field studies. First estimates of benefits and costs were made. An Advisory Committee for the work was appointed and met to review first findings and to make suggestions about emphases and approaches.

A report on work during this period was issued (1), and several internal discussion papers were developed for use within the project. A plan for Phase I investigations was developed.

Initiation of Phase I Investigations: It was planned that Phase I investigations would begin in July 1990 and require about twelve months. Investigations were to examine benefits and costs, market viability, and road infrastructure requirements for a Lean Machine- type vehicle. Emerging technologies that might enhance or supplement Lean Machine-type vehicle were also to be examined.[23] Following this work, and depending on findings, a Phase II set of investigations would examine vehicle choices, users, and uses, as well as the road infrastructure implications from vehicles. It was projected that Phase I would be completed by June 1991.

Phase I investigations on the Berkeley Campus were initiated

[22] These were tasks 1, 2, and 3 in the work plan: Preliminary Study, Development of Phase I Study Plan, and Establishment of Advisory Committee.

[23] These were Tasks 4, 5, and 6 in the Work Plan.

on schedule. However, in the Fall of 1990 GM elected to delay their participation in the coalition effort. This slowed the start-up of work by BAH. Actually, that slow down enabled BAH use of the results of work ongoing at Berkeley, and that enhanced what they were able to accomplish, as will be discussed later.

The work at Berkeley focused on two matters: 1. an appropriate design strategy for modification of road infrastructure and 2. a method for estimating congestion reduction benefits. Although the Berkeley work did not and could not review actual experience with facility modifications, it did strongly suggest that methods could be implemented to make simple, incremental adjustments to road facilities in order to accommodate narrow width vehicles such as the Lean Machine. It also suggested that these could be made in a cost effective manner. There would be savings by highway agencies as well as vehicle users.

The work at Berkeley was completed in the Spring of 1991, and a report was issued (2).[24]

Neishborhood Scale Analysis: Beginning in the Summer of 1991, an investigation of neighborhood scale vehicles, roads, and community designs was initiated at Berkeley.[25] Focus was on short trips made typically on local roads and streets. Would a small, inexpensive, low velocity vehicle serve such trips? Would modifications need to be made to local roads? What about places

---

[24]This represented completion of Task 5: Study of Roadway Design Needs and Task 6: Impacts Analysis, Benefit-cost Analysis of Congestion Relief.

[25]Task 7 in the Work Plan.

where short trips require crossing or using a segment of high capacity roads such as arterial highways? Safety? To deal with some of these questions and other questions, one part of the study addressed issues, many of which would also apply to station and commuter cars.

The second thrust of the study focused on neighborhood designs. It explored the extent to which the use of small vehicles and modifications of local roads might allow for revisions in the design of existing communities or new approaches to the design of new communities.

A report from this work was completed in June 1992. (4).

Comnletion of Phase I Work: As stated, GM decided to delay its participation in the study effort. Delay ended in the Fall of 1992 when GM resumed its in-house investigations, and began to support BAH work. At that time, work by BAH oriented to road infrastructure issues began, and BAH submitted its report in August 1992 (3).[26] The BAH report extended work completed at Berkeley. Researchers interviewed transportation and planning officials in California to acquaint them with study findings, identify barriers, and develop planning requirements. The report stressed the complexity of planning and implementation tasks, and, especially, the long lead times that may be required.

Work by GM included six marketing clinics in California. Those clinics served to identify potential purchasers of vehicles

---

[26]This was the first of two rounds of work on Task 4 of the Study Plan: First Field Examinations.

and potential uses. They also identified the types of road infrastructure improvements given priority by potential users.

Based on the results from the clinics and earlier work, BAH initiated additional field examinations in January 1993.[27] That work merged data on potential markets and how commuter vehicles might increase road capacity with information about two major California markets (San Francisco and Los Angeles) in order to sharpen data on potential benefits and road infrastructure issues. The report from that work was completed in July l.993. (5)

Working Papers (Unpublished)

During the course of the research, working papers aided discussions of issues and the exchange of information. They were:

Technology and the Future of Transportation, An Industrial View.
Assessment of the Urban Benefits of Half Width Cars.
A Plan to Study the Deployment of Half Width Automobiles in Selected Urban Areas.
Some Transportation Opportunities: Lean Machines and Neighborhood Cars.
Lean Machine Crash Worthiness Review.
AASHTO on Vehicles and the Geometric Design of Highways.
Geometric Designs for Minicars.
More on Residential Street Designs.
Varieties of Small Vehicles: Market Niches and Regulatory Issues.
City Planning and the American Urban Form.
New Neighborhoods--New Vehicles.

Participants

Booz Allen & Hamilton: Gary Schulman, Robert Kreeb, James Dolan, and James A. Mateyka.

California Department of Transportation: Roy Bushey, David Aschuckin, Charles Price.

General Motors Corporation: Alan Chernomski and Bridget Cassidy.

---

[27] Part b of Task 4: Final Field Examinations.

Albert J. Sobey and Associates: Albert J. Sobey.

Stander Research Associates, Inc.: David M. Stander.

University of California at Berkeley: William L. Garrison, Mark E. Pitstick, Daniel Cullinane, Kevin Gilson, Peter C. Bosselmann, Carl M. Maxey, and A. Mitra.