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Lean Machines: Preliminary Investigations

William L. Garrison
Mark E. Pitstick

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Abstract

Divided into five topical Sections, this Report presents information from early work on a study of the potential for the General Motors Lean Machine in California markets. The vehicle is small and energy efficient, and if widely adopted, it might reduce congestion and air pollution as well as energy consumption.

The first Section of the Report identifies California and other participants in the study; describes its preliminary organization and the roles of the University of California at Berkeley, General Motors, Booze, Allen & Hamilton, and an Advisory Committee; and gives the timing of the phases of the multi year study.

The second Section provides descriptions of the Lean Machine and the California situation. Market segmentation and market penetration questions are then discussed; questions to be investigated are identified.

The cost savings from the small parking spaces required by the Lean Machine are considered in the third Section. Savings depend on the type of parking facility, surface lot or structure, and whether existing spaces are restriped, all or part of an existing facility is reconfigured, or a new facility constructed. Depending on the situation, daily savings might range from $3.20 to $4.80.

Ownership and operating costs are considered in the next Section of the Report. Comparisons are made between the Lean Machine and larger vehicles. The comparisons indicate that Lean Machine costs might be from one half to one third lower than the costs of conventional vehicles. However, cost savings depend on how the Lean Machine is used.

The final part of the Report, the fifth Section, considers the impact of the Lean Machine on road capacity. Impact depends on the facility type, the quantity of road use, and the number of Lean Machines in the traffic stream. The discussion in this Section considers selected situations and the impact of the Lean Machine in those situations. There is a discussion of congestion costs and their incidence.

Preface

This Report provides information on a study assessing the potential for the transition of the fleet of highway vehicles to lean vehicles. When compared to current vehicles, lean vehicles are imagined to be, say, a factor of two more energy efficient, less expensive to own and operate, and less polluting. The particular lean vehicle under study, the General Motors Lean Machine, might serve commuting functions. It offers high performance and has a small footprint. For these reasons, it may increase highway capacity and decrease congestion.

The initiating phase of the study has been completed, and the first major phase of the study has been outlined but not implemented as of the date of this Report, July 1990. The initiating phase included contacts with California communities to explore opinions about benefits and costs, market niches, and appropriate field studies; the plan for Phase 1 of the study was developed based on this information. Preliminary exploration of benefit-cost topics was undertaken during the preliminary phase of the study: namely, parking and ownership and operating topics. Work was also undertaken on the affect of the Lean Machine on highway capacity and implications for the adjustments of highway designs that would assist achieving capacity increases.

This Report provides information on the organization of the study and the results of preliminary explorations of parking, ownership and operating, and highway capacity topics. In addition, a discussion paper provides a broad brush treatment of topics bearing on the adoption and use of the lean vehicles in California.

The topics covered in this Report do not fully scope our work. Topics not yet addressed include the affect of lean vehicles on air pollution and energy consumption. These are complex topics because consideration must be given to lean vehicles in the context of the uses of different types of vehicles. In addition, air pollution and congestion benefits are site specific, and all benefits turn on market penetration and use questions. Future work will introduce these considerations.

Contents

1. ORGANIZATION OF THE STUDY; PARTICIPANTS

Abstract

This short Section identifies California and other participants in the study; describes its preliminary organization and the roles of the University of California at Berkeley, General Motors, Booze, Allen & Hamilton, and an Advisory Committee; and gives the timing of the phases of the multi year study.

The study is a cooperative endeavor representing the coming together of California and General Motors' interests. Knowing of the Lean Machine and imagining how there might be substantial benefits from its use in California, the California Department of Transportation (Caltrans) initiated a small, preliminary study by the Institute of Transportation Studies at the University of California at Berkeley in June of 1989. At that same time, interest in the work was expressed by the California Air Resources Board and the California Energy Commission. The preliminary study included a reconnaissance of local study sites, the development of preliminary information on the nature of benefits and costs, and the outlining of a work plan.

The Lean Machine and other vehicles based on similar concepts were developed to prototype stage by General Motors about a decade ago. There has been continuing interest there. But because these vehicles are novel, market uncertainties, business risks, and regulatory hurdles have blocked a production decision. The production decision is risky, and there are many unknowns. However, interest expressed in California and the possibility of substantial benefits interested General Motors in the cooperative study.

Roster of Organizations: The resulting cooperative arrangement identified these organizational participants:

- The California Department of Transportation
- The California Air Resources Board
- The California Energy Commission
- University of California at Berkeley
  - The Institute of Transportation Studies
- The General Motors Corporation
  - Chevrolet Motor Division
  - Advanced Vehicle Engineering
  - Marketing and Product Planning
- Other Organizations in California
- Consultants
- A Project Advisory Committee

Not all of these participants are currently involved in the study. Representative markets will be examined, and it is planned to engage not-yet-identified organizations in California as study participants. These will include local and regional governments and, possibly, firms that might encourage employee utilization of the vehicle or use it for their purposes. We anticipate active participation because these organizations might benefit if there is substantial adoption of the vehicle.

There is need for a good amount of market and market situation data, and it is planned to engage Booz-Allen & Hamilton (BAH) to assist in market studies.

A Project Advisory Committee has been established to assist in guiding the study and to assure that interested and contributing parties are represented. This Advisory Committee may be enlarged as the study proceeds. (A list of members of the Advisory Committee is provided as an Appendix to this Section.)

Working **Arrangement:** The Institute at Berkeley will serve as one locus of work, and the Chevrolet Marketing Division will serve as a second locus. Although responsibilities are overlapping, The Institute will take primary responsibility for California interests in facility requirements and congestion, energy, and air pollution impacts. Chevrolet will work with GM in-house resources to interpret market information and vehicle engineering and design. To the extent practicable, GM will make available equipment to illustrate the Lean Machine concept. As may be understood, some of the work executed by GM with its resources will be proprietary in character.

Work by BAH will support work at Berkeley and at General Motors.

Preliminary work has outlined some regulatory issues. These issues should be clarified by BAH as work proceeds. It is planned that all participants will be involved with these issues, and it is expected that State and local agencies will lead in resolving issues, if necessary.

As local governments and other organizations become involved in the work, it is expected that they will provide information and may undertake their own impact analyses.

Timing: Preliminary work was begun in July 1989. The first major phase of work, Phase 1, was scheduled to begin in January 1990 and continue through June of 1990. However, contracting delays **have** forced a six months time slippage, and first results from the BAH work will not be available until early Winter 1990. In addition to work on regulatory and safety issues, Phase 1 work will include gathering and analyzing data in representative California situations. If this work suggests a market significant to GM and to California, the next phase of work will aim for more detailed information supporting business and government decisions.

Commitments: California and GM commitments to the work extend only to the first phase. Further work by GM will be undertaken only if it is highly probable that the vehicle can and should be placed in production. Even if that is the case, California interest may wane if the forecast market penetration and analyses of benefits and costs do not uncover a potential for significant benefits to the State.

Appendix: Advisory Committee

Mr. Michael R. Appleby, Manager
Automotive Engineering Department
Automobile Club of Southern California

Mr. Vincent C. Barabba, Executive Director
Market Research and Planning
General Motors

Mr. B. B. Blevins, Advisor to the Chairman
California Energy Commission

Professor Sadler Bridges, Associate Director
Texas Transportation Institute
The Texas A and M University

Mr. Roy Bushey, Chief
New Technology and Development Branch
Division of Transportation Planning
California Department of Transportation

Mr. Alan J. Czarnomski, Market Analyst
Chevrolet Marketing Planning
General Motors

Professor William Garrison
Institute of Transportation Studies
University of California, Berkeley

Mr. James Gosnell
Southern California Association of Governments

Professor David T. Hartgen
Coordinator of Transportation Studies
The University of North Carolina at Charlotte

Mr. David O. Lundin, Manager, Advanced Planning
Chevrolet Product Planning
General Motors

Mr. Michael Scheible, Assistant Executive Officer
California Air Resources Board

Mr. Earl Shirley, Chief
Division of New Technology
California Department of Transportation

Mr. Albert J. Sobey, Consultant
Bloomfield Hills, Michigan

Mr. John Vostrez, Chief
Office of New Technology and Research Management
California Department of Transportation

Ms. Patricia F. Wailer, Director
University of Michigan Transportation Research Institute

Mr. James A. Mateyka, Vice President
Booz Allen & Hamilton

2. THE VEHICLE AND ITS ADOPTION AND USE IN CALIFORNIA

Abstract

This Section provides a description of the Lean Machine and the California situation. Market segmentation and market penetration questions are then discussed; questions to be investigated are identified.

The Vehicle: Small is a relative word, and in saying that the Lean Machine is a small vehicle we mean that it is smaller than conventional vehicles: micro cars, compacts, etc. In prototype form it weighs about 400 pounds, has a tread width of about 28 inches and a width of about 3 feet, the wheelbase is about 6 feet, and it is about 9 feet in length overall. (Figure 1)

The Lean Machine is by no means the only small vehicle. The Oldsmobile of the first decade of this Century was a small car. A number of small cars have been proposed and sometimes offered in the market subsequently. About 20 such vehicles were proposed in the U.S. during the energy crises of the 1970s and, perhaps, 100 prototypes were constructed. Some of these were electric vehicles. Figure 2 provides an example of one of these vehicles.

Vehicles have been available, but have not succeeded in the market. Even so, we are exploring the market for the Lean Machine because the reasons why small vehicles have failed market tests may be overcome by the Lean Machine design.

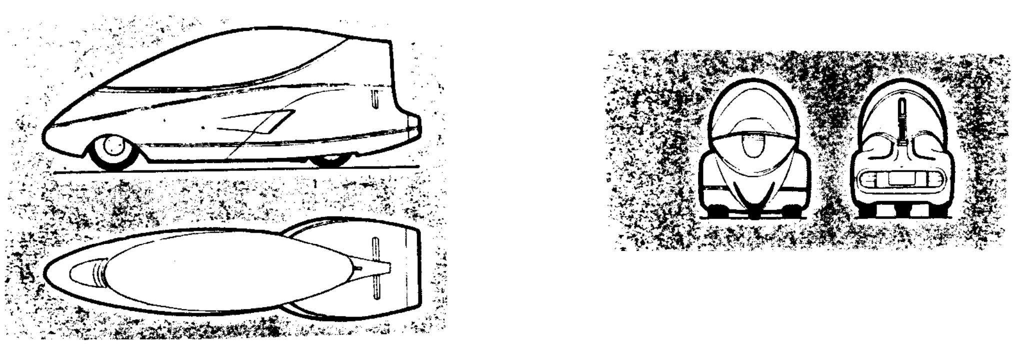

Figure 1. The Lean Machine Prototype.

Stability has been an inherent problem of small vehicles. The high center of gravity relative to vehicle size, especially tread width, is the culprit. To provide occupant comfort, a seat positioned above the floor pan is required, and that plus the height of many of a vehicle's mechanical devices, especially the engine, raises the center of gravity. This limits the extent to which tread width can be reduced without the vehicle tipping over when cornering.

Figure 2. Sparkle, a Proposed Electric Vehicle.

Today's larger automobile vehicles are very stable when cornering at conventional velocities, and the small vehicle must be competitive for safety and ride quality reasons. Absent striking marked irregularities of the road surface or curbs, most of today's cars will corner safely at about .75g (g = gravitational force), and high performance cars will corner at as much as .85g.[1] Again assuming a good road surface, the limiting factor is tire adhesion, the car will slide before tipping over.

In day-to-day driving situations, however, ride quality is the constraint on cornering velocities. On ordinary road surfaces, drivers could routinely corner at .5g with a comfortable margin of safety. But drivers typically turn corners at .2g or less. They seem to do so to avoid sliding across the seat and to avoid uncomfortable side forces. So on turns with small radii, such as right turns in grid-iron street systems, drivers will typically corner at about 7 to 5 mph or less.

Although it is small, the design of the Lean Machine enables both safe and comfortable cornering. The engine is located in the rear of the vehicle at a low height. The passenger compartment and front wheel camber when cornering, as a bicycle or motorcycle does. The resolution of forces is such that the ability of the tires to handle slip energy is as great as that for vehicles with high performance tires. Forces are aligned with the vertical axis of the driver's body, and the driver is pressed into the seat rather than pushed across it. The result is safe and comfortable

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[1]These statements apply to conventional passenger vehicles. Higher center of gravity vehicles behave very differently.

cornering relative to conventional vehicles. Unlike motorcycles and bicycles, the Lean Machine can recover from a skid, say, on an ice covered road.

Stability and maneuverability, contribute to safety, of course, but safety questions remain. Indeed, safety is an inherent problem for small vehicles simply because of their low weight compared to ordinary vehicles and their lack of crush space. The Lean Machine provides crush space in the front. It is imagined that the driver will be surrounded by a cage and protected by a sturdy, energy absorbing seat. So if a collision is unavoidable, the driver will be protected in a manner similar to a race car driver.

With respect to striking pedestrians and fixed objects, the small frontal area and maneuverability of the Lean Machine should be an advantage.

Cost and quality have historically been problems for small cars. Part of the reason has to do with the nature of automobile vehicles. They are assembled from, say, 14,000 parts, and part handling and assembly costs are incurred whether the car is conventional or small. The small car weighs less, and that does reduce costs. Averaged out, the materials in an automobile cost about $1.25 per pound, so there is about a $1,900 dollar material cost savings for a 500 pound car compared to a 2,000 one.[2] Suppose a 2,000 pound vehicle cost $10,000; cost reduction is disproportionate to weight reduction. Halving the weight saves about ten percent of cost. Optional accessories are a good part of car cost, and they vary little with the weight of the car.

Efforts to reduce cost are part of the reason quality can be a problem. However, the quality lesson has been learned, beginning as long ago as the depression of the 1930s. At that time, there were efforts to market low performance, striped of luxury items "depression cars," efforts that were unsuccessful. Experiences with compact cars in the 1970s retaught that lesson. So the Lean Machine is not viewed as degraded quality vehicle. It is planned to have high ride quality and other quality features, with bundles of accessories available.

Fuel economy and low emissions are to be expected for small vehicles. They follow because good performance can be achieved with small engines. A compact car weighing 2500 pounds achieves good performance with, say, a 2000 cc displacement engine. That suggests that similar performance could be achieved by a Lean Machine with a 400 cc engine.

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[2]The per pound material cost for the Lean Machine will likely be greater than that for conventional vehicles, and this estimate may overstate cost savings.

That comparison is very general. Actual performance would depend on engine configuration, the harnessing of torque, and aerodynamics. Because of the small engine, a continuously variable transmission (CVT) might be used and provide for very effective use of torque. The aerodynamic shape and small size of the Lean Machine will reduce cruising power requirements compared to conventional vehicles.

Issues: The manufacturer will be dealing with a number of engineering and production issues stemming from the interaction of design, manufacturing, cost, and market matters. It may be desirable to differentiate the vehicle for different markets. The extent to which cambering should be under the driver's control is not known, and there are some questions about the affect of cross winds on vehicle stability. There is the question of size of market and whether the production of the Lean Machine is a feasible business proposition.

It is simple to say that the vehicle should be about as safe as a larger vehicle. Issues may arise because it is different, safer in some situations and less safe in others. The complex of safety standards and vehicle test procedures are oriented to conventional vehicles, and appropriate safety requirements for the Lean Machine will have to be developed. This may prove to be both technically and politically difficult, for large amounts of analysis, program development, and political effort have been invested in existing requirements.

Present standards for pollutant emissions take a "not greater than x grams per mile" form. They present no great problem for a vehicle with, say a 400 cc engine, and the manufacturer can produce a vehicle meeting standards without great difficulty. (There is also no difficulty in meeting fuel efficiency requirements.) However, for a vehicle to be especially attractive to those concerned with air pollution, some lower level of emissions is required. Some way will need to be found to negotiate manufacturers', users', and air shed managers' interests.

The California Situation

In comparison with most of the Nation, the words "more so" capture the California situation. Focusing on the negative attributes of I'more so, II California has major congestion problems, acute air pollution problems, and is highly dependent on petroleum and, thus, sensitive to energy issues.

There are some 20 million road vehicles in California, and although there are many persons for whom services are limited by weI economic, or other factors, the market is essentially saturated, as it is in most parts of the U.S. However, the number of vehicles is growing, for population growth is strong. The average personal automobile in California is driven about 12,000 miles per year, about ten percent more than the national average.

As a consequence of the increased population and, thus, number of vehicles, between 1981 and 1986 annual traffic increased from 160 to 215 billion vehicle-miles. There is a simple equation at work driven by population increases. For every 100 persons added to the population, there is an increase of about 1 million miles of personal travel per year, largely by automobile, thus there is an increase on the order of 600,000 personal vehicle miles of travel per year. With annual population increases of about .5 million, vehicle miles of travel increases by billions.

Ever increasing congestion is the result, for highway facility development has fallen far behind increases in travel. State highway investments in real (1947) dollars peaked at about .55 billion in 1967 and dropped to about . 1 billion in the subsequent 15 years. Currently it is running about .2 billion. The Los Angeles Basin provides a specific example. Freeway miles per one million members of the population increased from about 10 in 1954 to about 79 in 1978 and have been declining since. Travel is increasing about five times as fast as the provision of facilities. It is estimated that over one third of urban and interstate freeway miles are severely congested at some period of nearly every day of the year. Investment is lagging hopelessly while travel is increasing. Increased congestion with no end in sight is the result.

State and Federal regulations and programs have sharply reduced pollutant emissions from new vehicles and have increased average fuel economy. Even so, the growth in number of vehicles and their uses has resulted in increases in the consumption of vehicle fuels. As the less polluting new vehicles have entered the fleet, there has been a downturn in total vehicle emissions. However, in critical air basins, and especially in the Los Angeles Basin, the quantity of emissions remains so high that air quality goals can not be achieved without stronger controls. Although vehicle aging and turn over of the vehicle fleet by replacement vehicles continues to reduce emissions, growth effects will erode gains being made.

Turning now to positive aspects of the California situation, a variety of policies and programs have been introduced or are being considered because of worsening congestion and not yet tamed air quality and energy problems. Traffic signal timing programs have improved the flow of traffic, and a battery of Transportation System Management (TSM) tools have been introduced, such as high occupancy vehicle (HOV) lanes and ride sharing. Many cities now require implementation of TSM measures when land is developed. Such measures have salutary impacts on congestion, air pollution, and energy consumption. However, opportunities for implementation are limited, and many of the gains to be achieved have already been achieved.

A variety of longer term, far reaching policies and programs are under consideration or in beginning phases. Stronger controls on single occupancy vehicle use are being implemented to reduce emissions, and there is National and State consideration of further limiting allowable emissions. The Caltrans has plans to improve and extend freeway operations systems in major urban areas. It is supporting research exploring and developing applications of advanced technology vehicle and traffic control systems. In the interest of air quality improvements and shifting from petroleum based fuels, methanol is being introduced in the Los Angeles area. Interest in electric vehicles continues, and the industry has programs to increase deployment of electric vehicles in market niches.

Facility expansion is underway at critical chokes in the highway net, although traffic growth continues to consume capacity faster than it can be supplied.

Issues: There have been active searches for programs and policies to manage problems and accommodate growth while maintaining or improving the quality of life in California and the California environment. Actions have been taken. However, actions in individual problem areas are not achieving long term problem management. Problems are interrelated, and action taken to ease one problem, such as the mobility problem, may worsen other problems, such as energy efficiency.

The question for California is whether the Lean Machine might contribute to problem management while maintaining or increasing mobility. It might decrease pollutants and fuel use. Operating side-by-side on single freeway lanes in congested situations and parked two or more to a conventional parking space, the Lean Machine might sharply ease congestion.

Markets and Market Penetration

The discussion now turns to a discussion of the diffusion-adoption of the Lean Machine in California markets.

Innovation and Innovation Diffusion Paradigms: It is known that economic and social progress depends on innovation and the diffusion of innovations, and much attention has been given to those processes. In simple situations, the processes run this way: An innovation is created by an actor or actors and emerges in a prototype stage. There is then a period of product refinement during which the prototype is improved from standpoints of durability, costs, and manufacturability. There may be some market testing during this period of revision, or major revision may be delayed until there is considerable market experience. Financing, production, and marketing arrangements are made, usually following the consideration of alternative schemes. At that point, the product is placed on the market and fails or succeeds.

If the innovation is a straightforward substitute for an existing product, then the diffusion process can run very quickly. The quartz-battery watch, for example, displaced the production of mechanical watches in a matter of a few years. The product's advantage was clear, and the technology transferred easily.

Diffusion can also be ra id if the product does something new and desirable. Liquid Paper® for typing corrections and Post-it® pads for memo uses in offices are examples of such products. These products fitted functions or needs. Although they were quite different from previous products, they fitted easily into existing situations. Other situations are more complicated.

> Sometimes standards of one type or another may thwart or delay the development, introduction, and diffusion of a technology. Standards may be formal, such as those created by governments or private standard setting organizations, or they may simply represent custom and standard practice, as is the case for the arrangement of keys on typewriter keyboards.
>
> Sometimes innovations havelimitedmarkets as substitutes for existing products. The producer's refinement of the product and the adoption of the product may be slowed by the time it takes to develop new uses. The telephone is an example. It was only in part a substitute for the telegraph and message services, and its deployment did not "take off" until a broad market for interactive communications developed.
>
> In transportation and communications, the pace of diffusion may depend on an interactive dynamics of adoption. The adoption of the FAX illustrates the idea. FAX machines used at only a few places are of limited value. But as more places acquire machines, the opportunities for communications increase exponentially. The use of containers for freight shipment illustrates the same dynamic. The problem is that of getting enough use of the innovation so that it shifts from a product of little value to one of great value.
>
> Finally, there are situations where the adoption of a single innovation depends on other innovations. A computer without operating programs is of little value; development of street paving methods created an environment for the development of the automobile.

The development of the Lean Machine prototype represents only the first step in the innovation and innovation-diffusion processes. It is an innovation untested in market situations; it is yet to be revised from experience in markets. Obtaining market experiences requires initiation of the adoption or diffusion process, and consideration of the nature of the innovation and its market says that the situation is complex indeed. Many standards apply to vehicles, roads, parking garages, and vehicle operators, and these must be considered. The Lean Machine may substitute for vehicles now used for single person trips, but travel patterns and household decisions about purchase of vehicles are very complex. It will be difficult to estimate just how the Lean Machine choice would change use and purchase patterns. It will also be difficult to begin to understand the uses that may develop for the vehicle as users gain experience with it.

Adoption Dynamics: The adoption or diffusion process is well represented by a logistic curve, the symmetric S-shaped curve shown in Figure 3. Initial market penetration is slow, penetration then turns sharply upward, and then slows again. Curves with this shape fit diffusion processes well, as stated, and they have been fitted to a large number of transportation cases: locomotives, canals, air travel, size of jet engines, etc.

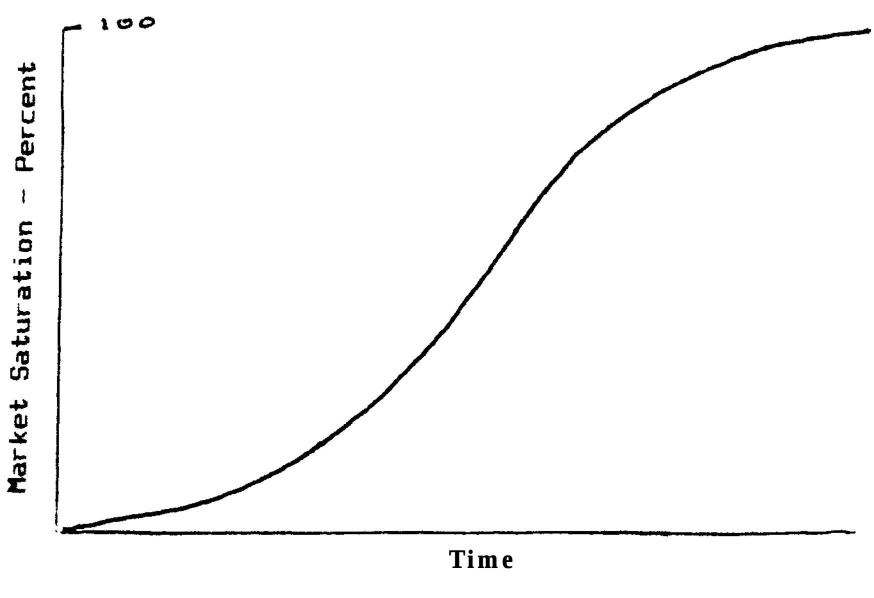


Figure 3. The S-Shaped Curve Characterizing the Diffusion of an Innovation.

Three parameters define the curve. There is the amount of market penetration at saturation, the time it takes for the process to run (measured, say, by time it takes to run from 10 percent penetration to 90 percent penetration), and the mid point of the curve. Estimates may be made of the parameters of the curve once the adoption process is initiated. Although the market is not yet saturated, for example, the growths of passenger miles of air travel, aircraft size, and aircraft fleet size have been estimated using logistic growth curves.

Researchers have fitted curves to highway system topics. One interesting finding is the difference in the time it has taken for the automobilization process to run. Measuring automobilization by the adoption of the automobile and referring to the time required to go from 10 percent market penetration to 90 percent, this pattern emerges:

> The United States began widespread adoption of the automobile early, and the process ran about 60 + years.
>
> Although automobiles were present in Western Europe countries prior to World War II, widespread adoption did not take-off until the 1950s. Adoption took from 20 to 30 years.
>
> The take-off of adoption of the automobile in Japan began later; adoption was completed in about 11 years.

While this pattern is known, we know of no effort to study the reasons for the country to country differences in detail. Perhaps that is because a driving reason seems obvious. One might suppose that levels of and increases in personal incomes played **a** role, the greater the income, the faster the process ran. It ran very fast in Japan at a time when personal incomes were high. The differences among European countries appear income related, and the U.S. adoption process ran over a period beginning when only a few rich could afford vehicles and continued over a fair period of time as more and more persons became "rich enough." The "becoming rich enough" period of time was shorter elsewhere.

Considering the personal income situation in California and the growth of the economy, the Lean Machine adoption period might be comparable to that of Japan. Assuming that the vehicle became available in volume on the market in 1994, then the adoption process might follow the trajectory indicated in Figure 4.

Further considerations press for a slower adoption process. Although not discussed in the literature, the adoption of the automobile in Europe and Japan was surely enhanced by learning curve and infrastructure considerations. Conversely, in was slow in the U.S. for the same reasons.

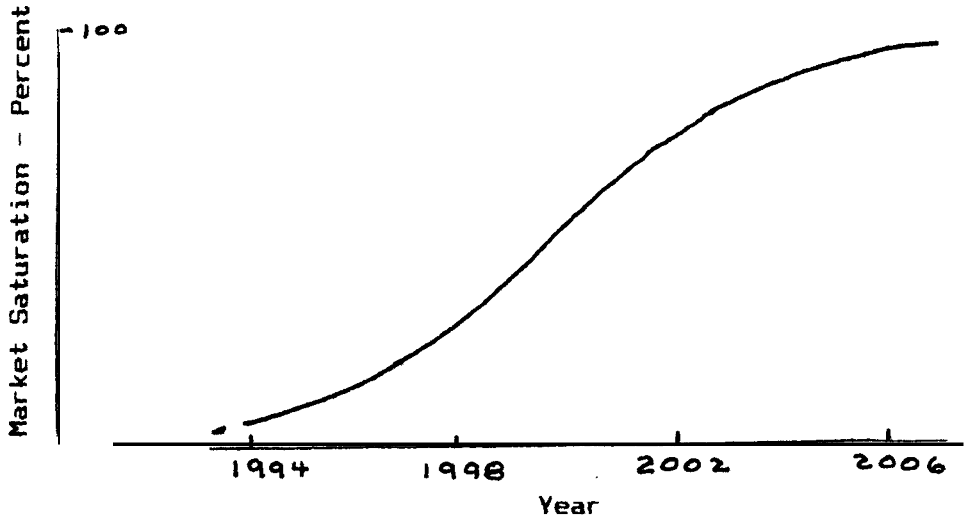


Figure 4. Example S-shaped Curve for the Diffusion of the Lean Machine in the California Market.

Briefly, there was a several decade period of learning in the U.S., beginning, say, when the Model-T was produced and extending through the 1930s. Although vehicles had been available prior, the Model-T was the first mass market vehicle. Feedback from the market to vehicle and production technologies was initiated, and it took until the end of the 1930s for vehicles to evolve into a form close to their modern form. Urban roads had begun to be paved in the late 1880s, but the emergence of appropriate roads, especially in rural areas, occurred in the 1920s and 30s as the state primary highway system evolved and as the cities learned to organize and finance the production of arterial and local access street. Traffic control protocols and devices emerged in the same time frame.

Considering uses, first automobiles carved out some unique roles, especially their use for touring and other recreation. They also began to substitute for functions previously performed by buggies and wagons, and substitution ran its course into the 1930s. Beginning in the 1920s the everyday uses seen today began to emerge, commuting, shopping, etc., along with suburban trends.

Similar learning and infrastructure developments occurred in other places, but we suppose that the period of time was much shortened because of the U.S. model.

Also, statements may be made for trucks and their use that are similar to those made about automobiles. In the U.S. the diffusion process began in the middle 1930s and ran for about four decades. The process began later and ran faster elsewhere.

The Lean Machine is a new vehicle, the notionthat it will take time to learn what it should be, how it should be used, and infrastructure needs may apply. But although learning may be needed, it should occur fairly rapidly because of the previous experiences of users and organizations.

We believe that there will be needs for road infrastructure changes, and they take time. The manufacturer will need time to change the vehicle as needs for changes emerge. Changes in regulatory areas may also take time.

Some families or fleet owners may purchase or rent Lean Machines, in addition to the vehicles they now own and operate. Others may replace conventional vehicles, just as the conventional automobile displaced wagons, buggies, interurbans, and much urban transit. We would expect that most households would retain a conventional vehicle. Some fleet operators might transition almost entirely to Lean Machines, other operators might not find the vehicle suitable. However the turnover works, the replaced vehicles would move elsewhere as used cars, and the turnover of the total fleet would be slowed. (Figure 5) Motor vehicle survival probabilities suggest that twenty years will be required for the near-full displacement of conventional vehicles by Lean Machines.

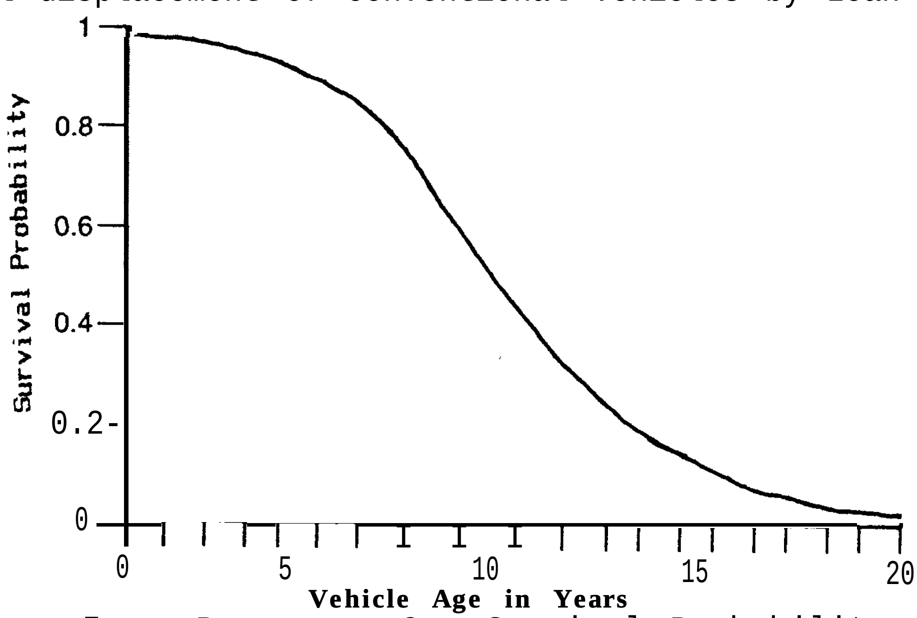


Figure 5. Passenger Car Survival Probability 1970-1982 (Data Source: Motor Vehicle Manufacturers Association of the United States).

It is quite possible that "displacement" describes only a small part of the diffusion process. The holding of a more diverse fleet of vehicles may well characterize future households.

How Large a Market? The discussion above describes some insights about the time it might take for the Lean Machine to be diffused in markets. If there were no barriers, 10 or 11 years might be a good guess. But considering the infrastructure and regulatory changes that may be required and the time they will take to implement and considering the life spans of existing vehicles, 20 years might be a better guess.

In addition to question of the time required, there is the question of, How big? How large will the market prove to be? Disregarding the growth of the vehicle population in California, an upper bound on the market might be reasoned in this way: There are about 19 million automobiles registered in California. (About 6 percent of these are in fleets. For this approximation, these will be ignored.) Households on average have about 2 vehicles each. If households trend to holdings of one conventional vehicle and one Lean Machine, twenty years after the vehicle enters the market there will be about 9.5 million Lean Machines in California. If this approximation considered small trucks used in an automobile fashion, the growth of population and the vehicle fleet, and the purchase of Lean Machines in multiples by households (the average number of vehicles held by households is increasing), then the upper bound approximation would be somewhat larger. (Note that this is a size of vehicle population measure, sales over the period would be larger.)

Except as a mental exercise, an estimate such as that just made has no value. Critical decisions about placing the vehicle in markets require more than a guess.

The luxury of waiting until market penetration is well along before estimating how market penetration will unfold is not available in the Lean Machine case.

> The vehicle manufacturer will not refine the vehicle and make it available in markets unless market estimates support feasible business plans.
>
> Other parties concerned will not undertake actions supportive of vehicle marketing and use unless signals about the market are supportive of their interests.

And the situation is even more complicated, for the decisions are interactive. No feasible business plan for the manufacturer is likely to emerge without supportive action by other actors, and other actors are not likely to take supportive actions unless the manufacturer successfully refines the vehicle in **ways** that improve marketability and are supportive of other actors' interests.

One way to ease this market information quandary is to use comparative information. That has to be done with caution, for the

Lean Machine is a radical departure from previously developed small vehicles and from conventional vehicles.

A number of analysis tools are available to deal with questions about known products. One might apply consumer choice modeling or simply use elasticity analysis to explore questions such as consumer choices for one vehicle or another as prices vary. Consumers have exercised such choices (revealed their preferences) in existing markets, and there are data on which to base analyses. Indeed, an extensive literature exists on how choices are affected by vehicle attributes such as size, fuel efficiency, and purchase cost.

Absent comparative vehicles, stated preference analyses will be necessary. Market research firms and similar organizations have considerable experience with these analyses. One approach is to use interaction in small groups or clinics. Individuals are presented with products or ideas and asked to judge them. Through interaction, a range of judgments may be identified, clarified, and refined through discussion. Another approach is to infer purchase behavior by asking individuals, usually using interviews and lists of questions, about purchasing patterns. Often consumers are classified in sets, some behave this way, some that way.

Issues: The Lean Machine market testing, product refinement, and market adoption processes are complex. Information is needed to reduce risk. But because the product is quite different from products now on the market, it will be very difficult to identify market segments and estimate market size until the product is placed on the market.

The extent to which Lean Machines might displace conventional vehicles or be purchased as an additional, special purpose vehicle is unknown. This issue is important to manufacturer, and it bears on broad benefit-cost analyses of congestion, energy, and air quality impacts.

Many of the decisions and actions that might detract from or enhance the product are not under the control of the vehicle manufacturer. Even if successful in the market, the rate of adoption-diffusion may be accelerated or decelerated by actions of many parties.

An Analysis Strategy

It will be useful in presenting the analysis strategy to indicate the classes of actors that will be involved, the stakeholders. Each of these can be expected to act on the basis of their interests. They will examine risks, benefits, and costs and can be expected to take supportive, do nothing, or detracting actions depending on the advantages to them.

Examples of Stakeholders:

Users: Users will not purchase the vehicle unless it is available in the market, of course. When available, they will purchase vehicles if they judge them to be to their advantage. They will consider price, safety, service advantages, and comfort and quality. However, there are more "ifs," three, for example are: If insurance is available, (for many) if financing is available, and if driver licensing requirements are not onerous.

Intermediate Actors: The ease of purchasing the vehicle and unfolding of service advantages will turn on the actions of many intermediate actors. We have in mind automobile dealers and repair shops; urban planners and designers; insurance, financing, and licensing organizations, as just mentioned; land and property developers; local political and community leaders; and employers.

Producers: The vehicle manufacturer is the obvious producer, but there are others who play production roles whose actions will bear on the Lean Vehicles' adoption and use. City and county public works and traffic agencies will be involved, as will the Caltrans.

There are many involved in what may be thought of as producing safety: the Department of Motor Vehicles and agencies involved with vehicle and highway safety standards, including traffic law enforcement agencies. We can also think of the production of clean air and fuel efficiency, and there are Federal and State agencies and private organizations concerned with these tasks.

Public Interest: Finally, there are actors concerned with overall public welfare. Such actors may operate in the political process or may be social critics or "opinion molders." Their role is to balance the interests of stakeholders against the overall public interest.

Benefit/Cost Analyses; Relations Among Actors: The list of stakeholders is preliminary and partial, and the divisions among classes of stakeholders is not crisp. For example, we certainly do not wish to imply that concern about the overall public interest is limited to one class of actors. But even with its faults, the identification of stakeholders indicates the diversity of benefit and cost considerations, as well as how stakeholders responses to benefits and costs will bear on the diffusion of the Lean Machine.

We desire benefit-cost information for stakeholders, of course. While obtaining that information will not be easy, the task is clear. The interpretation of the benefit-cost information in the context of the diffusion of the innovation is less clear. For one thing, all stakeholders do not play equal roles. For instance, if users do not judge high benefits relative to costs, then the diffusion will be slow if it occurs at all, regardless of calculations by others. More generally, we must be concerned about the intensity of supporting or obstructing interests and their affects.

Benefit-Cost Dynamics: Benefit-cost analyses consider the temporal streams of benefits and costs and discount these over time. That procedure works very well in structured situations where actors have well defined decision criteria and good information. The Lean Machine situation is more complex. There is lack of information about the long term, and some actors, such as political actors, are not in situations where actions based on long term considerations are easily taken. Also, the Lean Machine and other novel vehicles may well change the structures of the production and use of transportation. Benefit-cost questions extend beyond streams of values from alternative actions to changes in the competitive situations and roles of stakeholders.

Work must be undertaken on situations and how they might shape the actions of stakeholders. Now, the best we can do provide some examples of possible complexities.

Consider the Federal Highway Administration (FHWA). Working with the states, one of its important historic roles has been the setting of standards for facilities, and that role continues. The FHWA places high value on unitary technology. For reasons of efficiency, assuring the quality of constructed facilities, safety, and bureaucratic simplicity in managing programs, it works with the states to assure, for example, that signs everywhere are the same and similar road designs are used for similar classes of routes. Implementation of the Lean Machine confronts that role and the value placed on it, for the Lean Machine may require a variety of site-specific and novel design changes. Such requirements may conflict with established standards, processes of decision making, and custom. We do not know if conflicts might develop and if actions or lack of actions might affect the diffusion of the Lean Machine.

Now consider a very hypothetical vehicle dealers' situation. The Lean Machine is placed on the market, and dealers would welcome the vehicle if they judged that the volume of sales would make it worthwhile. Their commitment to market the vehicle would involve vehicle inventory costs and costs to prepare for providing after-market services. Indeed, they might especially welcome the vehicle if they judged it would be a popular item with possibilities for short run high price mark ups.

But over the longer term, dealers might not be supportive of marketing. They might see the vehicle as a lower price item than conventional cars and as competing with conventional vehicles in markets. The success of the Lean Machine might negatively affect their long term profit outlook. So one can imagine that it would be in the interest of new vehicle dealers to oppose the marketing of the Lean Machine.

The role of dealers is important, they are stakeholders and must be players in the diffusion process. How should their unfavorable benefit-cost calculation be interpreted? We must consider the situation. The dealers are in a "no win" situation. The "not market" decision is not realistic for the individual dealer, for other dealers might market the vehicle and the dealer would lose profits. The dealers are in a lesser of two evils situation, the choice is between losing some or more profits. (The unfavorable benefit-cost calculation is hypothetical, of course.)

Many other situations can be imagined. One that might be important is where there is a mismatch between benefits and costs. A city building code manager, for example, might delay revising parking garage building codes to allow reconfiguring of parking spaces for Lean Machines until pressure for change is great. In turn, this might have adverse affects on the growth of the vehicle market. Here, there is a mismatch of benefits and costs. The costs of code revision fall on the code manager, benefits are elsewhere.

Proposed Analyses: Endless lists of stakeholders, results of benefit-cost calculations, and situations influencing behavior can be imagined, and more effort to structure the behaviors of stakeholders is certainly warranted. Yet without some experience, there is a real limit on how far mental exercises can go. For this reason, it is planned to begin to flesh out how the Lean Machine might fit in actual markets, that is, to pick out some study sites and begin to work with stakeholders.

Much of the conceptual background for the site investigations has been reviewed in this discussion. The work to be undertaken at sites dives roughly into two parts. It will be organized to:

Provide information useful to the manufacturer's decisions about vehicle refinement and the nature of markets.

Further define the stakeholders, their likely actions, and the ways their actions will interact with the diffusion process.

As this work at sites proceeds two off-site efforts will go forward. First, the manufacturer will be doing engineering and design work on the vehicle and investigating the viability of the business decision to place the vehicle in production. Second, the on-site findings will be interpreted for agency programs and policies and public actions in regulatory, liability, and, possibly, fiscal or other incentive spheres.

How Fast: How Large: Previous discussion pointed out that the diffusion of an innovation or the adoption of a product tends to follow an S-shaped curve. Such a curve will be in mind as the site work goes forward. First, one of the objectives of the work is to improve approximations of the curve in the Lean Machine case. The questions of how large the market might be and how rapidly it can be served are central to stakeholders' decisions and to public policy generally.

Second, the curve will serve as a heuristic for organizing the on- and off-site studies. To begin, times to saturation will be considered, times ranging from 10 to 20 years; the size of the market at saturation will range from 10 million downward. Cases or scenarios will be investigated that range across short to longer time periods and small to larger markets. Of course, work will focus on the more likely cases as estimates of the size of market and the time to saturation begin to harden.

We expect that this consideration of cases will highlight ranges of benefits and costs, their timing, and their incidence. We also expect that it will highlight critical decisions and the lead times for decisions and implementation of the results of decisions. Long lead times for decisions and their implementation may well control the speed of the vehicle adoption and use process. With respect to benefits and costs, we may well find mismatches of benefits and costs. For example, there may well be large social gains that are not well reflected as benefits to critical stakeholders.

Such findings will assist in identifying, clarifying, and finding paths through to the maze to be traversed to:

1. Estimate the potential California market for the Lean Machine,
2. Identify the actions required by the manufacturer, agencies, and individuals if that market is to be served, and
3. Estimate whether the adoption of the Lean Machine in California markets would contribute to improving mobility and managing congestion, energy, and air pollution problems.

3. PARKING THE LEAN MACHINE

Abstract

The cost savings from the small parking spaces required by the Lean Machine depend on the type of parking facility, surface lot or structure, and whether existing spaces are restriped, all or part of an existing facility is reconfigured, or a new facility constructed. Depending on the situation, daily savings might range from $3.20 to $4.80. There would be no savings, of course, if there is a more than ample supply of parking spaces.

The Lean Machine is smaller than conventional automobiles so its use would ease parking problems where space is in short supply and/or is expensive. Without restriping stalls, two vehicles would fit in a space used by conventional vehicles. If part of a parking area was restriped or a special lot designed, 3.5 to 4 Lean Machines could be accommodated in the area used by a conventional vehicle.

How much money would be saved? The annual expense for parking a conventional automobile is (land cost not included):

Surface lot:	$275
Above ground structure:	$1,085
Below ground structure:	$1,600

Lean Machine parking savings compared to parking for conventional size automobiles are:

Surface Lot

Lean Machines parked in existing spaces:	$140
Parked in restriped lot:	$195
In lot designed for Lean Machines:	$205

Above Ground Structure

Lean Machines parked in existing spaces:	$540
Parked in restriped lot:	$775
In lot designed for Lean Machines:	$815

Below Ground Structure

Lean Machines parked in existing spaces:	$800
Parked in restriped lot:	$1,145
In lot designed for Lean Machines:	$1,200

These are comparisons of annual costs savings. For example, it costs about $1,600 per year to provide a below ground parking space for a conventional automobile. If a below ground parking structure was configured for Lean Machines (mainly by repainting lanes and stalls), the savings would be $1,145 per Lean Machine per year. That calculation is simple, 3.5 Lean Machines could park in the area formerly used by a single conventional vehicle. The details of the cost comparisons are shown in Table 1.

Again, land costs are not included in the estimates, so the estimates of costs and cost savings are conservative.

Table 1. Cost Comparisons

	Cost Estimates per space ($)		
	Surface	Above Ground	Below Ground
Standard Space:			
Total development costs	1,500	7,500	11,200
Annual debt service (11%, 30 yrs.)	175	865	1,300
Annual operating costs	100	220	300
Total annual expense	275	1085	1,600
Daily expenses (250 days/yr.)	1.10	4.35	6.40
Lean Machines in Existing Spaces (2:1 Ratio)			
Development cost savings	750	3,750	5,600
Total annual savings	140	540	800
Daily savings (250 days/yr.)	.55	2.15	3.20
Lean Machines in Part of an Existing Lot (3.5:1 Ratio)			
Development costs savings	1,070	5,360	8,000
Total annual savings	195	775	1145
Daily savings (250 days/yr.)	.80	3.10	4.55
Lean Machines in Specially Designed Lot (4:1 Ratio)			
Development costs savings	1,125	5,630	8,400
Total annual savings	205	815	1,200
Daily savings	.85	3.25	4.80

The procedure followed in creating Table 1 was this. First, using information on parking lot design (discussed later), we examined how the Lean Machine would fit into spaces configured for conventional large and compact cars. Two Lean Machines could be parked in such spaces. We then considered taking an existing lot and reconfiguring a number of existing spaces: that is marking some spaces for Lean Machines, just as some lots now have spaces marked for compact cars. 3.5 Lean Machines could be accommodated in the space used for a conventional size automobile.

We then considered a lot designed for Lean Machines only. This increases the ratio to 4:1, because cross isles, entrances, exits, and ramps can be narrowed.

The calculation of costs assumed debt service at 11 percent over 30 years. Both development and annual operating costs were included, but land costs were not included.

Detailed designs of Lean Machine parking facilities have not been made: costs and cost savings would vary from situation to situation. Even so, our calculations appear to give a reasonable estimate of costs and savings.

Discussion

The discussion to follow will provide some comments on the incidence and amount of parking cost savings. It will then treat the design assumptions used to construct Table 1. It will also indicate that the estimates of cost savings are conservative.

Savings in Parking Costs, Who Gains? The overall savings in parking costs are real, for society would reduce the resources expended for providing additional parking facilities. But the savings are diffused among actors, and they may not play a role in motivating vehicle purchases.

There is a temporal pattern of vehicle use. Typically, vehicles are parked overnight at or near residences or in the facilities of fleet owners, home bases. They are then moved from their home bases to work, schools, shopping, or other places, often in a sequence or a chain of trips, before returning to their home bases. Because of the several locations of parking and conventions bearing on free, partially subsidized, or fully costed and priced parking and the diversity of parking situations and purposes, the incidence and amount of cost savings (or who gains and how much) is complex.

Case A: One extreme case is when the vehicle substitutes, say, for a compact car and is used exclusively for commuting. Parking is provided "free" to the owner in an apartment associated structure at the home base and in an employer's structure at work. Here the cost savings would be, say, about $1,000 dollars per year because there are savings at the work place and at the home base. Likely the employer would capture the savings at the work place and the apartment owner at the home base, although eventually competitive pressures might cause the apartment owner to pass all or part of the savings through to the vehicle owner. The existence of the savings assumes, of course, that the facility operators can avoid some of the costs of expanding supply.

Case B: If the vehicle owner paid to park at the home base and at work and if parking charges were based on the costs of providing the facilities, then the vehicle owner would capture the savings.

Case C: Another extreme case is when there is ample parking at the home base and at the work place, say, on streets. Here there would be no costs savings to the owner or to the space provider.

Case D: Most cases would not be extreme ones. At some trip ends the vehicle owner pays full costs, sometimes "free" parking is supplied. Such a mixture might occur when travel is from home to work, to shop, to a movie, and then to home. Here there is a mixture of the incidence of savings and amounts of savings. In a shopping center, for instance, a parking space would be used several times during the day. While the facility provider would incur cost savings, only a part of those would be associated with a particular vehicle.

This discussion of cases does not begin to exhaust the possibilities. However, they do illustrate the diversity of situations and they point to many situations where parking cost savings would not play an important role in motivating vehicle purchases. Now, we can think of only two cases where purchases might be motivated. One is when the owner pays the full costs of parking at all places where the vehicle is parked. Another is when a facility provider, say, an employer, might subsidize the purchase of vehicles by employees in order to avoid expanding facilities or to limit the size and cost of new facilities.

Overall Parking Costs Savings: While there is no doubt that society would benefit if the land resources devoted to parking are reduced, custom for the provision of parking spaces and the pattern of existing facilities say that benefits would start out small and unfold over a long period of time.

The overall savings in parking costs in a market, say, a city, would depend on Lean Machine market penetration, its use, and the supply of parking spaces. By and large, there is ample room in cities for parking. As a matter of custom, parking spaces are made available by building roads of ample width and by allowing for parking in the design of residential and activity centers. Even so, parking problems are recognized because the demand for parking space doesn't match the availability of space. Also by and large, land values are low enough that many parking spaces are provided free to the user as a matter of custom. It's where land value is high and where demand for parking is great that multi level parking structures and parking charges are found.

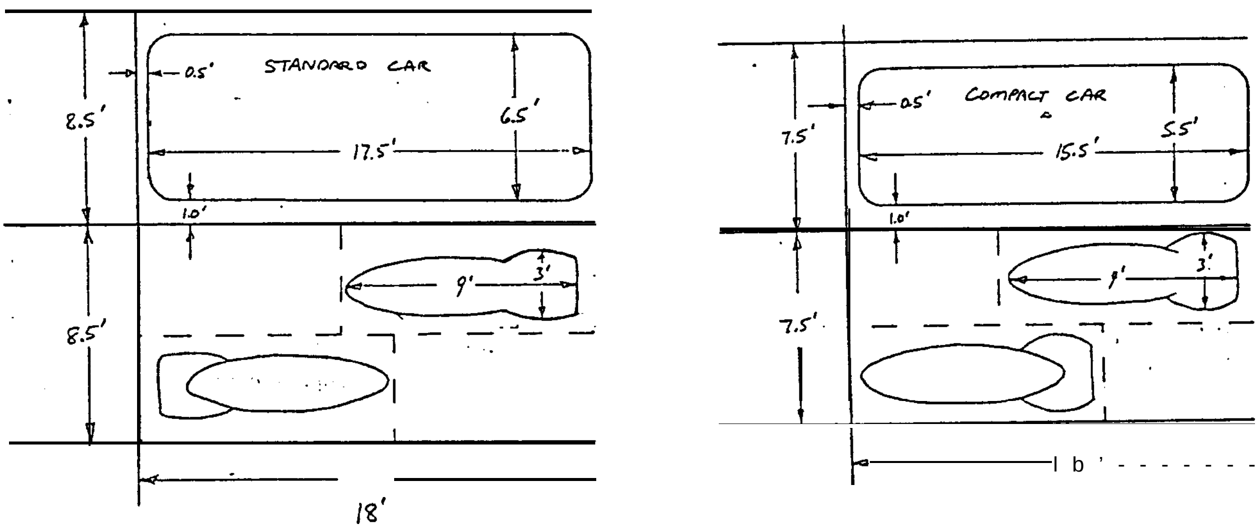
Considering the present situation, first savings would follow from the avoided costs of enlarging multilevel structures, savings dependent on the trip patterns of Lean Machine users, urban land values, and the dynamics of change in urban activity patterns.

These savings could well be small, with larger savings postponed until and if the presence of a large number of Lean Machine users affects the design of new facilities or the rebuilding of old ones.

Design Considerations

Fitting the Lean Machine into Existing Parking Spaces: As the percentage of half width, Lean Machine, or commuter cars in the vehicle population grows, managers may begin to increase the capacity of parking facilities by directing the vehicles to spaces previously used by conventional vehicles. Vehicle measurements bearing on the way spaces would accommodate Lean Machines are as follows.

Standard parking space width	= 8.5 ft
Standard vehicle width	= 6.5
Lateral clearance (8.5 - 6.5)	= 2.0
Compact parking space width	= 7.5
Compact vehicle width	= 5.5
Lateral clearance (7.5 - 5.5)	= 2.0
Lean Machine width	= 3.0
Lean Machine lateral clearance	= 2.0



Standard Spaces — Compact Spaces

Figure 1. The Lean Machine in Existing Parking Spaces.

Using these measurements, Lean Machines might be parked as shown in Figure 1. They fit two to a space. The Lean Machines are shown as staggered in standard and compact spaces. Staggering provides for easy vehicle entrance and egress by the user, which would be tight without staggering (depending on door designs, of course). Alternating head in and head out parking would also simplify entrance and egress.

Lean Machines in Redesigned Portion of an Existing Lot or in a Specially Designed Lot: If the percentage of Lean Machines in the vehicle fleet permits, parking managers might consider rearrangement or redesign of a portion of an existing lot or structure. They might consider constructing a specially designed lot or structure. Data bearing on these considerations are as follows:

Total area required for a standard space (with 62 ft isle width) = .5(8.5 ft x 62 ft) = 264 ft^2
Total area required for compact space (48 ft isle width) = .5(7.5 ft x 48 ft) = 180
Lean Machine space width = 5 ft (includes 2 ft lateral clearance); estimated isle width = 30 ft (depends on turning radius and staggering); area required for Lean Machine .5(5 ft x 30 ft) = 75

Comparing the areas required, we have:

Area ratio of standard vehicle to Lean Machine = 3.5
Area ratio of compact vehicle to Lean Machine = 2.4

These calculations consider parking stalls and adjoining turning and access isles. Parking facilities also require area for cross isles, up and down ramps in structures, entrances, and exits. This additional area adds 11 and 21 percent to the area required for each compact and standard space, respectively. Because of the turning ability of Lean Machines, we assume that a facility specially designed for Lean Machines would have only 7 percent additional area. This is a rough estimate, but it seems reasonable, because the percent additional area decreases as the size and turning radius of the vehicle decreases.

Incorporating additional area estimates, 4 Lean Machines could be parked in the area needed for a standard car, and 2.5 Lean Machines could be parked in the area required for a compact car.

Figure 2 shows how stalls and isles might be marked for Lean Machines, either in a lot remarked for Lean Machines or in a specially designed lot. This design takes advantage of the narrow nose of the Lean Machine by offsetting opposing spaces.

Conservative Estimates: The estimates made above are conservative. The dimensions for standard and compact parking spaces and for the areas required per stall are close to the minimum recommended values. Such minimum values are recommended for low-turnover, high-familiarity facilities such as those serving regular commuters. Many facilities are sized more generously and/or designed less efficiently. Also, most existing facilities (especially structures) contain unusable areas that could accommodate Lean Machines. Thus, the parking cost savings for Lean Machines could be even greater.

Finally, extensive use of Lean Machines and facilities for them would permit facilities more compact than existing facilities. Such compact structures might reduce walking requirements and/or be placed in small spaces convenient to destinations and provide quality of service advantages to users.

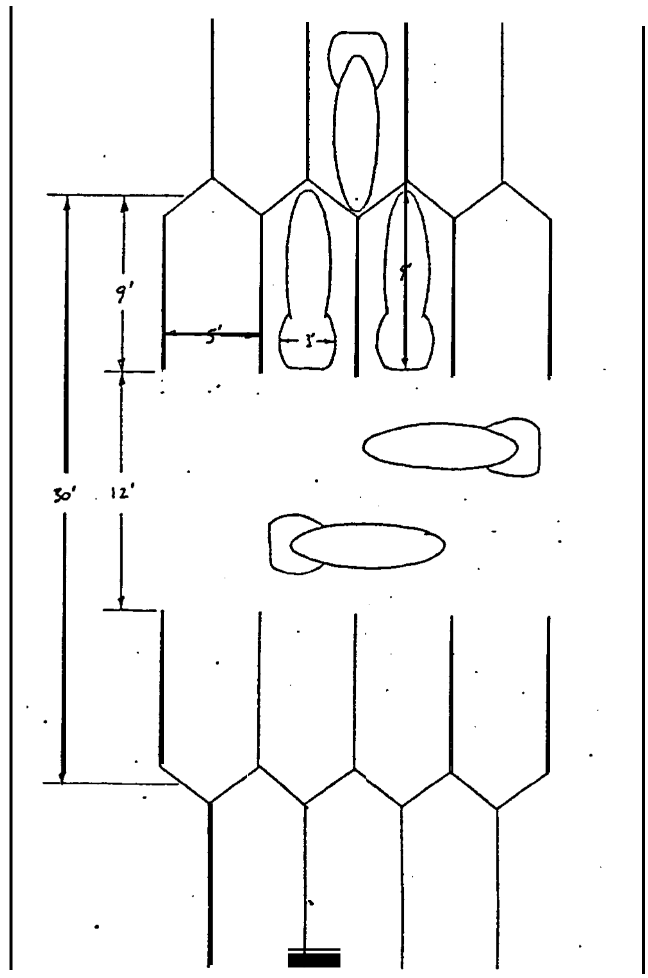


Figure 2. A Lean Machine Parking Lot.

Data Sources:

1. Standard and compact parking space and vehicle widths are from Shopping Center Parking: The Influence of Changing Car Sizes. (New York: International Council of Shopping Centers, 1984, pp. 8-9; 16-18.)

2. Total area requirements and unusable space estimates for standard and compact vehicles are from Vukan R. Vuchic's Urban Public Transportation: Systems and Technology. (Englewood Cliffs, NJ: Prentice-Hall, 1981, p 433.)

3. Cost estimates for standard spaces are from Edward M. Whitlock's Parking for Institutions and Special Events. (Westport, CT: Eno Foundation, 1982, p. 21.)

4. An additional reference consulted was A. P. Chrest, M. S. Smith, and S. Bhuyan's Parking Structures: Planning, Design, Construction, and Repair. (New York, NY: Van Nostrand Reinhold, 1989.)

4. COSTS OF OWNING AND OPERATING THE LEAN MACHINE

Abstract

Comparisons are made between the Lean Machine and larger vehicles. The comparisons indicate that Lean Machine costs might be from one half to one third lower than the costs of conventional vehicles. However, cost savings depend on how the Lean Machine is used.

Compared to standard size automobiles, the Lean Machine will be very fuel efficient. With fuel selling for, say, $1.20 per gallon and the Lean Machine achieving 130 to 150 mph, then gas and oil costs would run about one cent per mile or less. That's from one-fourth to one-seventh the costs for standard automobiles. Many persons judge costs in that way; they think of out-of-pocket costs.

Fully considered, vehicle ownership and operating costs are much higher than out-of-pocket operating costs. Here are some cost comparisons:

	Ownership and Operating Cost (cents per mile)
Large Car	27.5
Compact Car	20.8
Lean Machine	14.0

Fully considered, ownership and operating costs run 50 to 70 percent of the costs of standard automobiles. That's because maintenance, accessories, tires, and insurance costs for the Lean Machine may not be much lower than for standard automobiles.

Discussion: Estimates of the costs of vehicle ownership and operations are published from time to time by Hertz, the American Automobile Association (AAA) and the Federal Highway Administration (FHWA), and estimates vary depending on costing procedures. To make comparisons, we used the FHWA procedure and made some assumptions about Lean Machine costs. The full comparisons are summarized in Table 1, and Table 2 shows the details of the costs calculations for the Lean Machine.

We have not compared our estimates using FHWA costing procedures with those that would be obtained by using Hertz, AAA, or other procedures. The procedure we used is conservative. We suspect that actual costs for all vehicles are somewhat higher than we have estimated and that, compared to other vehicles, the estimate of Lean Machine costs are relatively higher than would be experienced.

Table 1. Automobile Ownership an, Operating Costs (cents per mile)

Size	Depreciation	MAT**	Fuel and Oil	Insurance	Total
Passenger Van	10.7	6.9	9.1	8.9	35.6
Large Car	9.6	6.0	7.0	4.9	27.5
Intermediate Car	8.6	5.2	5.7	5.6	25.1
Compact Car	7.3	4.6	4.6	4.3	20.8
Subcompact Car	5.9	5.1	4.4	4.9	20.3
Lean Machine	3.3	4.9	.9	4.9	14.0

*Sales and registration taxes, parking, tolls, and finance charges not included.
**Maintenance, Accessories, and Tires.

Source: Federal Highway Administration, **Costs of Owning and Operating Automobiles and Vans (Washington,** D.C., 1984, p. 2) and the calculations shown in Table 2. For a comparison of FHWA, Hertz, and AAA estimates see M. C. Holcomb, S. D. Floyd, and S. L. Cagle's **Transportation Energy Data Book, Edition 9** (Oak Ridge National Laboratory, 1987, p. l-45).

Table 2. Cost Calculations for the Lean Machine*

Cost Category	Total Costs $	Cents per Mile
Maintenance and Repairs (assumed same as subcompact)	5,380	4.5
Replacement Tires (assumed 75 percent of subcompact)	360	.3
Accessories, Floor Mats, Seat Covers, etc. (assumed 50 percent of subcompact)	100	.1
Fuel (120,000 miles, $1.164/ gallon, 150 mpg)	930	.8
Oil (assumed same as compact)	150	.1
Insurance (assumed same as compact)	5,930	4.9
Depreciation (100 percent of original value over 12 years)	4,000	3.3
TOTAL	16,850	14.0

*FHWA basis. 12 year vehicle life, 120,000 total miles. Finance charges, sales tax and registration fees not included.

Ownership and operating costs are only part of the cost story. Governments provide highway facilities, and not all costs **are covered by fuel taxes.** **Users** and others provide parking facilities. There are the social costs of accidents, which are greater than the costs of insurance, and there are the costs of driver training and enforcement of traffic rules. There are noise and air pollution costs.

Future work will seek to estimate the impact of Lean Machines on these types of costs. Reductions in facility and noise and air pollution costs are expected, of course.

The tables and the discussion above provide a "first cut" answer to cost comparison questions. Questions a deeper analysis might consider are introduced below.

Broad Questions: The question of broad social savings needs to be addressed. When environmental costs are considered, small vehicles such as the Lean Machine are expected to be rather benign compared to existing vehicles. They should generate much less noise and air pollution. Today, the exhaust is no longer the major noise source from automobiles--there is noise from the movement of mechanical parts, from the interaction of the tires with pavement, and from movement through the air. The smaller size of vehicles should dampen noise emissions from the first two sources, and aerodynamic configurations should sharply dampen noise generated by the movement of vehicles through the air. Assuming proper configuration of the propulsion system, the fuel efficiency of vehicles should translate to sharp reductions in air pollution.

Fuel efficiency also translates into reduced CO_2 emissions and the affect of burning fuel on the "greenhouse" effect. It translates into easing petroleum dependency issues.

In the long run, the availability and use of small vehicles might allow for cost reducing innovations in the uses of land.

There are some complex questions about users' savings. The FHWA costing procedure assumes that a vehicle is driven 10,000 miles per year. Suppose the Lean Machine serves as a market niche vehicle used just for commuting. If that were the case, it might be driven fewer miles, say, 5,000 miles per year. Fixed costs would be spread over a smaller number of miles per year than is the case for regular vehicles, and per mile cost would increase.

On the other hand, perhaps drivers with a larger than average commute would tend to invest in vehicle more than drivers with shorter commutes. If this were the case, the estimate if 10,000 miles per year might be appropriate. Also, the vehicle might be used for many purposes, and this would increase the annual mileage.

It is known that new cars tend to be driven more miles per year than old ones. Old cars are often assigned to "short trip, park all day" roles--the drive-to-school car or the vehicle parked in transit station parking lots. These examples illustrate some of the patterns of vehicle holdings and uses by households, and little can be said now about how the Lean Machine would fit into or change these patterns. There are cost implications, but they are not known.

It is entirely possible that the availability of specialty vehicles would increase the number of vehicles owned by individual households. If mobility is improved, households will purchase the tools to obtain it. So considering all vehicles, the household's overall cost of transportation may increase.

With respect to facility cost questions, cost reductions are expected. If sufficient numbers of small vehicles appear in traffic streams, more efficient use of existing facilities may be made. The expansion of facilities to accommodate the vehicles should not be as costly as expanding facilities for conventional vehicles.

However, the fuel efficiency of the Lean Machine vehicle implies sharply reduced fuel tax payments. As a result, there might be increases in costs not covered by fuel taxes for facility providers.

5. IMPACT OF THE LEAN MACHINE ON HIGHWAY CAPACITY

Abstract

The impact of the Lean Machine on road capacity depends on the facility type, the quantity of road use, and the number of Lean Machines in the traffic stream. The discussion in this Section identifies some situations and the impact of the Lean Machine in those situations. There is a general discussion of congestion costs and their incidence.

The Lean Machine is a small vehicle; its footprint is about 3 feet wide and 9 feet long. It is **also** highly maneuverable and has high performance. How do those attributes affect congestion?

Congestion costs in major California cities range from about $300 per year per vehicle in Sacramento to $1,040 in Los Angeles. Assuming that the Lean Machine finds a sizable market, in what situations might these costs be reduced? Our impressions are these: The Lean Machine will have little impact on traffic flow in situations where traffic is flowing freely and/or congestion is moderate. In congested situations, however, impacts might be quite significant. With respect to infrastructure changes to aid the use of the Lean Machine, our impression is that relatively simple, situation specific changes will aid the introduction of the vehicle, and those and more extensive improvements may play an important role in motivating Lean Machine ownership and use.

The subject is rather complex because impacts on congestion will depend on factors such as:

- The situation: road type, amount of traffic, turning maneuvers and presence or absence of turning lanes, etc.
- The number of Lean Machines in the traffic stream.
- Actions taken to accommodate the Lean Machine on facilities.
- How demands for road space might increase and partially consume freed up capacity as congestion relief is obtained.

The discussion to follow will address only the first three of these factors. It will identify some typical situations. Within each situation, it will consider increasing impacts as the population of Lean Machines in the traffic stream increases and as actions are taken to accommodate the vehicles. Although the situations to be discussed could be treated in an analytic style,[3]

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[3]Technical work has been initiated on the topics to be discussed. Preliminary results are available in William L. Garrison and Mark E. Pitstick, "Lean Vehicles: Strategies for

this is not a technical discussion: the properties of traffic flow and congestion will be considered in only a general way and they will be considered in everyday rather than technical language.

The second section of the discussion will provide remarks on estimates of congestion cost, road infrastructure changes, and whether the benefits of congestion relief will motivate the purchase and use of the Lean Machine.

Situations

Freeways and Expressways: In situations where traffic is flowing freely or where there is modest congestion (say, traffic is moving at 40 to 50 mph and passing opportunities are only moderately limited), the congestion impact of the Lean Machine would likely be small. The small footprint of the Lean Machine does require less space than conventional vehicles, but that is of little matter because the headways of vehicles would be about the same regardless of the type of vehicle, and headway requirements dominate the need for road space (Figure 1).

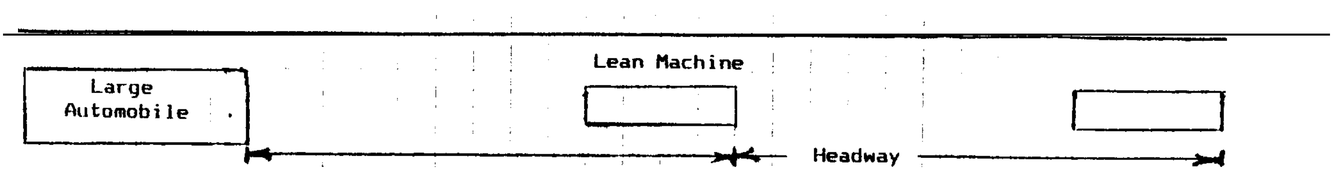

Figure 1. Single Freeway Lane; Modest Congestion. The percentage decrease in road space requirements due to the shorter length of the Lean Machine is very small.

Under free flow conditions, there would be only a 4 percent decrease in freeway space requirements, even if all vehicles were Lean Machines (Table 1). Decreases in space requirements emerge as the amount of traffic increases. If the traffic was composed of one third Lean Machines, in peak hour, heavy traffic conditions space requirements would be reduced by 5 to 16 percent.

The presumption in Table 1 is that Lean Machines are not being driven side-by-side in a single lane. They could, of course, for the typical lane width provides ample space for side-by-side driving. The opportunity for side-by-side driving is there, and it

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Introduction Emphasizing Adjustments to Parking and Road Facilities," SAE paper 901484 (1990) I forthcoming in SAE publication SP-833 (1990).

would begin to be taken up as the number of Lean Machines in the traffic stream increases. If, say, one third of the vehicles were Lean Machines, then a sizable portion of these might be driven side-by-side. This would further increase the number of vehicles a mile of lane could accommodate and the throughput by, say, one-eighth to one-fifth.

Table 1. Percent Decrease in Freeway Space Requirements

Traffic Condition	100 Percent Lean Machines	33 Percent
Free Flow, 1,000 Vehicles Per Lane Per Hour	4.2	1.4
At Capacity, 2,000 Vehicles Per Lane Per Hour	14.0	4.6
Bumper to Bumper	44.0	16.0

As the number of vehicles in a lane mile increases traffic slows, and stop and go and queueing situations occur. Here, headways are smaller and the small footprint of the Lean Machine would begin to make a difference in the number of vehicles that could be accommodated in a given area. Again, the impact depends on the number of Lean Machine in the traffic stream, and major additional impacts could be derived from side-by-side driving (Figure 2).

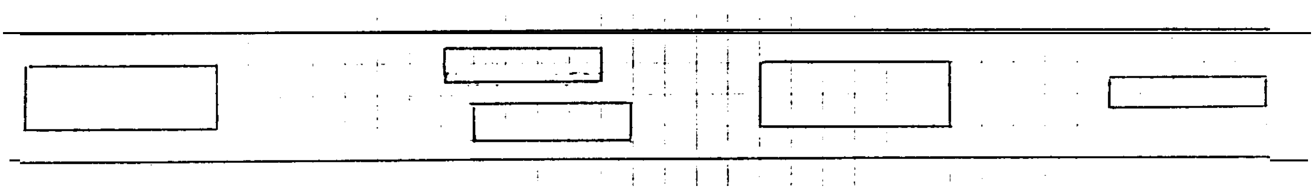

Figure 2. Single Freeway Lane; Moderate Congestion. Two Lean Machines side-by-side.

The increase in capacity and reduced congestion as the number of Lean Machines and the amount of side-by-side driving increase can not be verified absent experience with the vehicles. The amount of side-by-side driving would depend on the willingness of drivers to drive side-by-side in a single lane. That certainly depends on traffic velocity, and the congestion relief would be greater the lower the traffic velocity because of increased side-by-side driving.

Other possibilities may be considered. If traffic is stopped or moving very slowly, Lean Machines could pass conventional size automobiles as motorcycles do. In effect, the Lean Machines move out of the congested stream, and if the number of Lean Machines was great enough, considerable congestion relief would be achieved (Figure 3).

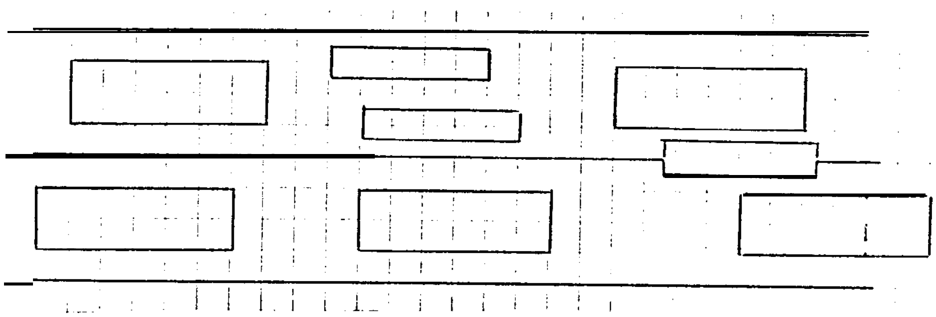

Figure 3. Two Freeway Lanes; Heavy Congestion. Two Lean Machines side-by-side. One Lean Machine passing other vehicles.

The opportunity for congestion relief could be enhanced by highway and traffic control agencies. Simple actions such as painting lines in the centers of existing lanes or placing signs encouraging side-by-side driving or passing might be helpful. There might be situations where the use of highway shoulders by Lean Machines is practicable. Inexpensive, lightweight pavements for Lean Machine use might be placed in some unused right of way. Car pool lanes could be made available to Lean Machines.

Some of these actions would have to be thought through carefully. Signs or additional lane striping, for example, might be confusing to drivers at times when traffic is not congested.

Arterials: Modern California arterial highways are of high type design and many traffic signals are timed so that platoons of traffic move at facility design velocity through green signal after green signal. Considering this type of traffic movement, the impacts of increasing numbers of Lean Machines in the traffic stream would be similar to those previously described. However, because of lower velocities on arterials, opportunities for side-by-side driving would be increased. Also, the size and performance of the Lean Machine might contribute to more effective packing of vehicles in platoons.

In addition, there should be favorable impacts when there are turning movements at intersecting streets. Increased numbers of vehicles could be accommodated in left turning lanes, and Lean Machines would maneuver through turns quickly. Slowing for right turns would be reduced, although this might not be important where right turn lanes exist. Where there is entrance and egress at driveways, the maneuverability of Lean Machines should reduce traffic conflicts.

Painting lanes and other actions such as those already noted would enhance congestion reduction. In addition, a number of other opportunities may open as the number of Lean Machines in the traffic stream increases. For instance, light weight, simple flyovers for left turns might be introduced (Figure 4). These might be preconstructed off site and erected quickly. Their narrow width might enable them to be fitted into existing street spaces. In addition, some rights of way not now developed for traffic might be usable: for example, public utility or abandoned railroad rights of way.

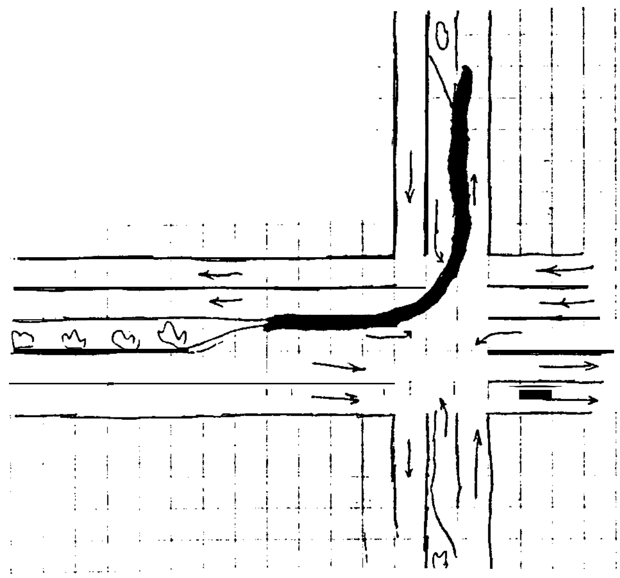

Figure 4. Intersection of an East-West Four Lane Arterial Highway and a North-South Local Street. Left turn lanes are provided for conventional vehicles. Additional capacity for eastbound to northbound turns is provided by a flyover for Lean Machines.

Access Points: Traffic is often congested at freeway or expressway access ramps, at entrances to parking lots, and at other places where there are transitions from one facility to another. At such points, the Lean Machine may contribute to congestion reduction in the ways described before.

If the number of Lean Machines in the traffic stream warrants action, there may be opportunities to enhance congestion reductions in addition to the opportunities already mentioned. In particular, investments might be made in specially configured access (and egress) ramps (Figure 5). Because of the small size and maneuverability of the Lean Machine, these might be relatively inexpensive; they might use space that was otherwise unusable.

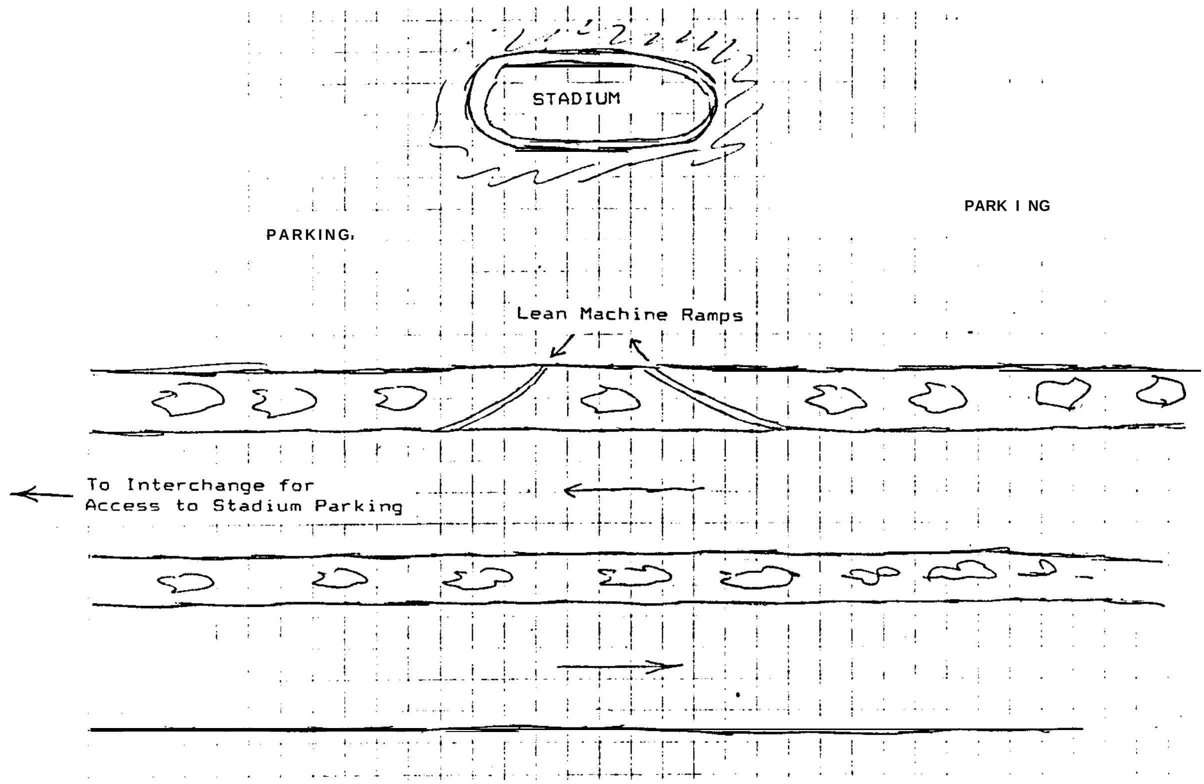

Figure 5. East-West Freeway Adjacent to a Stadium. Lean Machine on and off ramps provide additional capacity for eastbound entrance to parking and eastbound egress. Such ramps might be provided by adjoining property owners.

Interactive Considerations

This section will contain remarks on the cost of congestion, the incidence of the benefits of congestion relief, and the nature of road infrastructure improvements.

Benefits of Congestion Relief: J. W. Hanks, Jr. and T. J. Lomax's Roadway Congestion in Major Urban Areas (Texas Transportation Institute, October 1989, FHWA/TX-90-1131-2) provides comparisons of congestion costs in 39 urban areas for the year 1987. The researchers calculated vehicle delay and translated delay to the cost to individuals using $8.50 per hour. Traveling in congested situations increases fuel consumption, and estimates of increased fuel cost were made. The researchers noted that vehicle operators in congested areas pay more for insurance than operators in less congested areas, and an insurance increment to vehicle operating cost was calculated.

To estimate recurring congestion, the researchers examined freeways/expressways operating at greater than 15,000 average daily traffic (ADT) per lane and arterial streets operating at greater than 5,750 ADT. It was assumed that 45 percent of the ADT occurred during peak periods. Delay due to incidents (accidents) was also estimated. Results for four California cities are shown in Table 2.

Table 2. Congestion Cost in Four California Cities
(1987, Millions of Dollars)

Cost Component	Los Angeles	Sacramento	San Diego	SF-Oakland
Recurring Delay	2,510	130	250	770
Incident Delay	2,900	120	190	980
Recurring Fuel	400	20	40	130
Incident Fuel	460	20	30	160
Insurance	1,660	80	60	350
TOTAL	7,940	360	580	2,370
Per Capita and Per Vehicle (Dollars)				
Per Capita	730	300	280	670
Per Vehicle	1,040	377*	440	805

*Recalculated. Source document entry is incorrect.

It is tempting, but would be incorrect, to use these data and the information on road space requirements, such as that provided by Table 1 and the discussion of side by side driving, to calculate estimates of reductions in congestion costs as the Lean Machine is introduced into traffic. Such estimates would be incorrect for the following reasons.

> First, as vehicles enter the traffic stream, delay in the traffic stream increases in a sharply nonlinear fashion. The Lean Machine has the effect of reducing the number of standard vehicles, and a small percentage of Lean Machines might provide considerable delay reduction.
>
> Second, delays are situation specific. There are recurring delays and incident delays. There are route and time considerations, and these must be related to the use of the Lean Machine.
>
> Finally, as we have stressed, changes in road infrastructure mightmultiplythe delay reduction impacts of the Lean Machine.

Estimates incorporating these considerations have not been made; they are the subject of ongoing work. Now we have only impressions, and, as mentioned, we judge that congestion cost reductions may be "quite significant."

Incidence of the Benefits of Congestion Relief: The discussion turns now to the impact of congestion cost reduction on the Lean Machine operator and others in order to point out a mismatch.

The driver entering a congested traffic stream incurs delays, the negative benefits of congestion. In addition, the driver imposes additional delay on following vehicles. In congested situations the delay created by the addition of a vehicle to the traffic stream may be much larger than the delay experienced by the driver of the added vehicle. There is a mismatch between cost incurred and cost occasioned. This is the rational of congestion pricing: drivers should be aware of the full costs of their actions.

Suppose a driver elects to use a Lean Machine rather than a conventional vehicle. The use of the Lean Machine provides congestion relief for other drivers, and that relief may be much greater than the relief obtained by the Lean Machine driver. Here, there is a mismatch between the actor creating congestion relief and the incidence of the relief. Congestion pricing with prices for Lean Machines lower than prices for ordinary vehicles would temper the mismatch.

Congestion pricing is of great interest to policy makers. Indeed, it may be imposed in partial ways in some situations, such as on toll bridges and roads. If this were the case, it might motivate the purchase and use of Lean Machines on such facilities. However, most critics doubt the political feasibility of the introduction of congestion pricing. Absent congestion pricing, to what extent will the benefits of congestion relief motivate the purchase of Lean Machines?

There seem to be two considerations. First, although the operator is not capturing all of the congestion relief benefits, the congestion relief obtained by the Lean Machine operator may be sizable and motivate purchase. As pointed out, the Lean Machine could pass other vehicles in very congested traffic and ease its operator's travel around incidents or through traffic choke points generating recurring delay. In addition, if the road infrastructure is improved to accommodate Lean Machines, then in some situations the reduction in the Lean Machine driver's delay might also motivate purchase and use of the Lean Machine.

Further, with respect to road infrastructure improvements, the full analysis of their benefits and costs should consider all the delay reductions they achieve. Here, the calculation of benefits extends to the traffic stream rather than just to Lean Machine operators' benefits. Use of facilities where investments were made using the total benefits criterion would return some of the stream of total benefits to Lean Machine owners and operators.

Road Infrastructure Improvements: As just stated, road improvements to accommodate Lean Machines may be warranted by the overall consideration of congestion relief; they may play an important role in individuals' decisions to own and operate vehicles. What types of improvements might be made? How might they be sequenced.

Several types of improvements were noted in earlier parts of this discussion: for instance, flyovers, lanes on unused rights of way, and lines in the middle of freeway lanes. There are many other types of improvements. For instance, if the number of Lean Machines in the traffic stream warranted, some facilities might be double decked with simple, lightweight structures for exclusive Lean Machine use. Considerable revamping of stretches of freeways and arterial roads (mainly by adjusting lane widths) might provide extensive routes for Lean Machine use.

We have only begun to examine some of the road improvement options, but have already reached the conclusion mentioned in the introduction to this document. It appears that many of the road improvements helpful to the Lean Machine can be first implemented in simple, site specific ways. In some cases, the improvements might be motivated and funded by abutting property owners. The menu of improvements is such that additional, more extensive improvements can be added in incremental ways if desired. These are desirable attributes of an investment program: improvements may be matched to growth in use of the Lean Machine and the appearance of benefits justifying those improvements.