Planning a New Vehicle and Roadway System for Developing Countries

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Mechanized vehicles are needed in developing countries, because even though mass transit may be the most important means of transportation, mass transit cannot reach everywhere. The automobile is not affordable—the average price of an automobile is 30 times and its annual operating cost is 4 times the annual average wage of the workers in Shanghai, China. A new vehicle should be developed. Using socioeconomic data from San Francisco and Shanghai, a new vehicle was planned with the following attributes: a top speed of 22 mph would provide a similar capability for going to work, shopping, and visiting friends as the automobile does in San Francisco; a two-passenger vehicle with an optional two-seat compartment would satisfy most trip purposes; vehicle dimensions of 3.6 ft long, 3.0 ft wide, and 4.7 ft high would minimize investment and be technologically feasible to build. A price of $874 would be affordable to the general public. To produce such a vehicle at such a price is possible. The new vehicle, being small, cheap, requiring little space to park, can be specialized in neighborhood access and connection to mass transit. It enables mass transit to be specialized in line-haul services—concentrated on major routes with fewer stops. As a result, mass transit services would be more frequent and faster. A spoke and hub system could be developed. The spokes represent extensive local roads for the vehicle. The hubs are mass transit stations with frequent and fast buses or trains running through them. The vehicle together with mass transit would form an efficient transportation system.

The automobile is the most common vehicle in developed countries. Although there are automobiles in developing countries, they are for the rich and do not represent a viable means of transportation for the general public. To be a viable means of transportation, the use of the highway system also has to be considered. The highway system in the United States, which was developed decades ago, has reached maturity. It can be served as a maximum extent of development for future systems. To build a system similar to that of the United States would require huge investment that may not be affordable. A logical decision would be to develop mass transit. However, no matter how good mass transit might be, it cannot reach everywhere. A mechanized vehicle would still be desirable.

An appropriate vehicle and its roadway system can be explored. In order to illustrate, San Francisco and Shanghai, China, are used as example cases. In the following, what Shanghai would be like if it attained the level of automobilization as in San Francisco is described. Planning a new vehicle with respect to speed, size, power, weight, shape, and price is then discussed. Finally, the characteristics of a new vehicle and roadway system are sketched.

All data are assumed to be in base year 1987 unless stated otherwise.

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IF SHANGHAI ATTAINED COMPARABLE AUTOMOBILIZATION AS SAN FRANCISCO

What would Shanghai be like if it attained comparable automobilization as in San Francisco? The following sections describe this possibility in relation to vehicle, roadway, operating and maintenance requirements, and costs. Table 1 presents some of the data used to compare San Francisco and Shanghai.

Vehicle Requirement

In order to attain comparable automobilization, Shanghai would have similar automobile ownership as San Francisco (2.3 persons per vehicle). In Shanghai this rate would amount to 3,260,870 automobiles, representing a 12,300 percent increase from the present 26,236 automobiles (*7*). The average price of an automobile of $13,000 (*10*) in San Francisco would correspond to an expenditure of $42.1 billion in Shanghai.

Roadway Requirement

Because automobiles are parked most of the time, parking space is an important issue. San Francisco has 227,200 on-street parking spaces (*4*) that can hold 71 percent of its automobiles. To provide similar parking spaces, Shanghai would require 9,210 mi of roads (using 42 ft of curb per parking space, see Table 1). This amount represents a 1,070 percent increase from its present 786 mi of roads (*9*).

Capacity is another important roadway issue. Assuming all vehicles maintain a 2-sec headway, San Francisco's roadway capacity for different speeds would be as presented in Table 2. For instance, if the speed was 20 mph, the roadways of San Francisco would be able to accommodate 60 percent of its automobiles. To have similar capacity, Shanghai would require 9,080 mi of roads (assuming 2.4 lanes per road, as in San Francisco). This represents a 1,060 percent increase.

Table 3 presents the construction cost for new roads. Using $840,000 per lane-mi as the construction cost, the 1,070 percent increase in roadways would amount to $18.6 billion.

Operating and Maintenance Requirements

The national average operating cost for a compact car in 1984 was 17.3 cents/mi (*13*). The national average annual mileage per passenger vehicle was 9,625 mi in 1986 (*14*). Assuming

TABLE 1 DATA FOR SAN FRANCISCO AND SHANGHAI

	SAN FRANCISCO	SHANGHAI
POPULATION	742,700 (*1*)	7,500,000 (*6*)
AREA, SQ MILES	45 (*1*)	107 (*6*)
TOTAL NUMBER OF MOTOR VEHICLES	430,097 (*2*)	130,104 (*7*)
PASSENGER AUTOMOBILES	318,834	26,236
TRUCKS AND BUSES	70,087	66,728
MOTORCYCLES	17,400	18,110
OTHERS	23,776	19,030
NUMBER OF BICYCLES	NA	3,687,700 (*8*)
MILES OF ROADS	893 (*1*)	786 (*9*)
TOTAL ROADWAY AREAS, SQ MILES	7.6 (*3*)	5.0 (*9*)
ON-STREET PARKING		
NUMBER OF SPACES	227,200 (*4*)	NA
AVERAGE CURB LENGTH PER SPACE, FT.	42[a]	NA
LANE MILES	2,140 (*5*)	NA
NUMBER OF LANES PER ROAD	2.4 (*5*)	NA
POPULATION DENSITIES, PERSONS/SQ. MI.	16,500	70,400
AUTO OWNERSHIP, PERSONS PER AUTO	2.3	285.9

NA - Not available
a - (893 x 2)miles/227200

TABLE 2 SAN FRANCISCO'S ROADWAY CAPACITY

SPEED (MPH)	SPACING (FT)	% OF AUTOMOBILES ROADWAY COULD HOLD[a]
10	29	121%
20	59	60%
30	88	40%
40	117	30%
50	147	24%
60	176	20%

a - (2140 lane miles/spacing in feet)/(318834 automobiles)

TABLE 3 CONSTRUCTION COSTS FOR NEW ARTERIALS

LOCATION	POPULATION GROUPS: 500,000 - 1,000,000	POPULATION GROUPS: OVER 1,000,000
CBD	1.18	1.43
FRINGE	0.92	1.18
RESIDENTIAL	0.84	0.98

Notes: 1. Costs in million dollars per lane mile, including periodic resurfacing.
2. Costs projected from 1976 dollar value (*11*) to 1987 dollar value using composite construction cost indices of 58.9 and 115.6 for 1976 and 1987 respectively (*12*).

TABLE 4 SAN FRANCISCO'S MAINTENANCE EXPENDITURE FOR STREET AND ROAD PURPOSES (*15*)

FISCAL YEAR	MAINTENANCE EXPENDITURE[a] ($)
1985 - 86	14,050,339
1984 - 85	11,462,199
1983 - 84	9,156,522
1982 - 83	8,383,842
1981 - 82	8,394,919
1980 - 81	6,992,199

AVERAGE PER YEAR: $11,926,656 (1987 VALUE)[b]

a - Includes patching, overlay, scaling, street lights, traffic signals, and other street purposes maintenance.
b - By converting the expenditure of each year into the present worth in 1987, using an interest rate of 4% per year.

these figures were also true for San Francisco in 1987, the annual operating cost per vehicle would be $1,665. Table 4 presents the maintenance expenditure for street and road purposes in San Francisco (*15*). From 1981 to 1987, San Francisco spent $12 million (in 1987 dollars) per year to maintain its roadways. Shanghai would have to spend a similar amount or more.

Affordability

The average price of $13,000 and the average annual operating cost of $1,665 for an automobile were about 68 and 9 percent, respectively, of the per capita annual income of San Francisco (*16*). The average wage per worker in Shanghai was 437 U.S. dollars (*17,18*). Thus, the average price of an automobile was 30 times and its average annual operating cost was 4 times the average annual wage of the workers in Shanghai. Even though Shanghai's government would be willing to spend the $18.6 billion to build the roadways, the people would not be able to buy or operate automobiles. A new vehicle system should be developed.

PLANNING THE NEW VEHICLE

Because a developing country has limited resources, in planning a new vehicle the following objectives must be established:

- The vehicle must provide basic mobility needs,
- It must be affordable by the general public, and
- Although the vehicle needs roadways to function effectively, the investment in roadways should be minimized.

In the following paragraphs, some of the design parameters (speed, size, power, weight, shape, and price) are explored with respect to these objectives.

Vehicle Speed

Basic mobility needs include going to work, visiting friends, and shopping. The mean travel time to work for San Franciscans who live in and work within San Francisco was 24.4 min (*19*). Assuming an average distance of 5 mi (the north-south and east-west cross town distances in San Francisco are 8 and 7 mi, respectively), the average speed for going to work in San Francisco would be 12 mph. This value of 12 mph may serve as the desirable vehicle speed for going to work in Shanghai.

The ability to visit friends or to shop is in general directly proportional to the number of people that are reachable. The area covered by possible trips is

$$2DW + \pi W^2/2 \quad (1)$$

where

D = distance traveled by vehicle, and
W = walking distance (see Figure 1).

The number of people that can be reached is

$$(2DW + \pi W^2/2)P$$

or

$$[2V_vT_vV_wT_w + \pi(V_wT_w)^2/2]P \quad (2)$$

where

V_v = vehicle speed,
T_v = travel time by vehicle,
V_w = walking speed,
T_w = walking time, and
P = population density.

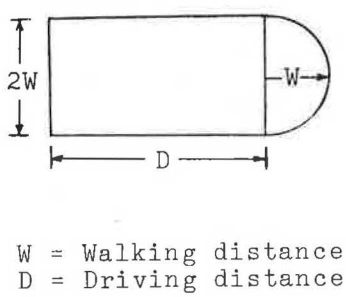


FIGURE 1 Area covered by a trip.

Given the population density in San Francisco of 16,500 persons per square mile, assuming a combined freeway-arterial speed of 45 mph and a walking speed of 4 ft/sec, a 60-min trip (including a 5-min walk) will reach 311,000 persons; a 10-min trip will reach 29,500 persons. Given the population density of 70,400 persons per square mile in Shanghai, to reach 311,000 persons in 60 min the required vehicle speed would be 11 mph. To reach 29,500 persons, the required vehicle speed would be 9 mph. Therefore, if the vehicle speed in Shanghai is 11 mph, a driver would have the same ability to visit friends or to shop as in San Francisco, because most such trips are less than 1 hr.

Although the top speed of today's automobile is about 100 mph, the a.m., p.m., and midday travel speeds in San Francisco range from 14 to 22 mph (*20*). These travel speeds may be served as a guideline for vehicle speeds.

The preceding discussions indicate that speeds ranging from 11 to 22 mph would satisfy most mobility needs in Shanghai.

Vehicle Size

The average automobile occupancy in San Francisco was 1.4 persons per vehicle (*21*). However, most automobiles were vehicles for four or more passengers. Perhaps, because the automobile is a long-term investment, people expect occasions that require the vehicle to carry four or more passengers. The effect is a waste of roadway space and energy because of moving the unused portion of the automobile.

The new vehicle should be variable in size, so that roadway space and energy can be effectively used. An approach is to design a two-passenger vehicle with an option of attaching a two-seat compartment to its rear. Figure 2 shows this concept, where *A* is the two-passenger vehicle and *B* is the attached compartment. *B* can be disconnected from *A*.

The desirable dimensions for the vehicle would be such that it could be accommodated by the existing roadway system to minimize roadway investment. To explore this, it is assumed that the new vehicle system in Shanghai would attain similar capabilities as the automobile system in San Francisco, that is, that Shanghai would reach similar vehicle ownership, parking space, and roadway capacity as those of San Francisco.

Similar ownership means Shanghai would have 3,260,870 vehicles. Assuming the 786 mi of roads in Shanghai (*9*) are linearly continuous and vehicles are parked on both sides of the roads, to park 71 percent of the vehicles, the maximum length of the vehicles would be 3.6 ft. Similar roadway capac-

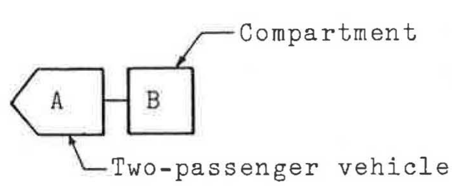


FIGURE 2 Vehicle design concept.

ity means Shanghai's roadways would be able to hold 60 percent of its vehicles during commute hours. Assuming a headway of 2 sec and an average commute speed of 10 mph (the average commute speed in Beijing, China, is about 10 mph (*22*); Shanghai is assumed to be the same), it would require 10,860 lane-mi. To provide 10,860 lane-mi, each road would have 13.8 lanes. Because the total roadway area of Shanghai equals 5 mi² (*9*), the average roadway width would be about 2.4 ft. Hence, the maximum vehicle width would be 2.4 ft. Therefore, if the vehicle is 3.6 ft long and 2.4 ft wide, roadway investment would be minimized.

Is it possible to have such dimensions? A 201-lb seated male requires space of 3.1 ft long, 1.6 ft wide, and 4.7 ft high (*23*). A 132-lb seated male requires space of 2.7 ft long, 1.4 ft wide, and 4.3 ft high (*23*). Assuming these two males are the design passengers, the minimum space would be 3.1 ft long, 3.0 ft wide, and 4.7 ft high if they sit side by side.

From these discussions, the size of the vehicle for two passengers would be 3.6 ft long, 3.0 ft wide, and 4.7 ft high, plus an optional 3.1 ft long, 3.0 ft wide, and 4.7 ft high two-seat compartment.

Vehicle Power, Weight, and Shape

The power of a motor vehicle can be estimated by the following equations (*24*, p. 163):

$$P = 0.0026RV \quad (3)$$

where

$R = R_a + R_c + R_g + R_i + R_r$,
$R_a = 0.0006FV^2$,
$R_g = 20WG$,
$R_i = 91.1WA$,
$R_r = 27W$,
$W = (W_c + W_p)/2{,}000$,
P = power actually used for propulsion (hp),
V = vehicle speed (mph),
R = sum of total resistance (lb),
R_a = air resistance (lb),
R_c = curve resistance (lb) = 40 lb,
R_g = grade resistance (lb),
R_i = inertial resistance (lb),
R_r = rolling resistance (lb),
F = frontal cross-sectional area (ft²),
W = gross vehicle weight (tons),
G = gradient (percent),
A = acceleration rate (mph/sec),
W_c = vehicle curb weight (lb), and
W_p = payload, including driver, passengers and cargoes (lb).

Substituting into Equation 3, we have

$$P = 0.0026V[40 + 0.0006F(V^2) + (1/2{,}000) \cdot (W_c + W_p)(27 + 20G + 91.1A)] \quad (4)$$

On the basis of the previous discussion, the following characteristics of the design vehicle were obtained:

- Maximum speed = 22 mph,
- Payload = 333 lb (666 lb if a two-seat compartment is included), and
- Frontal area = 14.1 ft² (3.0 by 4.7 ft).

With the above specified, the unknowns are propulsion power, curb weight, and acceleration. Figure 3 shows the curb weight to power relationship of today's automobiles (*10*). The regression line has an R^2 value of 0.64, indicating there is a good linear relationship between curb weight and power. If we apply the power to curb weight ratio of 0.05, the curb weight of the vehicle would be 188 lb (assuming an acceleration of 2 mph/sec and the propulsion power is 60 percent of the rated horsepower). The rated horsepower would be 9 hp.

Is it possible to build a vehicle with all the attributes discussed so far (i.e., horsepower 9 hp, curb weight 188 lb, payload 333 lb, maximum speed 22 mph, dimensions 3.6 by 3.0 by 4.7 ft, acceleration 2 mph/sec, and capacity of two passengers)? What form and shape would the Shanghai vehicle be? To explore the possibilities, refer to existing vehicles.

Table 5 presents the characteristics of some automobiles. The Shanghai vehicle has less weight, power, and speed than the automobile. We may not be able to build the Shanghai vehicle with desired dimensions while maintaining the same form and shape as the automobile, because the ratio of curb weight to payload for an automobile is about 3, whereas that for the Shanghai vehicle is less than 1. Furthermore, the minimum curb weight of the automobile is about 1,500 lb, which is out of the range of the Shanghai vehicle.

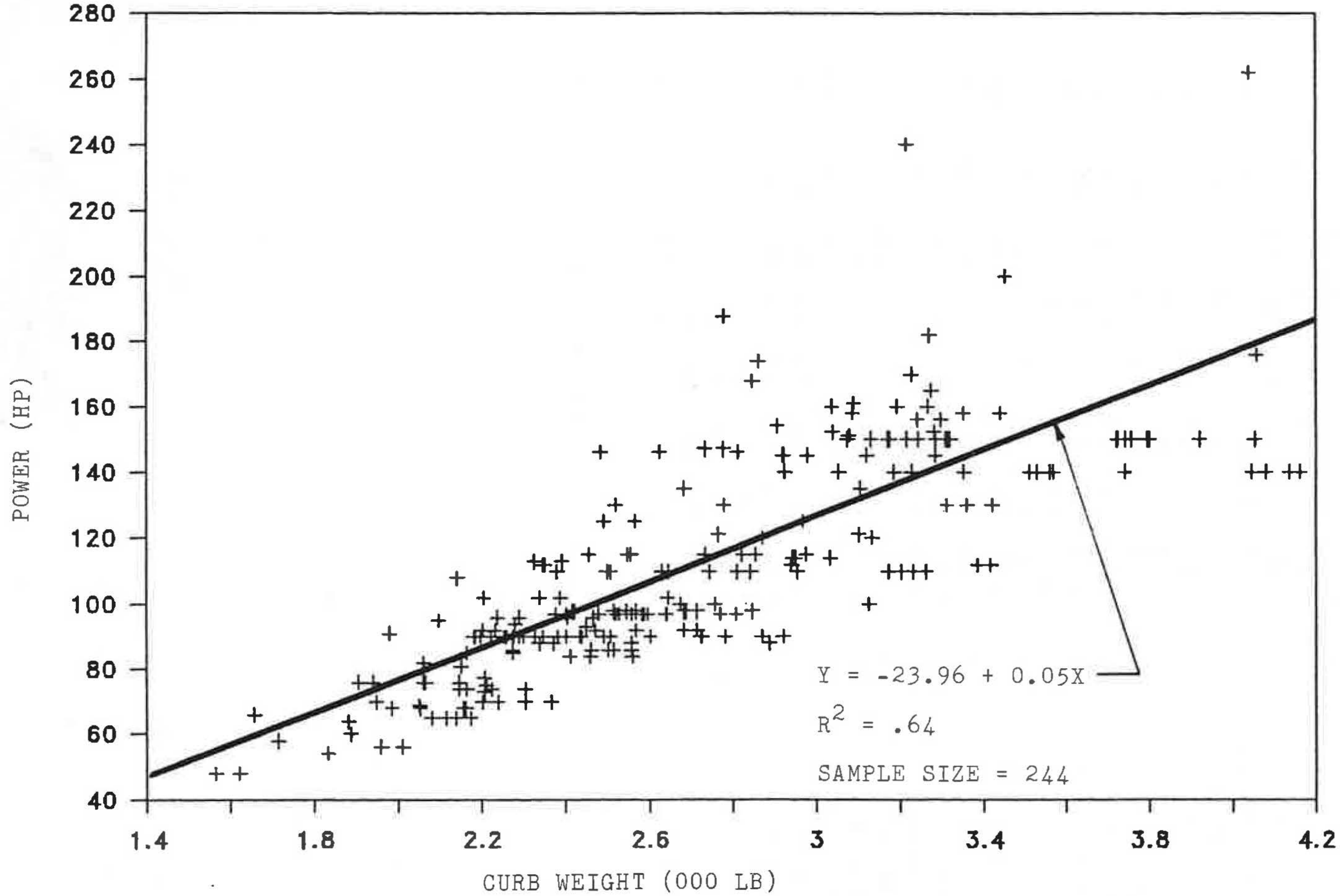
However, the shape and form of an automobile need not be maintained. Studies indicate that over 53 percent of an automobile's weight is for passenger comfort, enclosure, and safety, whereas only 47 percent of its weight is for propulsion (*26*). The Shanghai vehicle should be simple and emphasize mobility needs.

Table 6 presents data for a typical scooter with similar curb weight, payload, speed, and power as the Shanghai vehicle (*27,28*), which suggests that it is possible to build a self-propelled vehicle similar to the Shanghai vehicle. However, the scooter is not self-balanced.

Figure 4 shows a typical all-terrain vehicle. Table 7 presents its characteristics (*29*). A typical all-terrain vehicle has similar curb weight, payload, size, and probably speed and power as the Shanghai vehicle. This similarity means it is possible to build a self-balanced, self-propelled vehicle similar to the Shanghai vehicle. The all-terrain vehicle is generally not enclosed. Figure 5, however, shows how some users have added an enclosure (*30*). A similar enclosure can probably be added to the Shanghai vehicle.

Figure 6 shows some small, simple motor vehicles. Table 8 presents their characteristics (*31*). Although these vehicles are larger, heavier, and faster than the Shanghai vehicle, their ratios of curb weight to payload are similar to that of the Shanghai vehicle; therefore, it is possible to build a vehicle with the dimensions of 3.6 by 3.0 by 4.7 ft while maintaining a similar form and shape as the vehicles shown in Figures 4–6.

The above discussions indicate that we can build a vehicle with the specified attributes. Table 9 presents various power and curb weight requirements for different speeds and grades for the Shanghai vehicle.



NOTE: All 1987 model U.S. and imported passenger cars with base price less than $40,000, as listed in (10; pp. 57-59, 64-65, and 77-80)

FIGURE 3 Power and curb weight relationship of automobiles.

TABLE 5 CHARACTERISTICS OF AUTOMOBILES (*25*)

MAKE/MODEL	NUMBER OF SEATS	PRICE[a] ($)	POWER (HP)	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	CURB WEIGHT (LB)	TOP SPEED (MPH)	ACCELE-RATION (MPH/SEC)
BMW 325IX	5	33,645	168	14.6	5.5	4.6	2998	126	7.7
BMW 735I	5	49,790	208	16.1	6.1	4.6	3550	143	6.6
BMW 750IL	5	69,780	300	16.5	6.1	4.6	4247	158	9.2
BMW M3	4	34,810	192	14.3	5.5	4.5	2857	141	8.7
CHEVROLET BERETTA	5	13,000	125	15.6	5.7	4.4	2804	120	7.1
CHEVROLET CAMARO IROC-Z	NA	18,083	215	16.0	6.1	4.2	3400	135	8.5
CHEVROLET CAVALIER Z24	5	13,365	125	14.5	5.5	4.3	2672	119	7.2
CHEVROLET CELEBRITY EUROS	5	17,751	125	15.7	5.8	4.5	2986	118	6.7
CHEVROLET CORSICA LT	5	13,500	125	15.3	5.7	4.7	2860	110	6.5
CHEVROLET CORVETTE	2	33,598	245	14.7	5.9	3.9	3313	154	10.7
CHRYSLER LEBARON TURBO	5	17,883	146	15.4	5.7	4.2	2920	109	6.5
CHRYSLER NEW YORKER	6	22,088	136	16.1	5.7	4.5	3319	112	5.6
CHRYSLER SHELBY CSX	5	14,160	175	14.3	5.6	4.3	2749	131	8.6
FORD ESCORT GT	NA	10,532	115	13.9	5.5	4.5	2484	109	6.3
FORD FESTIVA L	4	5,765	58	11.7	5.3	4.6	1720	95	5.9
FORD MUSTANG GT	NA	14,432	225	15.0	5.8	4.3	3300	137	9.5
FORD PROBE GT	4	17,000	145	14.8	5.7	4.3	2940	134	9.0
FORD SIERRA RS COSWORTH	5	28,500	201	14.6	5.7	4.5	2682	142	11.1
FORD TEMPO 4WD	5	12,117	94	14.7	5.7	4.4	2834	104	4.3
FORD TEMPO GLS	5	12,085	100	14.8	5.6	4.4	2721	110	5.6
FORD THUNDERBIRD TURBO	5	17,416	190	16.8	5.9	4.5	3485	131	7.1
TOYOTA CAMRY	5	12,213	115	15.2	5.6	4.5	2810	110	6.5
TOYOTA CELICA ALL-TRAC TU	4	20,000	190	14.3	5.6	4.2	3295	135	8.2
TOYOTA COROLLA	5	10,593	90	14.2	5.4	4.4	2312	103	5.3
TOYOTA COROLLA FX16	NA	10,183	108	13.3	5.4	4.4	2332	107	7.2
TOYOTA MR2	NA	15,468	115	NA	NA	NA	2466	118	6.5
TOYOTA TERCEL	5	8,028	78	13.9	5.3	4.3	2087	98	5.1

NA - Not available

a - Retail price of the vehicle, including options, as used during the vehicle road test.

TABLE 6 CHARACTERISTICS OF SCOOTERS (*27,28*)

MAKE/MODEL	RETAIL PRICE ($)	CURB WEIGHT (LB)	PAYLOAD (LB OR PERSON)	TOP SPEED (MPH)	POWER (HP)
HONDA HELIX	2,799	342	350	75	NA
HONDA ELITE 250	2,299	280	335	70	NA
HONDA ELITE 150	1,799	240	338	60	NA
HONDA ELITE 150D	1,799	232	330	60	NA
HONDA ELITE 80	1,398	172	330	45	NA
HONDA ELITE 50 LX	1,098	138	200	40	NA
HONDA ELITE 50E	899	107	180	35	NA
HONDA AERO	899	128	180	38	NA
HONDA SPREE	499	94	180	35	NA
YAMAHA RIVA RAZZ	699	115	NA	40	5
YAMAHA RIVA 200	1,999	269	(2)	75	20
YAMAHA RIVA 125	1,649	209	(2)	65	13
YAMAHA RIVA JOG	699	122	NA	35	5

NA - Not available

( ) - Number of persons

FIGURE 4 A typical all-terrain vehicle.

TABLE 7 CHARACTERISTICS OF ALL-TERRAIN VEHICLES[a]

MAKE/MODEL	RETAIL PRICE ($)	CURB WEIGHT (LB)	WHEELBASE (IN)	WIDTH (IN)	ENGINE DIS-PLACEMENT (CC)
HONDA FOURTRAX TRX125	1898	300	41.7	39.4	125
HONDA TRX200SX	2298	353	41.9	39.4	199
HONDA TRX250R	3098	340	49.8	45.7	246
HONDA TRX250X	2698	351	45.3	43.7	246
HONDA TRX300	2798	439	49.0	43.8	282
HONDA TRX300FW	3298	475	48.6	41.9	282
HONDA TRX350D 4WD	3998	590	47.6	40.9	350
KAWASAKI KLF110A2 MOJAVE	1399	264	40.9	38.4	103
KAWASAKI KLF110B2 MOJAVE 110	1499	275	40.9	38.4	103
KAWASAKI KLF185A4 BAYOU	1999	357	43.3	39.4	182
KAWASAKI KLF220A1 BAYOU	2299	399	43.9	40.0	215
KAWASAKI KLF300BI BAYOU	2749	492	47.6	43.9	290
KAWASAKI KSF250AZ MOJAVE 250	2599	372	44.3	42.9	249
KAWASAKI KXF250AZ TECATE 4	2899	328	48.2	44.5	249
POLARIS TRAIL BOSS	2227	400	49.5	43.7	244
POLARIS TRAILBOSS 2X4	2267	440	45.5	43.5	244
POLARIS TRAILBOSS 4X4	2915	490	47.5	44.5	244
RECREATIVE INDUSTRIES MAX II	3795	650	50.0	56.0	436
SUZUKI LT230SJ QUADSPORT	2488	337	44.5	41.3	229
SUZUKI LT250RJ QUADRACER	2899	325	51.2	44.7	246
SUZUKI LT300EJ QUADRUNNER	2659	450	46.2	43.7	293
SUZUKI LT500RJ	3499	392	53.1	47.4	500
SUZUKI LT80J QUADSPORT	1279	220	37.0	31.7	83
SUZUKI LTF250J QUADRUNNER	2899	495	45.3	44.1	246
SUZUKI LT-4WDJ QUADRUNNER	3499	500	45.3	44.3	246
SUZUKI QUADRUNNER	2599	379	44.9	41.7	229
YAMAHA BANSHEE	3149	375	50.4	43.3	347
YAMAHA BIG BEAR	3649	549	47.6	43.1	348
YAMAHA BLASTER	1949	313	43.3	40.7	195
YAMAHA CHAMP	1419	243	40.6	34.8	98
YAMAHA WARRIOR	2999	390	47.2	42.5	348
YAMAHA YFM 200DX	2219	386	44.1	41.1	196
YAMAHA YFM225	2599	452	46.7	43.9	223
YAMAHA YFM350ER	2899	496	46.7	43.9	349
YAMAHA YFM80	1119	213	37.2	32.5	79

a - All 1988 model all-terrain vehicles as listed in (29) except the 2-wheelers.

FIGURE 5 All-terrain vehicles with enclosures.

FIGURE 6 Small motor vehicles.

TABLE 8 CHARACTERISTICS OF SOME SMALL MOTOR VEHICLES (*31*)

MAKE/MODEL	TOP SPEED (MPH)	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	CURB WEIGHT (LB)	POWER (HP)	PAYLOAD (LB + PASSENGER)
CUSHMAN HAULSTER 455	39	9.3	4.0	5.8	960	18	1,000 + 1
CUSHMAN HAULSTER 452	30	9.6	4.0	5.8	1,080	18	1,400 + 2
CUSHMAN FLATBED PICKUP 451	18	9.0	4.0	5.8	945	18	1,000 + 1
CUSHMAN FLATBED PICKUP 453	18	9.0	4.0	5.8	930	12	1,000 + 1
CUSHMAN FULLTON 450	18	10.9	4.0	5.8	1,060	18	2,000 + 1
CUSHMAN FULLTON 459	18	11.5	4.0	5.8	1,195	18	2,000 + 1
CUSHMAN MINUTE-MISER 319	14	6.8	2.9	3.2	520	7	250 + 1
CUSHMAN DELIVERY VEHICLE 456	39	9.3	4.0	5.8	1,340	18	1,000 + 1
CUSHMAN DELIVERY VEHICLE 458	29	9.8	4.0	5.8	1,475	18	1,000 + 1
CUSHMAN POLICE VEHICLE 454	39	9.3	4.0	5.8	1,165	18	1,000 + 1
CUSHMAN REFUSE VEHICLE 457	29	10.4	4.0	5.8	1,380	18	1,000 + 1

TABLE 9 SUMMARY OF DESIGN PARAMETERS FOR THE SHANGHAI VEHICLE

	LENGTH (FT)	WIDTH (FT)	HEIGHT (FT)	PAYLOAD (LB)	CURB[a] WEIGHT (LB)	PROPULSION[a] POWER (HP)	RATED[a] ENGINE POWER (HP)	ACCELERATION (MPH/SEC)	SPEED[a] (MPH)	GRADE (%)
TWO PASSENGER VEHICLE ITSELF	3.6	3.0	4.7	333	188	5.6	9.4	2	22	0
									18	5
									15	10
					251	7.5	12.6	3	22	0
									18	5
									15	10
TWO PASSENGER VEHICLE AND COMPARTMENT	6.7	3.0	4.7	666	271	8.1	13.5	2	22	0
									17	5
									14	10
					385	11.5	19.2	3	22	0
									18	5
									15	10

a - Computed from equation 10 by assuming 1) power to curb weight ratio of 0.05 and 2) 60% of engine power is available for propulsion for given frontal area, payload, acceleration and grade.

Vehicle Price

The vehicle should be affordable. In order to define an affordable automobile, refer to the experience of the United States. The automobile was available in the United States in the 1800s. However, before about 1910 it was regarded as a rich person's toy rather than a means of transportation. After 1910, the percentage of U.S. residents owning automobiles increased rapidly, as shown in Figure 7. By 1930, about one-fifth of the population owned an automobile (*32*). One reason was the automobile was mass produced and became affordable to the general public. The curves in Figure 7 show that the rapid growth of the automobile started at the time when the average wholesale price of the automobile was below the average annual family income. This fact suggests that a reasonable price during the development stage of the Shanghai vehicle should be about the same as the average annual family income. Assuming a typical family has two workers, the average annual family income in Shanghai would be $874 (*17,18*). This price would be the desirable price for the Shanghai vehicle.

Is it possible to build the vehicle for $874? Some idea can be obtained from existing vehicles.

Light pickup trucks also emphasize mobility. Figure 8 shows the price and curb weight relationship of light pickup trucks (*33*). The regression line has an R^2 value of 0.75, an intercept of 927, and a slope of 2.75. The R^2 value indicates that price is highly related to curb weight. The intercept may be related to the complexity of the production process. Today's automobile contains thousands of parts. Inventory and a well-orchestrated assembly plant are required to put these parts together. The process is complex and expensive. The setup cost for this process is about $927, as interpreted from the intercept. The price for each pound of curb weight is $2.75, as interpreted from the slope. If we apply this relation to the Shanghai design vehicle, the price would be $1,444.

Figure 9 shows the price and curb weight relationship of all-terrain vehicles. The regression line has an R^2 value of 0.67, an intercept of 287, and a slope of 5.82. The R^2 value indicates that price is highly related to curb weight. The setup price, as interpreted from the intercept, is $287. This price is less than that of the pickup truck, because the all-terrain vehicle is simpler. The cost per pound is $5.82, as interpreted from the slope. This is higher than that of the pickup truck because of economy of scale of production. Pickup trucks are produced more than are all-terrain vehicles, therefore the unit cost is less. Applied to the Shanghai vehicle, the price would be $1,381.

These facts suggest the price would be over $1,000. However, the $874 price level could be attainable because the Shanghai vehicle would be as mass produced or even more mass produced, considering the population of China, as the light pickup truck, and would be as simple as the all-terrain vehicle. If we apply the slope of the regression line of the light pickup truck (2.75) and the intercept of the regression line of the all-terrain vehicle (287) to the Shanghai design vehicle, the price would be $804.

The $874 price level could be attainable from another point of view. Table 10 indicates that the average cost of material for an automobile was about $0.33/lb. Assuming the Shanghai vehicle is made of the same materials, the material cost would be $62. The average cost of an automobile ($13,000) is 13 times its average material cost ($1,053), as interpreted from Table 10. If we apply this price to material cost relationship to the Shanghai vehicle, the vehicle price would be $806. Moreover, the labor cost in the United States is much higher than in China. The hourly wage of motor vehicles and equipment workers in the United States is $13.49 (*38*). The average hourly wage of Chinese workers is $0.21 (*17,18*), which is 64 times lower. Therefore, the production cost and hence the price would be lower.

THE NEW ROADWAY SYSTEM

At first, the vehicle would use the existing roadway system so that investment could be minimized. Research indicates that a lane width of 2.5 ft greater than the car itself is adequate (*39*). Thus, the vehicles could operate on 5.5-ft-wide roadways. The maximum vehicle speed of 22 mph is similar to that of bicycles. As a result, the existing roadways, including

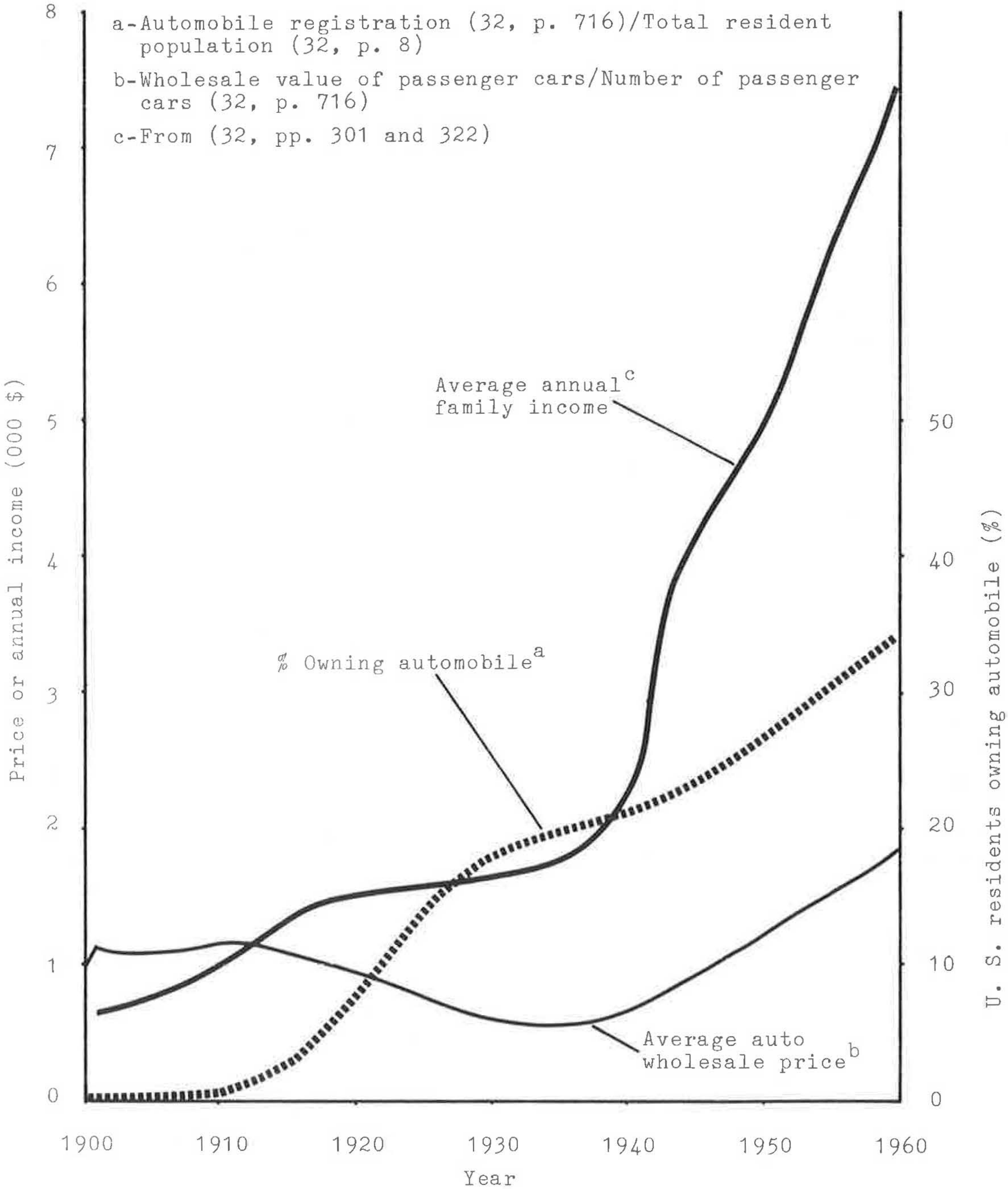
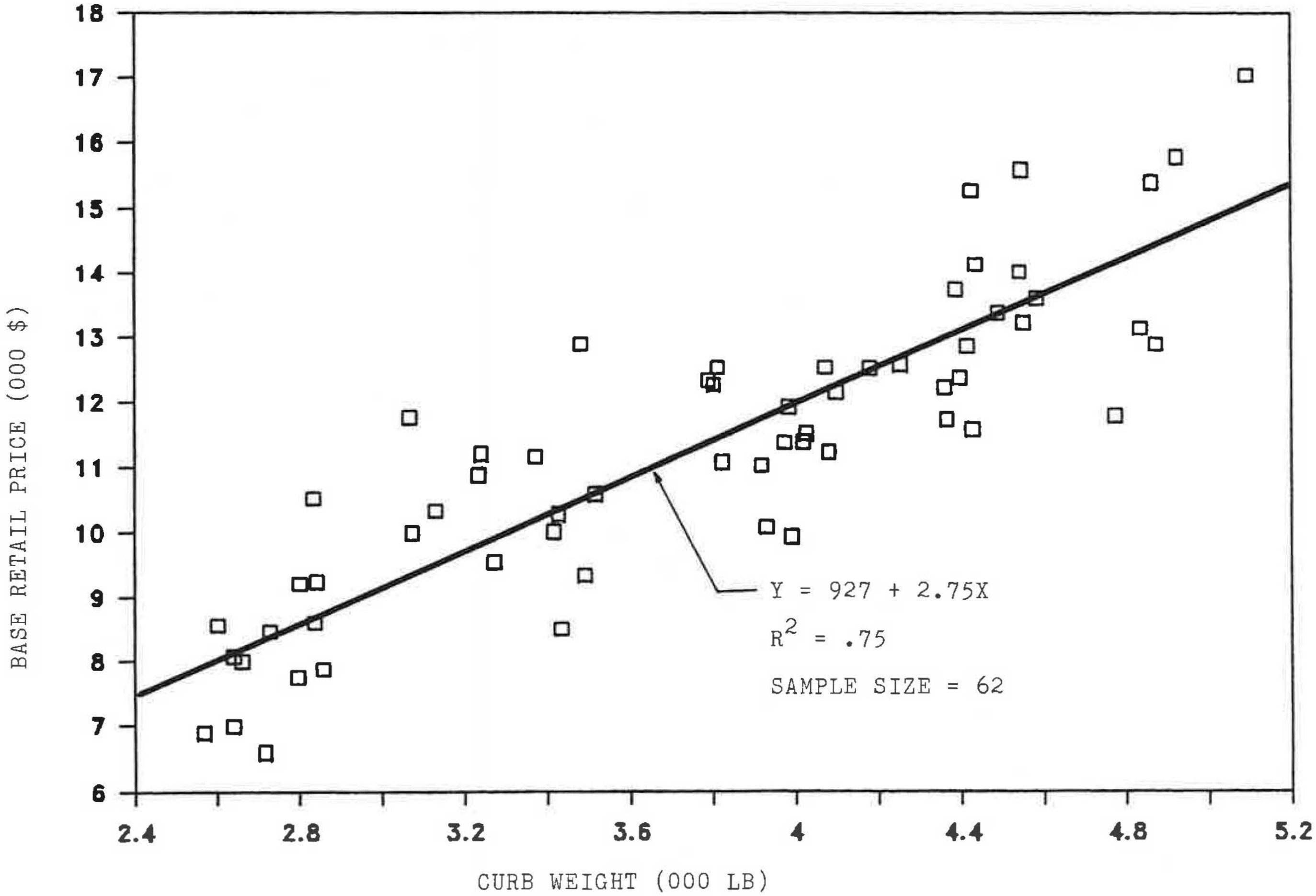
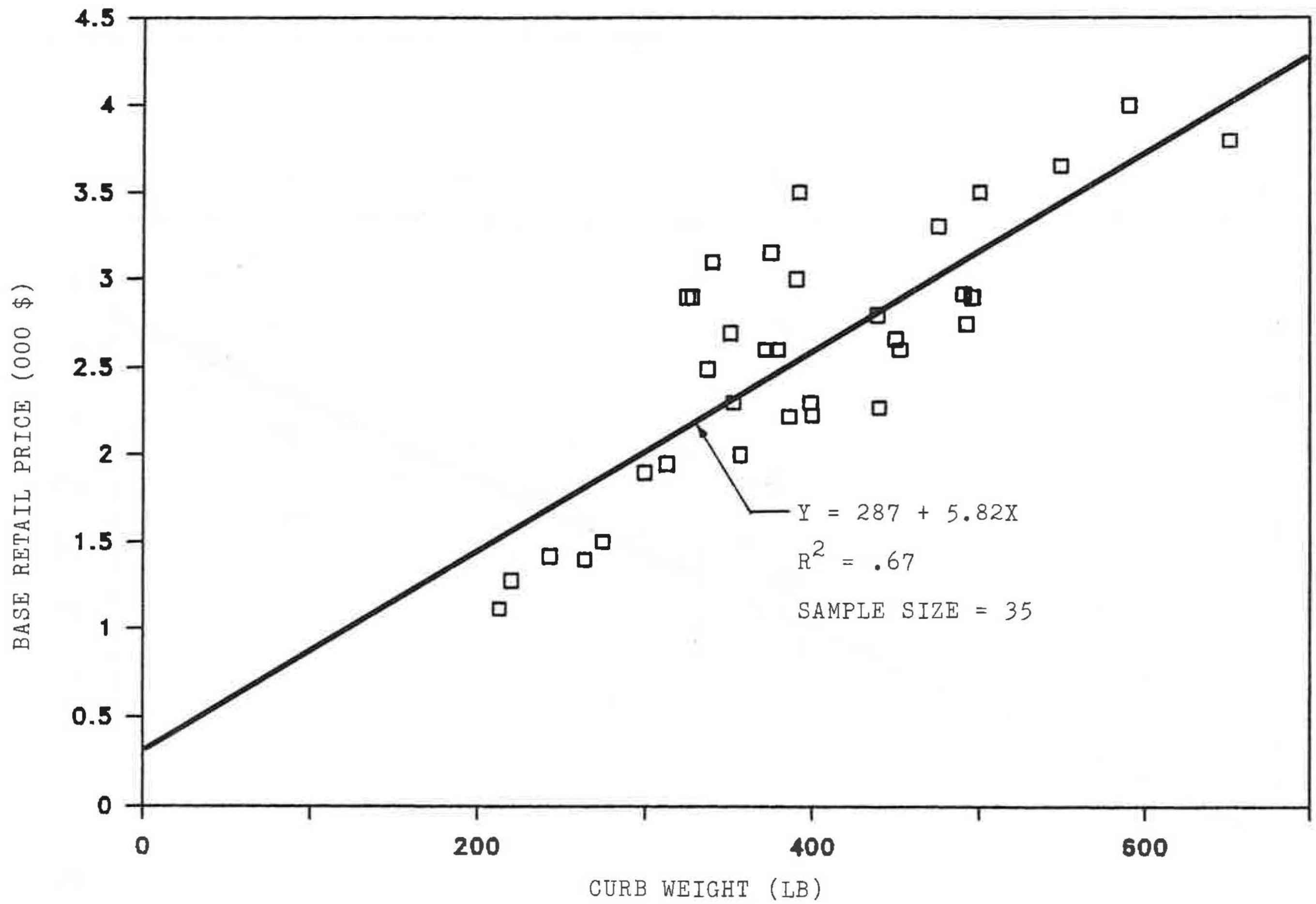


FIGURE 7 Automobile wholesale price, family income, and percent of U.S. residents owning automobiles.



NOTE: All 1987 model light pickup trucks produced in the U.S. as listed in (33, pp254-256)

FIGURE 8 Price and curb weight relationship of light pickup trucks.



NOTE: All 1988 model all-terrain vehicles as listed in (29), except the 2-wheelers.

FIGURE 9 Price and curb weight relationship of all-terrain vehicles.

TABLE 10 MATERIALS FOR AN AVERAGE PASSENGER CAR

MATERIAL[a]	WEIGHT[a] (LB)	WEIGHT[a] (%)	UNIT PRICE[b] ($/LB)	PRICE OF MATERIAL ($)
PLAIN CARBON STEEL	1,459.0	45.9	.21	306.39
HIGH STRENGTH STEEL	228.0	7.2	.31	70.68
STAINLESS STEEL	32.0	1.0	1.49	47.68
OTHER STEELS	55.5	1.7	NA	38.85
IRON	460.0	14.5	.05	23.00
PLASTICS/COMPOSITES	221.5	7.0	.51	112.97
FLUIDS/LUBRICANTS	183.0	5.8	NA	128.10
RUBBER	135.5	4.2	.43	58.27
ALUMINUM	146.0	4.6	.70	102.20
GLASS	86.0	2.7	NA	62.20
COPPER	25.0	0.8	.68	17.00
LEAD	24.0	0.8	.29	6.96
ZINC DIE CASTINGS	18.0	0.6	.40	7.20
OTHER MATERIALS	104.5	3.3	NA	73.15
TOTAL	3,178.0	100.1	0.33[c]	1052.65

NA - Not available (assumed to be $0.7/lb, same as aluminum)
a - From (*33*, p. 30)
b - Iron and steels from (*35*), plastics/composites from (*36*), rubber from (*37*) and the rest from (*34*).
c - This is the weighted average unit price, by assuming $0.7/lb for NA items and taking the weighted average.

those designated for bicycles, could be used. Other existing facilities, such as traffic signals and service stations, could also be used.

As more and more people use the new vehicle, special systems should be considered. The vehicle, being small, can reach anywhere. It can be specialized in providing neighborhood access and connection to mass transit. Mass transit, on the other hand, can be specialized in line-haul services, concentrating on major corridors with fewer stops. Hence, transit service would be faster and more frequent without additional investment.

A spoke and hub system could be developed. The spokes represent roadways for the new vehicle. The hubs represent transit stations. Roadways connecting the hubs would be specialized for efficient buses, trains, or other mass transit services, whereas roadways for the spokes would be emphasized on local access. Park-and-ride lots and retail stores would be built at the hubs. Renting of the new vehicle and the optional compartment would also be available at the hubs. The idea is to make the hub the shopping and transportation center. People would drive the new vehicle from home to the nearest hub to get their basic needs. If they need to go farther, they would use transit to go to the further desired hub, where they could rent or lease another vehicle, if necessary, to go to their destinations. Such operation is possible because the vehicle is small, and park-and-ride lots would be easy to provide. Because the vehicle is cheap and simple to maintain, renting outlets would be easy to establish and the renting price would be cheap.

Because transit service is frequent and fast, it would be convenient to transfer from the new vehicle to transit, and from transit to the new vehicle. Developing retail stores and other activities around the hubs has great implication on shaping the travel patterns. It minimizes the need to use the new vehicle to travel long distances. It also ties the new vehicle and mass transit together. They complement each other; more use of the new vehicle would require better transit service, and better transit service would encourage more use of the new vehicle. Together they form an efficient transportation system.

Other systems could also be developed. The vehicle-train system shown in Figure 10 is an example. A person can drive the vehicle directly on board a train. The train provides efficient line-haul or intercity service, whereas the vehicle provides efficient connection from origin to the train, and from the train to the destination.

CONCLUSIONS

A new vehicle has been planned for Shanghai, China. The same rationale can be applied to any developing country. Although the new vehicle is simple and small, it would satisfy people's mobility needs. It can be connected with mass transit to form an efficient means of transportation.

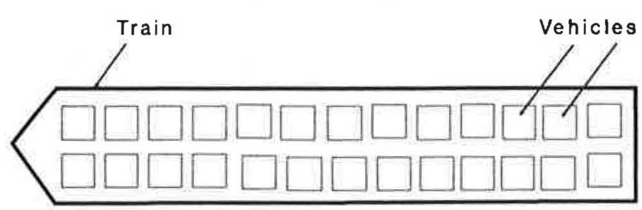


FIGURE 10 Vehicle-train system.

In China, a small farming tractor is widely used on regular roadways for transporting people and goods. This indicates there is demand for a vehicle similar to what has been described.

The Shanghai vehicle parameters were based on diesel engine technology. The reason is that because the diesel engine is a mature technology, no additional research is needed. Therefore, once the desired parameters are formulated, the vehicle can be built.

SUGGESTIONS FOR FURTHER RESEARCH

1. Because the new vehicle is small and meant to be driven at low speed and for short distances, it may be powered by an electric engine. Similar studies on developing the vehicle parameters should be based on electric engine technology. An electric vehicle, if feasible, may be more energy efficient and produce less air pollution.

2. As more people begin using the vehicle, air pollution and energy consumption become issues. Research on such impacts should be conducted.

3. The vehicle-train system is only an idea. Further research on the design of stations, logistics of vehicles getting on and off the train, arrangement of vehicles and passengers on board the train, etc., are needed before the idea becomes practical.

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