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THE SHARED-RIDE TAXI SYSTEM REQUIREMENT STUDY

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16. Abstract

Shared-ride taxi (SRT) is different from the exclusive-ride taxi (ERT) in that the taxi may be shared by unrelated passengers with different origins/destinations. By simultaneously serving more than one passenger, SRT may improve vehicle productivity, permit fare reductions, and increase taxicab ridership. SRT may also serve as an integrated-transit feeder to conventional transit in suburban communities, thereby attracting new ridership to both SRT and transit.

The major objective of this study is to develop the system requirements and perform a functional design of the computer control system (CCS) for an automated shared-ride taxi system. A secondary objective is to identify the environmental and system context in which these requirements are applicable. This study provides substantial evidence that the SRT-CCS concept is not only technically feasible and within the present state-of-the-art but also economically attractive for SRT fleets of 50 vehicles or more. Certain technical problem areas have been identified and should be resolved, but they do not appear to be unsolvable or to jeopardize the technical success of the concept. It is recommended that a developmental experiment, followed by several exemplary experiments, should be implemented to confirm these conclusions.

Appendix A of this report provides a bibliography that covers the entire study, not just this final report.

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PREFACE

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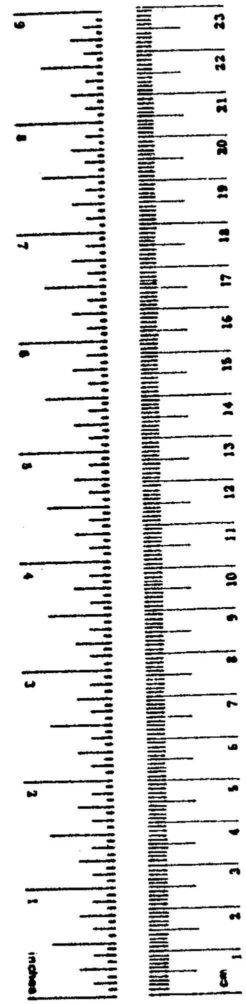
METRIC CONVERSION FACTORS

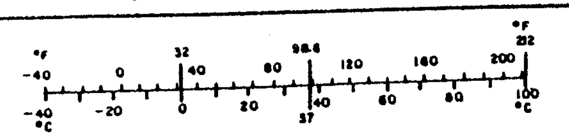
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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GLOSSARY

Various authors use paratransit terminology in different and often ambiguous ways. In order to distinguish the meaning of SRT as used in this study from other closely related forms of paratransit, a brief glossary is provided:

(a) Demand-Responsive Transit (DRT). Service provided without schedule or fixed route and initiated at the request of the passenger. (ERT, SRT, DAR, DAB are all forms of DRT.)

(b) Dial-A-Bus (DAB). This is similar to DAR except that it is operated by a public bus company, such as a transit district, whose primary business is fixed-route buses and which employs regular transit bus drivers to operate DAB. The vehicle is usually a minibus or midibus rather than the taxi sedan or van used in SRT.

(c) Dial-A-Ride (DAR). This is similar to SRT except that the service is provided under contract to a governmental agency and that it does not include regular taxi services. Fares are below cost (the median fare is $0.50) and the agency pays the operating deficit (i.e., the operator, which is often a taxi company, is not concerned with covering costs through passenger revenues).

(d) Exclusive-Ride Taxi (ERT). This is the type of taxi service currently available in most communities. It provides door-to-door service at the exclusive use of the occupant and is operated by private (for profit) companies in a competitive business environment. Requests for service can be by telephone, street hail, or at a taxi stand. Passenger revenues are expected to exceed costs, though subsidies to individual users (user-side subsidies) may be involved in the form of guarantees, tickets, tokens, or scrip.

(e) Fixed-Route Transit (FRT). This is conventional bus transit in which buses run along fixed routes on a fixed schedule, making stops at pre-established and well-identified fixed points (i.e., bus stops). It is normally operated by a public bus company, such as a transit district, and employs regular transit bus drivers.

(f) Shared-Ride Taxi (SRT). This is an extension of ERT in which the taxi company has the right to give concurrent shared-ride service to multiple users (also called Share-A-Cab). Shared-ride permits a taxi to operate more efficiently in that it can carry more passengers per hour and thereby charge lower fares. A company providing SRT service may still offer ERT service.

PART I: EVALUATION OF THE FEASIBILITY OF THE SHARED-RIDE TAXI CONCEPT

1.0 INTRODUCTION AND SUMMARY

This report summarizes the work conducted in the Shared-Ride Taxi Computer Control System Requirements Study (Contract No. DOT-TSC-1272). Additional detail may be found in the individual task reports listed below.

Task 1 Report: Role Definition

Task 2 Report: Concept Development

Task 3 Report: System Analysis

Task 4 Report: System Requirements

The results of the study indicate that shared-ride taxi (SRT) can be an essential element of an areawide demand-responsive transit system. Further, SRT, when properly implemented, may improve the economic viability of the taxicab industry. The study also shows that the dispatching procedures of SRT operations are much more complex than exclusive-ride taxi (ERT) operations. Further, automation should be considered for SRT fleets in excess of 25 vehicles.

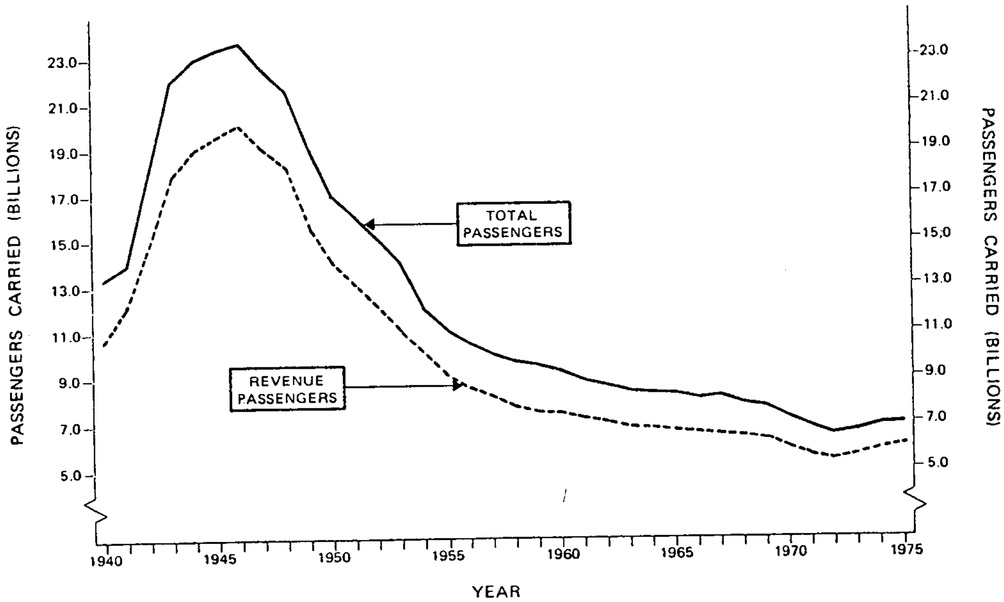
1.1 CHANGING TRANSIT NEEDS

Transit's role in providing public transportation services in the U.S. has undergone major changes in the last quarter-century. Two key indicators of these changes are:

(1) Transit ridership has declined from 19.8 billion revenue passengers in 1946 to 5.6 billion in 1975 (Figure 1-1); and

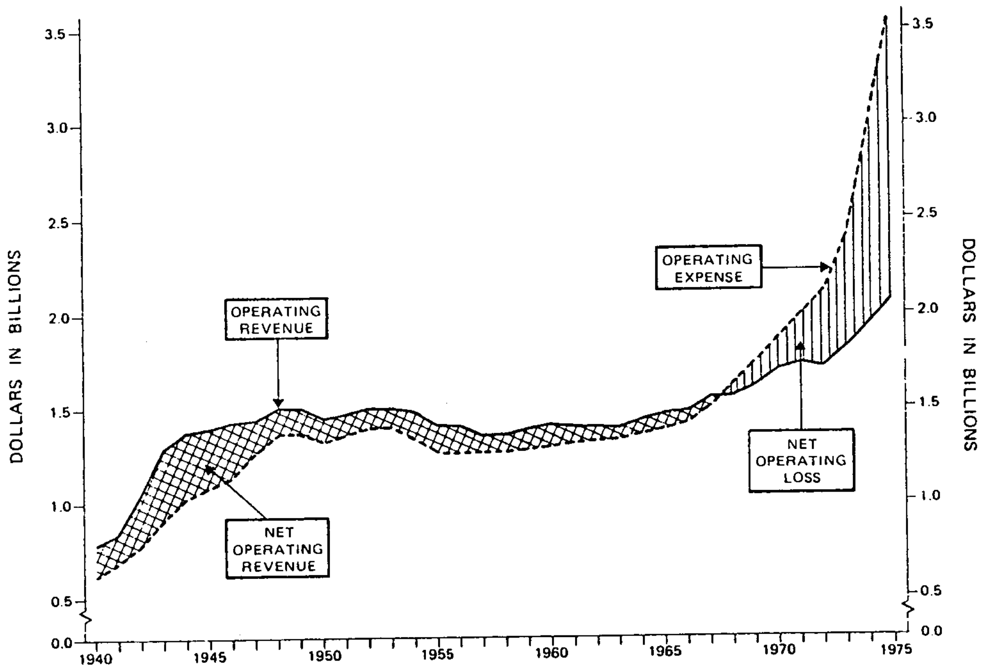
(2) The declining ridership, a policy of maintaining low fares, and the steadily escalating cost of labor have caused average net operating revenues to decline from a break-even point in the mid-1960's to a current operating loss of several billion dollars per year (Figure 1-2).

The fundamental cause for these changes has been a significant population movement toward less dense urban areas -- the suburban population density in the U.S. has declined steadily throughout the century from approximately 7,000 residents per square mile to about 4,000 residents per square mile currently. More than half of the urban U.S. population now lives in low- or medium-density suburbs (Maring, 1974, p. 36) and,



SOURCE: APTA, 1976.

FIGURE 1-1. TRANSIT RIDERSHIP 1940-1975



SOURCE: APTA, 1976

FIGURE 1-2. RESULTS OF TRANSIT OPERATIONS 1940-1975 to serve this low-density urban living, government, business, and other institutions have relocated into the suburbs away from the central business district (CBD).

With this shift to the suburbs, a changed travel pattern in the typical urban area has emerged, from a pattern in which most trips were oriented toward the CBD to a new pattern involving trips scattered throughout the area. Under the latter conditions, it has become increasingly difficult for conventional fixed-route transit to serve travel needs. The number of trips whose beginning and ending points are located near a common transit route is too low to support conventional transit in many areas (New York Regional Plan Association, 1976, p. 6).

The automobile remains the overwhelming choice for suburban travel. Approximately 89 percent of all trips are taken by private automobile, while bus and rail transit serve about four percent (see Table 2-2). The automobile has advantages of convenience, speed, and comfort which public transit cannot match, but it has undesirable impacts such as limiting the mobility of those without access to automobiles, pollution, congestion, and often excessive energy consumption. National transportation policy (UMT Act of 1964, Section 2) implies that public transportation alternatives are needed for those who do not wish to contribute to these conditions by driving, and also those who do not have access to an automobile, such as the young, the elderly, the poor, and the handicapped. Lack of effective public transportation forces the former to drive and the latter to remain isolated from urban opportunities.

The implications and requirements of national policy have received increasing attention (1974 National Transportation Report; Ward and Paulhaus, April 1974; Ward, July 1975; and Orski, 1976) and a variety of innovative suburban services have been either contemplated or attempted in various locations across the nation. Couched under the term "paratransit," these innovations include car and van pooling, subscription bus, jitneys, and demand-responsive services such as shared-ride taxis and dial-a-ride.

Individual development of each type of transit service is only the first step in solving the problems. To provide truly effective areawide service, these innovative services must be integrated with conventional transit (Ward, July 1975). By careful choice of the combination and extent of each element of an area-wide transportation system, the costs and service quality can be controlled. Integrated transit and paratransit regional systems might consist of a variety of modes, each operating in its appropriate environment and connecting with higher- and lower-level modes. Transit can be reconfigured to improve fixed-route service along arterial corridors while taxi service can be expanded to provide effective coverage in the suburbs (Ward and Paulhaus, 1974). It is from this perspective that SRT appears to offer some solutions to improve the overall transit situation.

1.2 SHARED-RIDE TAXI CONCEPT

Shared-ride taxi (SRT) is different from the exclusive-ride taxi (ERT) service in that the taxi may be shared by unrelated passengers (or parcels) with different origins and/or destinations. By simultaneously serving more than one passenger, SRT may (1) improve vehicle productivity (see Sections 3.1 and 4.3.1); (2) permit fare reductions (see Section 4.3.2); and (3) increase taxicab ridership (see Section 4.4). However, the level of service as perceived by the passenger may be reduced.

In addition to providing more efficient taxi transportation, SRT may serve as an integrated-transit feeder to conventional transit in suburban communities, thereby attracting new ridership to both SRT and transit and releasing conventional transit for improved services in high-demand corridors.

1.3 STUDY OBJECTIVES

The major objective of this study is to develop the system requirements and perform a functional design of the computer control system (CCS) for an automated shared-ride taxi system. A secondary objective is to identify the environmental and system context in which these requirements are applicable. The results of the study provide a firm basis for rational development of a SRT-CCS.

1.4 STUDY RESULTS

The results of the study can be described in terms of the four tasks identified in the statement of work. These results are summarized below:

1.4.1 Task 1: Role Definition

The roles of SRT fall into two principal and one supplemental categories which can operate simultaneously:

(a) SRT performs the same role as ERT except that, by ride sharing, SRT does the job more efficiently and at a lower cost per trip. Basically, a typical ERT productivity is 2 - 3 passengers per taxi-hour. Converting from ERT to SRT could increase the productivity to 4 - 6 passengers per taxi-hour (see Sections 3.1 and 4.3.1). Since this would reduce the fleet size (see Section 4.3), the operating costs would also decline, reducing the costs per trip.

(b) SRT feeds a fixed-route mass-transit (FRT) system in addition to (a) above, thereby increasing the effective service area as well as increasing both fixed-route and SRT ridership. An excellent example of a Dial-A-Ride (DAR) integrated system increasing ridership is the Ann Arbor system where the ridership increased from 677,000 in 1973 to over 2,000,000 today (see Section 3.2.2.2). Most of this increase is directly related to the increase in the service area. While the Ann Arbor system is not SRT, it is expected that the effects of integrating SRT with FRT will be similar.

One of the limitations of FRT in the suburbs is that passengers will not normally walk more than 1/4 mile to use the FRT system. This is especially a problem for the elderly and the handicapped. Introducing a flexible transit element such as SRT to collect and/or distribute passengers should encourage increased total ridership and improve the economic viability of both the taxicab company and public transit.

(c) SRT companies enter into separate contracts to perform supplemental roles such as a community DAR, small goods movement, and transportation of the elderly and handicapped. The contract will insure that the objectives of the taxicab operator are consistent with public objectives. This public/private involvement allows the taxi industry to participate in innovative paratransit systems.

1.4.2 Task 2: Concept Development

SRT services are expected to grow significantly. This growth in SRT ridership will come primarily because of modest population growth, larger proportions of working women, more elderly persons (see Section 2.1.1), steadily increasing fuel costs (see Section 2.3.2), integration of transit and paratransit (see Section 3.2), moderate auto disincentives, and a ridership switch from ERT to SRT. If SRT is also encouraged by government, SRT is expected to carry 10 billion passenger-trips per year by 1995, three times the present number of all taxi passenger-trips (see Section 2.2.2).

SRT can be operated under manual (human) control -- about one percent of all taxi trips are currently by SRT under manual control (see Section 2.2.1). However, the fleet size and ridership which can be accommodated are limited. For example, a fleet of 20 to 30 SRT vehicles is the maximum size that a single dispatcher can handle (see Section 5.1.1). Automation needs to be considered since the dispatching efficiency decreases as fleet size increases because the complexity of control starts to exceed human capability in all but the smallest operations. Further, the system analysis shows that a computer control system would be cost-effective for SRT service in a medium or large taxi operation.

1.4.3 Task 3: Systems Analyses

The cost-effectiveness analysis examined a large number of alternative circumstances for an ERT company to convert to SRT. In order to present the results in a comprehensible form, the scenarios were constrained to a medium city (population 90,000 to 500,000), a small city (population 18,000 to 90,000), and a large city (population over 500,000).

This cost-effectiveness basically considered the operating features, fares, and economic viability of a taxi company before and after conversion to SRT. In a medium-size city, SRT can achieve a 30-percent fare reduction and additional profits equivalent to 7.5 percent of costs (see Section 4.3.2). If there are a significant number of standing orders from commuters going to a station or other passenger groupings, even higher productivities and lower fares may be feasible.

For the small cities, on the other hand, any significant reduction in the SRT fare below that of the ERT fare quickly results in a reduction of profits. A prudent businessperson may be unwise to make a conversion from ERT to SRT based on the modest potential benefits and the high risk involved in a small city. Rather, in a small city, if SRT is to be implemented, it may be necessary to consider some form of subsidy -- i.e., in effect, a DAR service.

Profitability of SRT in a large city appeared to be most attractive. Substantial reductions in the fare can be achieved while still retaining satisfactorily increased profits. In fact, if the fare is reduced to on the order of 40 percent of the ERT fare, the new operation will probably resemble a downtown jitney service during the peak periods.

How the taxicab company operates the SRT fleet determines whether the ridership will increase or decrease. If the taxicab company seeks maximum profits, then ridership will decline. However, competition and/or regulations will improve service and limit profits so that ridership may increase (see Section 4.4).

An examination of existing manual SRT and DAR operations indicates that the human dispatcher is limited to controlling approximately 25 SRT vehicles (see Section 5.1.1). Thus, automation should be considered for SRT fleets greater than 25 vehicles. Further, the level of automation that is cost-effective for a specific fleet size must be determined. For example, the analysis showed (see Section 4.5) that a fully automated control system is cost-effective for a SRT fleet of 50 vehicles or more.

This analysis established the control system requirements and functional design of an automated SRT system. The basic computer control system operates as follows. Calls are received by an order-taker using a computer-aided CRT terminal. The order-taker types in the order which is validated by the computer against the service area street address file. The computer automates the scheduling and dispatching process similar to the Rochester Dial-A-Ride system which employed an MIT-developed scheduling algorithm (see Section 6.4). The computer dispatches the taxi to serve the request via a digital communication link. There are no human dispatchers except for the supervisor, who would intervene in special and irregular cases that could not be efficiently handled by the computer (for perhaps five percent of the orders). The dispatching instructions are presented to the driver via the mobile unit display.

In order to insure that a minicomputer can handle the computation load, a "filter" or field control technique is employed to reduce the number of trips and/or vehicles considered by the algorithm (see Section 6.4.5). It is estimated that when field controls limit the field to 30 percent of the fleet, and the stacking factor (the ratio of the average number of vehicles processed before a selection is made to the total number of taxis in the stack) is 40 percent, then a minicomputer can accommodate a fleet of 70 taxis as opposed to 25 SRT vehicles without field controls (see Section 6.4.4).

Further, stored messages can be selected by a computer to be transmitted in special circumstances. Automatic callback can dial the customer's phone number and inform the customer of any changes in pickup time or alert them of the imminent arrival of their taxi. It is expected that the customer must give his/her permission before being called by this automatic system.

Over a hundred CCS functional requirements were examined for applicability to SRT. For example, the functional breakdown at the top-level is structured in terms of communications; scheduling; system monitoring and maintenance; and system development and training functions. These top-level functions were further broken down to the fifth level. For example, the communications function was broken down further in terms of trip request telephone processing, telephone answering, processing deferred and periodic requests, and modifying deferred and periodic requests (see Section 6.3). Factors such as risk of implementation, cost-effectiveness, and modular utility are among the 15 criteria quantitatively applied in this examination process. Initial understanding of the CCS functions was obtained using a top-down, six-level hierarchy which extended to basic functional descriptions. These functions served as the basis from which hardware, software, and personnel methodologies were generated.

1.4.4 Task 4: System Requirements

The systems requirements effort encompassed establishing the following requirements:

1. Functional Requirements
2. Hardware Requirements
3. Personnel Requirements
4. Operational Requirements
5. Software Requirements

The functional requirements were described using the HIPO (Hierarchy, plus Input, Process, Output) method that provides a structure for software design and documentation, but does not constrain the design details (see Section 6.3.1). This requirements study undertook the HIPO functional decomposition to the sixth level, identifying over 120 HIPO's; the next levels of decomposition will occur in detailed design. Each of the HIPO functions will be mechanized by an assembly of software modules needed to perform the function. The basic hardware configuration is an on-line real-time interactive system that includes a minicomputer, disc unit and controller, alphanumeric and graphics terminals, digital communications, and auto-callback. The hardware (including digital communication displays) cost of the system (in production) for a fleet of 50 SRT vehicles is estimated to be $260,000 (1976 dollars) (see Section 7.1).

Personnel requirements were established as a function of the fleet size and percentage of hail and stand trips. Moderate reduction in the personnel requirements for larger systems were demonstrated.

Operational requirements were established. It was concluded that the system should incorporate both formula and zonal fare options (see Section 8.1.1). Further, the system must be able to handle hail and stand orders (see Section 8.1.2), problem passengers (see Section 8.1.4), as well as accommodate user-side subsidies and credit passengers (see Section 8.1.6).

The software requirements are derived from the HIPO functional decompositions. Twenty software module subsystems containing over 400 software modules were described (see Section 7.2.4). About 30 percent of the SRT-CCS program modules are new concepts developed during the study. The remaining modules are based on the MIT algorithm and software developed in Rochester and Haddonfield. About 25 percent of the modules are functionally identical to their Rochester counterparts. The remaining 45 percent of the total software is similar to the Rochester-Haddonfield software but adapted to the specific circumstances of SRT (Harris, T.W., et al. Task 4 Report: System Requirements, p. 196, August 1978).

1.5 REFERENCES

During the course of this study, an extensive literature search was made into the relevant topics. This is presented alphabetically in Appendix A and covers the entire study, not just this final report. References in the text are abbreviated versions of the complete listings in Appendix A.

2.0 POTENTIAL DEMAND

The previous section shows the important transit problems to which the SRT concept may offer some solutions. The essential first step in establishing SRT requirements is to estimate what future ridership demand for SRT services will be. Ridership prediction is a complex issue and estimates are subject to the many uncertainties of the changing society and its environment; nevertheless, by combining several independent studies of the subject, potential demand estimates were developed which are believed to be realistic.

The usable life of a CCS developed in the late 1970's cannot be expected to extend beyond 1990-1995 in view of anticipated continuation of growth in computer technology and potential social changes which cannot be foreseen. Accordingly, the following discussion addresses the evolution of the transit market and modal splits through 1995.

2.1 NEW TRAVEL PATTERNS

2.1.1 Demographics

Conservative estimates of future population increases appear to be justified. Immigration is controlled and the national birth rate has declined to 1.72 percent -- below the replacement rate of 2.1 percent. The U.S. population for 1990 is forecast at 245 million, which is lower than the figure used in most previous transportation studies.

These projections indicate that the number of elderly persons in the total population will increase both absolutely and proportionately and will require additional public transportation services. The elderly group, now just over 10 percent of the population, will increase to an estimated 12 percent by 1990. Approximately 19 percent of the elderly are physically handicapped in some way which precludes their use of regular fixed-route transit. The elderly handicapped often require door-to-door transit, and may consequently be considered potentially heavy users of SRT. If the proportion is the same in 1990 as today, urban areas will contain an estimated 5.5 million elderly handicapped (National Transportation Trends and Choices, 1976, p. 42 to 43).

Special paratransit service will also be required by the nonelderly handicapped. The current estimate is that there are 3.3 million nonelderly handicapped Americans who need special transit service; this population is estimated to increase to 3.7 million by 1990 (Voorhees, 1977, p.8). Adding both groups that require special transportation gives a total estimate of 9.2 million handicapped who will require paratransit service by 1990.

Another important demographic effect on transportation needs is the increasing size of the work force. The labor force will increase from 93 to an estimated 120 million by 1995. The percentage of working women in the labor force will increase from about 39 to an estimated 45, and in 1995 there will be many more two-worker families (National Transportation Trends and Choices, 1976, p. 45). Total annual trips will increase at an estimated compound annual rate of 1.29 percent. Initially, this will mean more automobile travel but, as traffic restraints (automobile restricted zones, pedestrian-transit malls, and freeway ramp metering) become more apparent and public policy increases the public's acceptance of multiple-occupancy vehicles, transit will increase its market penetration.

Public involvement with multiple-occupancy vehicles has increased significantly since the 1973 oil embargo. Some examples of this involvement, which were very rare less than a decade ago, are: Operation Oxygen which operates in the Los Angeles basin (Voorhees, A. M. [A], 1974, p. 8; Voorhees, A. M. [B], 1974, Appendix A), the 3M Commute-A-Van program (Highway Users Foundation, p. 7; Voorhees, A. M. [A], 1974, p. 10; Owens, R. D., 1974; Forstater, I., 1976, p. 58), transit authority organized car pooling in Knoxville, TN, (Voorhees, A. M. [A], 1974, p. 20; Voorhees, A. M. [B], 1974, p. 5; Forstater, I., 1976, p. 56) and the assortment of multiple-rider inducement concepts being used in Washington, DC, (Rennie, L. C., 1973, p. 15; Voorhees, A. M. [A], 1974, p. 7, 17; Voorhees, A. M. [B], 1974, p. 10). The private automobile remains as the dominant mode of transportation and will continue to do so in the foreseeable future, but the alternative shared modes of transportation are increasing and gaining a share of the travel market.

Suburbanization of the population will continue. Within standard metropolitan statistical areas (SMSA), the population in central cities will decline from about 32 percent to an estimated 24 percent of total population while the suburban population will increase from 37 percent to an estimated 42 percent of total population and nonmetropolitan areas from 31 percent to 33 percent (Statistical Abstract of the U.S., 1975, p. 17). Similarly, employment in central cities will decline from 52 to an estimated 45 percent, while the suburban share of metropolitan employment will increase from 48 to an estimated 55 percent. Consequently, there will be proportionately fewer jobs that can be effectively served by conventional fixed-route transit and more jobs in areas where SRT will be suitable.

Though population growth in small cities and towns will be proportionately greater than in metropolitan areas, in most instances these cities and towns are too small to warrant conventional fixed-route transit. SRT operations providing standing-order service for workers and demand-responsive service for shoppers and the transportation-disadvantaged would be a cost-effective method of providing public transit in small cities (Remak, 1975, p. 51-61).

2.1.2 Automobile Transportation

Realistic projections for the balance of this century show that energy shortages will develop and fuel costs will increase significantly. However, automobile usage is extremely inelastic with respect to gasoline costs, as evidenced by the increasing use of automobiles in countries where gasoline costs are two, three, and even four times greater than in the U.S. The automobile will inevitably continue to be the main transit mode through the end of the century. Increasing costs for gasoline will be offset by curtailment of vehicle miles traveled and by the adoption of more economical cars. Costs per passenger-mile associated with advanced-design automobiles beyond 1980 may in fact be lower than those for the average 1975-technology car (Energy Resources Council, Vol. II, 1976, p. 13-6).

Despite dependence on the automobile, the increasing scarcity of gasoline and auto disincentives (such as congestion, automobile capital costs, and limitations on automobile access in certain city areas) will create additional demands for public transportation. Although automobile usage may change only slightly, a modest decline in vehicle miles traveled can be expected even though person-trips by automobile will continue to increase -- the effect on transit usage will be significant. At the present time, approximately 89 percent of all trips are taken by private transportation while bus and rail transit serve about 4 percent. A transfer of 1 percent of automobile trips to public transportation would increase public transportation ridership by approximately 25 percent.

Modest auto disincentive plans are being implemented in the larger cities. Auto-free zones, high parking charges, and preference lanes for higher-occupancy vehicles are already in use. Such programs will increase as the federally mandated Transportation Systems Management (TSM) plans are adopted.

2.1.3 Areas of Applicability and Relative Costs of Fixed-Route and Demand-Responsive Transit

Evidence has been accumulating over the last few years which suggests that, in certain suburban communities, DRT can operate at significantly lower costs per passenger and attract greater ridership than fixed-route transit. The cities of Orange, CA (Hollinden, 1977, p. 28) and Mount Pleasant, MI (Michigan, 1976, p. 9-10) provide such evidence as shown in Table 2-1. In both cases, a DAR system was converted to fixed-route (with the same vehicles, drivers, and wages). Fixed-route service attracted far fewer riders and incurred a far higher per-passenger cost than DAR. This result was graphically emphasized when in both cases the fixed-route services were reconverted to DAR, whereupon ridership rose and per-passenger costs declined to original DAR levels. Again, in Regina, Saskatchewan, conversion of suburban fixed-route service to an integrated DAB service resulted in both reduced costs and increased ridership (Atkinson, 1974, p. 1-2).

TABLE 2-1

RESULTS OF
CONVERSION OF DIAL-A-RIDE TO FIXED-ROUTE
AND BACK AGAIN IN TWO SUBURBAN COMMUNITIES

	Mount Pleasant Michigan	City of Orange California
Original DRT		
Fleet Size	4 veh.	17 veh.
Daily Ridership	210 pass.	627 pass.
Cost Per Ride	N/A	$3.27
Conversion to Fixed-Route		
Fleet Size	4 veh.	12 veh.
Daily Ridership	74 pass.	301 pass.
Cost Per Ride	$5.14	$8.65
Reconversion to DRT		
Fleet Size	4 veh.	12 veh.
Daily Ridership	300 pass.	555 pass.*
Cost per Ride	$1.91	$2.28*

*This is updated information as of October 1977 supplied by Orange County Transit District.

It is apparent from these examples that the thesis that DRT can do a better job than fixed-route in some suburban areas is supported by experience. Though this must not be extrapolated to mean all suburban areas, it certainly calls the attention of transit organizations to review the effectiveness of their operations in suburban areas and to keep an open mind about implementing DRT to serve the suburban community and feed the fixed-route system.

2.1.4 Transit Costs and Wages

Transit operating costs have more than doubled in the decade 1967-1977 (Sale and Green, 1978, Tables 1 and 2). Annual operating costs have increased from 1.6 billion dollars to just over 4 billion. Inflation accounts for 48 percent of the increase ($1,143 million out of the $2,398 million). Increased wages, fringe benefits, and inflation account for the second largest share of the increase, 28 percent of the total, a $680 million increase. Furthermore, this rate of increase in labor costs is unlikely to lessen, since transit labor rates have increased as fast as those of other government employees in the major metropolitan areas (Sale and Green, 1978, p. 4). Few ways exist in which labor productivity in conventional transit can be improved and, for this reason, costs-per-revenue-hour and costs-per-passenger are anticipated to increase even when the effects of inflation are removed.

These costs are already causing operators to curtail conventional transit in some suburban areas where ridership is typically low. SRT service, however, has hourly labor costs which are usually about one-half those of conventional transit (Altshuler, 1976, p. 99 and Kirby, Paratransit, 1975, p. 89). This labor cost ratio has tended to remain relatively constant as the absolute wages of transit and paratransit drivers increased. Thus, while labor costs will increase, SRT is expected to maintain its cost advantage over conventional transit in providing service in low-density suburban areas. Though there will undoubtedly be pressure to increase SRT wages, fringe benefits, and work-rule constraints to "catch up" with transit operators, the private taxi company owner can be expected to resist such pressure in order to remain competitive and economically viable.

2.2 PASSENGER-MARKET PENETRATION

2.2.1 Present Passenger Market

In 1975, the nation's 188 million persons over age 5 generated approximately 149 billion person trips ([1970] Nationwide Personal Transportation Study). Of these, private transportation, including automobiles, trucks, and motorcycles, accounted for 88.7 percent or 132 billion person-trips. Public and other transportation accounted for the remaining 11.3 percent. Within public transportation, bus and rail transit carried 5,866 million person-trips or 3.9 percent of the total (Transit Fact Book 1975-1976), school buses accounted for 7,112 million, and taxis accounted for 3,409 million or about 2.3 percent of the 149 billion total (Wells, 1975, p. 2-1). Of the taxi trips, SRT accounted for approximately 1 percent, or 34 million person-trips, a miniscule share (0.023 percent) of total personal travel by all modes. Most of this ridership is in Washington, DC, and Little Rock, AR, where SRT services are offered widely.

2.2.2 Projected Passenger-Market Penetration

In projecting the future travel demand and the SRT passenger-market penetration starting from the present passenger market, a wide bibliographic search (Fielding, Task 2: Concept Development, Section 2.3.8) was made for estimates from available sources (generation of new demand-forecast data for travel was beyond the scope of this study). The results are presented in Table 2-2 which projects the annual person-trips through 1995.

Table 2-2 is based on assumptions of moderate evolutionary changes such as a one percent compound annual rate of population increase; extrapolation of geographic, age, and other changing demographic characteristics of the population; and non-extreme readjustments in our future "automobilized" society, particularly where fuel consumption, air pollution, or vehicle congestion are most acute.

If steps are taken to develop SRT's potential, it is estimated that 10 billion passenger-trips will be made annually by SRT in the 1990's -- nearly three times the number of ERT passenger-trips presently being

TABLE 2-2

ESTIMATED ANNUAL PERSON TRIPS BY MAJOR MODE OF TRANSPORTATION

Period	1970 - 1975		1990 - 1995	
Type of Vehicle	Annual Person Trips	Percent of Total Trips	Annual Person Trips	Percent of Total Trips
	(millions)		(millions)	
PRIVATE TRANSPORTATION (Includes auto, non-business truck, motorcycle, and auto and van pooling)	131,937	88.7	199,961	84.7
PUBLIC TRANSPORTATION				
Taxi (ERT)	3,375	2.3	1,889	0.8
(SRT)	34		9,915	4.2
Transit (bus and rail)	5,866	3.9	12,985	5.5
OTHER (Includes school bus)	7,548	5.1	11,331	4.8
TOTAL ANNUAL TRIPS	148,760	100.0	236,081	100.0

carried. The estimated increase in SRT ridership is achieved partly at the expense of diversion from ERT (declining at a compound annual rate of 2.9 percent) and partly from growth in overall taxi ridership (increasing at a compound annual rate of 6.4 percent). This projection is consistent with, but generally more conservative (i.e., lower SRT demand rates are used in this study) than, a number of recent paratransit studies -- e.g., Voorhees (1976) Study of Future Paratransit Requirements; Billheimer (1976) Deployment Scenarios for Integrated Regional Transportation Networks; and Ward (1975) An Approach to Region-Wide Urban Transportation.

Although the forecasts in Table 2-2 have been developed using the best published information available, caution is recommended in using them. Based on the range of projections in the above-cited references, the authors believe that the 1990-1995 SRT projections are probably accurate to within only plus or minus 25 percent. The primary reason for this uncertainty is a paucity of reliable statistics on taxis. Current information varies substantially, and the 1974 National Transportation Survey excludes taxis except for some inventory data (1974 National Transportation Report, 1975, p. 165).

2.3 CHANGE FACTORS

In addition to the demand for SRT created by the public, other factors such as the business climate, environmental policies and regulations, government policies, and the international energy situation will have an impact on the implementation of SRT.

2.3.1 Financial Condition of the Taxi Industry

Reliable data concerning the economic viability of taxi companies is very limited since these private companies are not required to publish statements of financial condition. A mail survey conducted in 1976 (Control Data Corp., Wells Research Company, 1977, p. 5-4) suggests that a significant proportion of taxi companies have and are experiencing economic difficulties: 25 percent of taxi companies responding state that revenues do not cover out-of-pocket costs, and 50 percent state that revenues do not cover capital replacements. Though mail-in surveys may result in some exaggeration because of the subjective nature of the responses, the general conclusion is confirmed in a study for the California Department of Transportation by Davidson and Gaylen (Davidson, Taxicab Management, Dec. 1977, Table B). Based on objective information, the study shows a failure rate in 1976 of 6.7 percent of all California taxi companies. Moreover, the rate of failure of taxi companies increased between 1972 and 1976 from 2.7 to 8.5 times the average California small-business failure rate; the study suggests that the deterioration is not due to a general economic decline but is a consequence of financial problems in the taxi industry.

The symptoms presented by these statistics are similar in many respects to the situation in the conventional transit industry in the early 1960's. As conventional transit companies were unable to continue operations, it became necessary for transit districts to be formed and to take over their operations at public expense. (Subsidies provided to conventional transit and specialized services for the elderly and handicapped who are traditional taxi users now contribute to some degree to erosion of taxi company viability [Black, 1974, p. 619-633]). To avoid a similar situation in the taxi industry, it is appropriate to encourage implementation of SRT to help forestall a widespread need to take over taxi operations as part of public transportation or to otherwise replace the services that taxis provide. The importance of insuring that private taxi transportation does not fail and have to be taken over by public agencies is more apparent when it is realized that the taxi industry is financially bigger than the bus and rail mass transit industries combined; in 1975, annual passenger revenue was $3.358 billion for the taxi industry vs. $1.861 billion for bus and rail transit; employment was 365,000 vs. 160,000 (Control Data Corp., Wells Research Company, March 1977, p. D-8).

2.3.2 Energy

Immediately prior to the 1973 oil embargo, U.S. crude oil imports were approximately 18 percent of domestic oil production; this increased to 65 percent in 1976 (Shonka, 1977, p. 347). Thus, an oil embargo would now cause a more serious transportation crisis.

SRT's passenger-market penetration projected in this study, however, assumes that no major energy crisis occurs; in other words, fuel prices will increase steadily, but there will not be another oil embargo. If an oil embargo were to occur, however, the SRT projections could be significantly below actual demand.

If SRT is to be included in the government's energy contingency planning, then it must be realized that conversion from ERT to SRT has to be done in advance of an embargo because the conversion takes months or years. Though some relatively inefficient shared-ride operations could probably be implemented on an emergency basis, the critical constraint is SRT personnel training which cannot be accomplished effectively in less than several months.

2.3.3 User-Side Subsidies

User-side subsidies are a particularly appropriate method of subsidizing the transportation-disadvantaged in low-density suburban areas where the general public is affluent enough to afford to pay the full price of transportation. For example, through user-side subsidies, the disadvantaged could spend their "chits" or "scrip" for the transit mode that best meets their needs (Crain and Fitzgerald, 1975). Taxi companies can be expected to respond to this new revenue source and provide the demand-responsive service that the transportation-disadvantaged desire. Initial results from Danville, IL, and other areas where the concept is being tested are encouraging (Bautz, 1977, p. 12). The subsidy per passenger-trip is on the order of \$1.00 -- a modest amount considering the low-density door-to-door service being provided. In fact, it appears that SRT, with subsidy going directly to the user, is often the least expensive and most efficient method of serving the transportation-disadvantaged.

2.3.4 Taxi Industry Employment

The cost-effectiveness analysis (Section 4.3.1) shows that SRT may have a productivity of about 184 percent of ERT's productivity. Thus, 1995 ERT employment would be an estimated 55 percent and SRT employment would be an estimated 158 percent for a total of 213 percent of the 1975 taxi-industry employment. The total employment in the taxi industry is expected to grow from 365,000 in 1975 to an estimated 775,000 in 1995 (a compound annual increase of 3.8 percent).

3.0 SHARED-RIDE TAXI SERVICES

In the preceding section, demand estimates for SRT were established on the basis of certain services which it provides. In this section, these services are discussed and defined, leading to a specific statement of SRT's projected role.

3.1 SHARED-RIDE TAXI CONCEPT

The SRT concept is an extension of conventional taxi service which permits existing taxi companies to reduce fares and improve productivity by providing a shared-ride service. Basically, the SRT concept provides for two or more passengers (or parcels) going in the same general direction to share taxi transportation, even though they are picked up from and/or delivered to separate locations. SRT's accomplish this by making detours to pick up and deliver passengers (or parcels) and, in doing so, they transport more passengers per mile (or per hour) than can be transported by ERT. This is illustrated by a comparison of two passenger trips being served by ERT or by SRT in Figure 3-1.

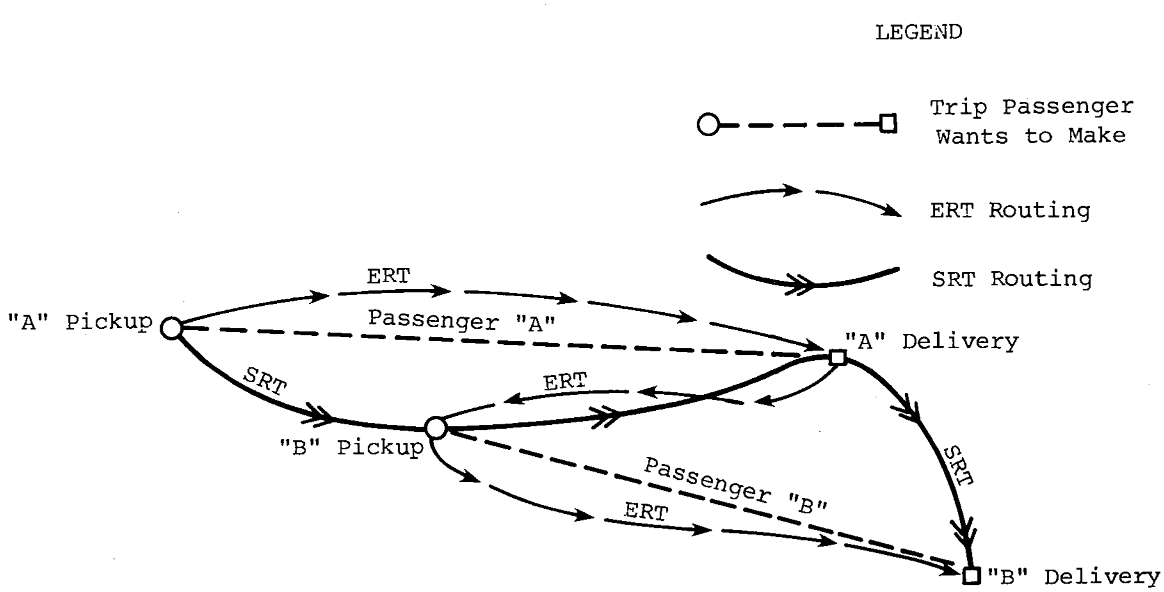


FIGURE 3-1. SHARED-RIDE TAXI VS. EXCLUSIVE-RIDE TAXI CONCEPT

Shared riding in taxis is explicitly permitted by ordinance in only a few U.S. cities; elsewhere, taxis are best known as providers of "premium" service, furnishing transportation to only one party at a time. SRT can accomplish all of the ERT functions because SRT does not eliminate ERT but augments it by adding the advantage of shared-ride service.

In those communities which do permit shared-ride taxi operations, the concept has proven to be relatively successful despite the fact that control is by nonautomated techniques and limited by the capabilities of the human dispatchers. The national average for ERT productivity is about three passengers per taxi-hour (according to the International Taxicab Association [ITA]). However, SRT can significantly increase productivity. Taxi operations in Davenport, IA, have shown productivities of over four passengers per taxi-hour (Davis, October 1974); in Little Rock, AR, taxi productivities of six (and sometimes up to ten) passengers per taxi-hour have been reported (Hall, J., private communication, April 1977); and about six passengers per taxi-hour are achieved in Red Bank, NJ, (Summers, D., private communication, December 1977). These efficiencies represent significant improvements over ERT; a phenomenon which has been noted in other SRT operations in cities such as Hicksville, NY; Pensacola, FL; Washington, DC; and Jacksonville, FL, where SRT is an ongoing viable form of public transportation.

These existing SRT operations demonstrate that even when limited by nonautomated control techniques, SRT is an economically viable and more productive form of taxi transportation than ERT. (The limitations of human dispatchers and the need for automation are discussed further in Section 5 of this report.)

Although SRT is often interpreted to mean the use of a sedan-type vehicle, numerous SRT services use vans and, occasionally, small buses. In theory, any size vehicle could be used for SRT; the SRT operator chooses the vehicle size most appropriate for the local operating environment. In practice, however, large buses would seldom be used because of the capital cost, excess capacity, and possible conflict of interest with bus companies.

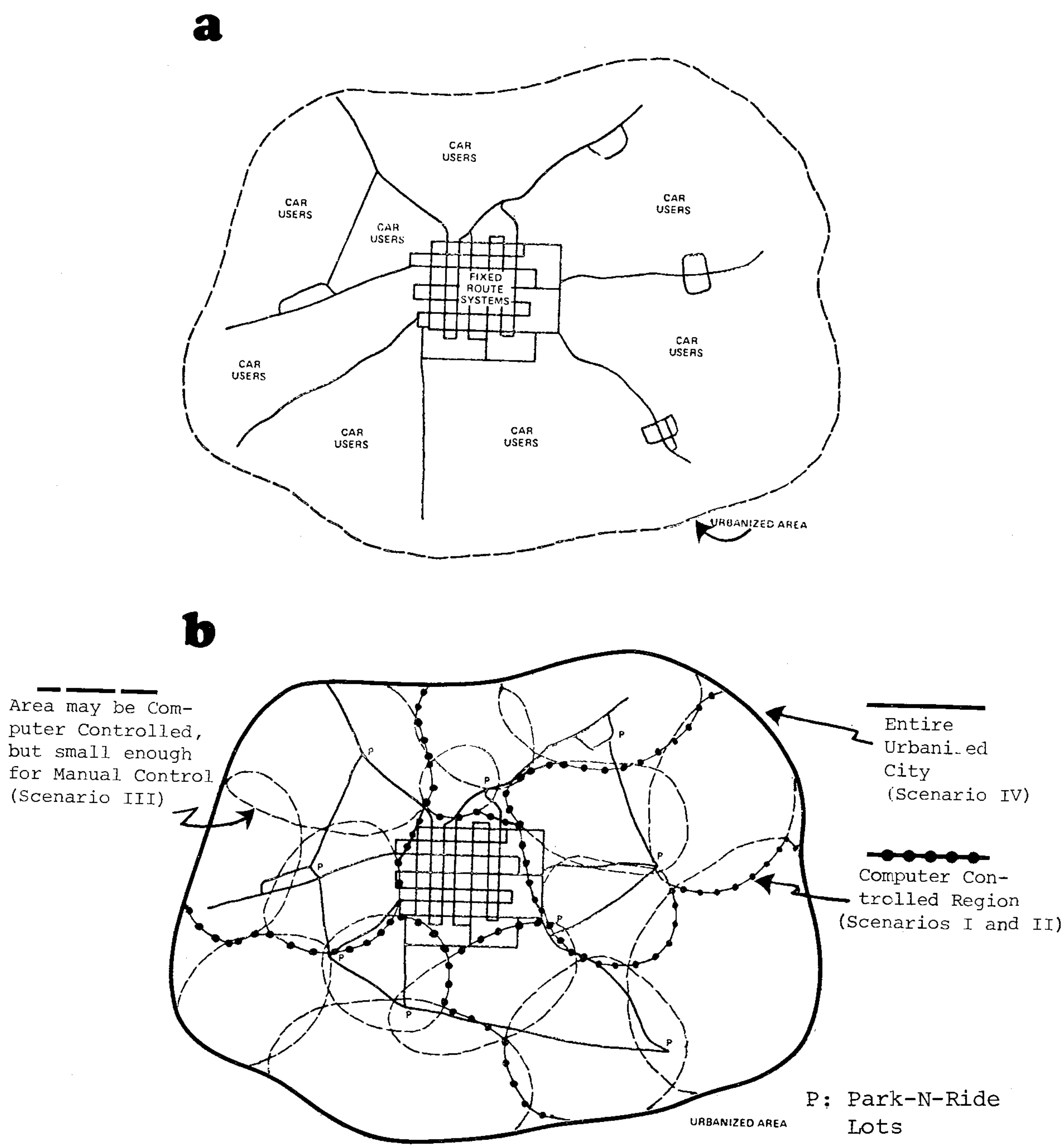
3.2 INTEGRATION OF TRANSIT AND PARATRANSIT

In addition to the ability of SRT to provide a more efficient form of taxi transportation, it also has the potential to feed regular transit with an efficient shared-ride service. This introduces a new dimension to taxi service because the integration of transit and paratransit yields a service which has greater benefits than the sum of the two component parts. Conceptual definitions of integrated transit have been given in studies by Ward (1974 and 1975), Remak (1975), Batchelder, et al. (1976), and Billheimer, et al. (1976); practical operating experiences with systems that incorporate integrated transit features are now becoming available from several locations. The following discussions are based on these studies and operations.

3.2.1 Integration Concept

An integrated transit system is a mix of transportation elements that complement and feed each other throughout a consolidated urban and suburban area so that the total service and ridership is greater than that of each element if operating separately. The evolution of such a system is shown conceptually in Figure 3-2.

In medium and large urban areas, the principal element of the integrated system is a fixed-route arterial network connecting high-demand density areas and extending partly into suburban or low-demand density areas. For the most part, however, low-demand density areas (where fixed-route buses often cannot be cost-effective) are served by a variety of paratransit modes, such as SRT, car pools, van pools, DAR, DAB, ERT and, perhaps, subscription buses. In contrast, the high-demand density areas, most notably the CBD, would be served by arterial fixed-route system and perhaps by downtown circulating buses, SRT, jitneys, and flexible-route paratransit vehicles. Finally, and perhaps most importantly, the parts of the transit system must be well integrated. Transfers at the suburban and CBD terminals of the arterial network must be quick, convenient, safe, and in pleasant surroundings. Shopping malls and other major activity centers could be ideal locations. The



AFTER: Ward, 1974, p. 184.

FIGURE 3-2. EVOLUTION OF INTEGRATED TRANSIT AND PARATRANSIT. Shows evolution from the typical fixed-route systems today (see "a" above) into an integrated demand-responsive system (b). Smaller, manually controlled SRT areas, each with about 70,000 people, are combined to form computer-controlled modules for areas with populations of about 200,000. Fixed-route transit routes are expanded and integrated with SRT and suburban park-n-ride terminals to provide a mix of modes operating cooperatively.

reliability of the transfer (the assurance that the passenger will be met by the desired vehicle without an excessive wait) is a crucial factor in gaining public acceptance.

3.2.2 Operating Experience with Integrated Transit and Paratransit

Though the concept of integrated transit is attractive, it has never been fully established in a metropolitan area. Case studies have been reported for small communities (Kirby and Miller, 1975), and there have been numerous planning studies. But, so far, SRT has not been fully integrated with transit to provide area-wide coverage for passengers and goods. Some of the principles of integrated transit have, however, been tried over the last few years. The five examples cited herein are probably the most significant, even though the DRT portion usually has not been operated by taxi companies.

In all cases, the principal method of requesting service in the lower-density suburban areas is by telephone. The request is recorded at a control center into a manual, computer-aided, or fully computerized control system. The control system assigns a vehicle to pick up the passenger at the passenger's point of origin and take him/her to the desired destination which can be either another point in the service zone or a transfer point to a fixed-route bus which will transport the passenger into another zone. (The total service area in integrated transit must generally be divided into several smaller service zones within which door-to-door service is provided by DRT without a transfer. When the origin and destination points are in different zones, transfer to a fixed-route bus which traverses both zones is necessary.) Usually, the passenger has to wait about 20 minutes from the time of the telephone call to the time of pickup, or he/she may arrange the trip in advance, or he/she may arrange a standing order to be picked up at the same time each day without daily requests.

3.2.2.1 Regina, Saskatchewan

The City of Regina was the first in North America to implement integrated transit features on a large scale. Fixed-route bus services in suburban areas were truncated at convenient transfer points and a DRT system called "Telebus" was introduced to provide door-to-door service to the outlying suburban areas (Atkinson, 1973). The DRT service is provided by smaller buses operated as a zonal DAB. The DRT and fixed-route systems are synchronized for convenient transfers. Drivers in both types of service belong to the same organization and are paid at similar transit-employee scales.

The first DRT zone was started in September 1971 and, as operating experience was obtained, other zones were introduced. Many suburban areas of the city are now served by a fleet of 26 buses, with 5 DRT zones in peak periods and 12 zones in off-peak periods (D. Hnetha, private communications, March 1977). Standing (or periodic) orders for service are recorded on a computer bookkeeping system, and lists of stops are printed each day for the drivers (McAdoo, 1975). In the first full year of operation, one direct result of replacing the fixed-route system with truncated fixed-route and DRT integrated services was that the overall operating subsidy was reduced by $67,000. At the same time, ridership doubled in areas of low population density and high income (Atkinson, 1974, p. 1, 2). This supports the thesis that an integrated transit system's effectiveness can be greater than the sum of its individual components though care must be taken in extrapolating Canadian experience into the U.S. environment and conclusions should not be based on a sample of one system.

3.2.2.2 Ann Arbor, Michigan

The system operated by the Ann Arbor Transportation Authority (AATA) is similar in many ways to Regina. DRT zones serve the outlying portions of the city and feed into arterial fixed-route lines. The DRT zone boundaries are changed to conform to peak/off-peak demand requirements, and the entire city is served by DRT on Sundays.

A computer-aided control system has been implemented to schedule and dispatch the Ann Arbor vehicles (Potter, 1976 and Neumann, 1977). It has been used routinely since August 1975 with voice dispatching, and digital communications have recently been added.

The Ann Arbor system evolved in a logical series of steps similar to the Regina system (Guenther, 1975). A single DRT zone was established on an experimental basis in September 1971. A 2.5 mill property tax was proposed to cover the cost of expanding the service and was passed in April 1973 by a 61-percent vote. (In a recent survey, 83% of the respondents said they would vote to continue this subsidy [Passenger Transport, December 9, 1977].) The local taxi company was invited to bid on operating the DRT system but declined. The taxi operator later sued, but in June 1972 the case was decided against him (Lax, 1973 and Gundersen, 1977). Since 1973, additional zones have been added so that, as of mid-1976, there were 13 DRT zones in peak periods, and ridership had grown from 677,000 in 1973 to over 2,000,000 today.

3.2.2.3 Santa Clara County, California

The most ambitious integrated transit program to date was inaugurated by the Santa Clara County Transit District (SCCTD). Although the system is no longer in operation, none of the postmortems attribute its failure to the concept of operation (Bechtel, 1975; Carlson, 1976; Pott, 1976). The attractiveness of the service created a crisis in expectations. Demand for service and the expectations of the public far exceeded the ability of the controllers and the computer system to handle the requests and the Transit District's ability to supply equipment (Bechtel, 1975). Service was fully installed on December 21, 1975, and had to be withdrawn 20 weeks later when all the equipment was switched to fixed-route service. There are many reasons for the failure, but the three most important appear to be:

(a) The all-at-once inauguration of service. Had the Transit District adopted an incremental strategy in which demand-responsive service was introduced in a sequence of expansion phases, then many of the personnel, equipment, and institutional problems could have been solved and the tide of discontent might have been stemmed (Pott, 1976, p. 9 and Metropolitan, May/June 1976, p. 14-22).

(b) The system was operated entirely by the District without participation of local taxi companies. A successful suit by the taxi companies based on a clause in the charter of the District placed the District in a position of considerable financial liability and could have resulted in the District having to take over all taxi services.

(c) The cost per trip was excessive due to the relatively high cost of the District's transit labor and the low efficiency of operations because of the all-at-once inauguration (Bechtel, 1975).

3.2.2.4 Orange County, California

The Orange County Transit District (OCTD) has adopted an incremental development strategy. The county has been divided into zones which are each served by one or more routes of the district-owned and -operated fixed-route bus system. Eight of the zones were selected for initial development as manually controlled DAR or SRT zones. Some are contiguous to allow development of proper transfer techniques. When adequate computer control becomes a reality, the manual control zones -- which range in size from 7 to 20 square miles -- can be aggregated into larger computer-controlled zones (DAVE Systems, 1974).

Currently, demand-responsive service is being offered in three zones. The minibuses, radios, and some facilities are owned by the District, although a significant number of privately owned taxis are also employed. All DRT services are operated by private enterprise. Each contractor coordinates service with the District's fixed-route bus service and transfers between DRT minibuses and taxis from different zones and between DRT and fixed-route buses are common. A County-wide DRT service for handicapped persons was initiated in the summer of 1977. In future planned expansions, combinations of small buses and taxis will be used, and taxi companies are expected to provide a substantial portion of the service. (A suit by the taxi companies contested the District's right to provide DRT services but, after several appeals, the courts found in favor of the District.) Costs have been less of an issue in Orange County than in other integrated transit examples. This is directly attributable to the lower costs of the private DRT operator compared to the public-agency labor used in the other examples (Hollinden and Blair, 1977).

3.2.2.5 Rochester, New York

To date, the Rochester-Genesee Regional Transit Authority's DRT program has been primarily oriented toward the development of a computer control system under an UMTA demonstration grant. As a part of that development, automated, synchronized transfer techniques between fixed-route and DRT vehicles have been tested, forming the beginning of an integrated transit system.

The system has been operated by drivers who are employees of the Transit Authority and who are paid at the transit wage scale. This has contributed to the high cost of operations. New DAR services due to start in Spring 1978, however, will be operated by competitively selected private operators, which may reduce costs (Urban Transport News, Jan. 16, 1978, p. 12).

3.2.2.6 Tentative Lessons

Three tentative lessons appear from these partial integrated transit projects that must be considered in defining the role of SRT:

(a) Involvement of the private sector is a key factor in keeping the cost of the DRT element down to an acceptable level (Rochester and OCTD), and such involvement may also avoid potential legal issues (Ann Arbor, OCTD, SCCTD).

(b) Overall cost savings may be achievable by truncation of fixed routes and substitution of DRT (Regina), especially in off-peak periods (Ann Arbor).

(c) Implementation of integrated transit must be done incrementally to avoid an overwhelming burden on staff and system control (SCCTD).

3.3 ROLES OF SHARED-RIDE TAXI

The roles of SRT fall into two principal and one supplemental categories which can operate simultaneously:

(a) SRT performs the same role as ERT except that, by ride sharing, SRT does the job more efficiently and at a lower cost per trip. Basically, a typical ERT productivity is 2 - 3 passengers per taxi-hour. Converting from ERT to SRT could increase the productivity to 4 - 6 passengers per taxi-hour (see Sections 3.1 and 4.3.1). Since this would reduce the fleet size (see Section 4.3), the operating costs would also decline, reducing the costs per trip.

(b) SRT feeds a fixed-route mass-transit (FRT) system in addition to (a) above, thereby increasing the effective service area as well as increasing both fixed-route and SRT ridership. An excellent example of a Dial-A-Ride (DAR) integrated system increasing ridership is the Ann Arbor system where the ridership increased from 677,000 in 1973 to over 2,000,000 today (see Section 3.2.2.2). Most of this increase is directly related to the increase in the service area. While the Ann Arbor system is not SRT, it is expected that the effects of integrating SRT with FRT will be similar.

One of the limitations of FRT in the suburbs is that passengers will not normally walk more than 1/4 mile to use the FRT system. This is especially a problem for the elderly and the handicapped. Introducing a flexible transit element such as SRT to collect and/or distribute passengers should encourage increased total ridership and improve the economic viability of both the taxicab company and public transit.

(c) SRT companies enter into separate contracts to perform supplemental roles such as a community DAR, small goods movement, and transportation of the elderly and handicapped. The contract will insure that the objectives of the taxicab operator are consistent with public objectives. This public/private involvement allows the taxi industry to participate in innovative paratransit systems.

These roles are summarized in a list of "potential generic roles," Table 3-1. Also shown in this Table are the percentage of existing taxi companies that provide the indicated service and the key features of SRT that are implicit in performing its role.

TABLE 3-1

OVERVIEW OF THE POTENTIAL GENERIC ROLE OF SHARED-RIDE TAXI SERVICES AND FEATURES

A. Potential Services Provided by a Shared-Ride Taxi Co.	Present Percentage Taxi Companies[1]
1. Shared-ride taxi service (primary mode of operation)	N/A
2. Exclusive-ride taxi service (private and emergency)	96.1
3. Dial-a-ride service (many-to-many, many-to-one, and zonal)	3.6
4. Hail-a-ride and stand service (includes returning commuters)	N/A
5. Subscription (or periodic) service (includes morning commuters and school busing)	Probably All
6. Integration with fixed-route transit (synchronized transfers)	N/A
7. Intercity transportation feeder (bus, rail, and air-line limousine)	N/A
8. Service for the handicapped (physical and mental)	25.0
9. Goods movement (priority and deferred)	71.4
10. Jitney service (fixed-route, variable schedule)	N/A
11. Fixed-route deviation (fixed-schedule check stops, demand-responsive in between check stops)	N/A
12. Fixed-route service (low density and off-peak routes)	3.9
13. Special charter or contract services (long distance trips, field trips, government and company employees, hospital patients, welfare trips)	Probably All

B. Key features implicit in generic service role of shared-ride taxi

1. Simultaneous provision of several types of service and flexible movements of vehicular resources between them
2. Several levels of priority and fares (zonal, meter, or formula)
3. Synchronized transfers between SRT and conventional transit
4. Control system initiated by the passenger by telephone or hail; scheduling process (manual, computer-aided, or fully automated); and radio dispatch (voice or digital)
5. Credit and subsidy provision (service-side and/or user-side)
6. Private operators (with vehicles driven by employees, vehicles leased to independent-contractor drivers, or vehicles owned by independent-contractor drivers)

SOURCE: After: Wells and ITA, 1975, p. 3-1.

[1]Approximate percentage of taxi companies that are presently providing the indicated services, based on a questionnaire mailed to 6,467 active operators in Fall, 1974. There were 667 usable responses to the question on services provided -- a 10.3 percent response, which the authors of the study considered to be a representative sample. "N/A" indicates that no information was available for this element of service. Though Wells does not breakout subscription or contract service in the form shown above, it is probable that virtually all taxi companies provide these services.

4.0 COST-EFFECTIVENESS OF SHARED-RIDE TAXIS

Previous sections have shown that SRT services can be supplied, that there is a demand for SRT, and that it is needed. Key questions to be addressed now are: is it a cost-effective mode of transportation; can the public expect lower fares; can SRT be provided at a profit by private taxi companies; and what effect will SRT have on service quality?

4.1 SCOPE OF ANALYSIS

Determination of the cost effectiveness of SRT is a complex problem which is compounded because there is a paucity of material available with which to calibrate the cost-effectiveness model. It was important to simplify the problem to a manageable scope while retaining realism, and to base the model upon parameters which can, to a maximum degree, be calibrated by available data from SRT, ERT, and DAR operations. The best available mathematical demand and supply models were utilized though their limitations are apparent in the analysis; future efforts can be expected to yield improved forecast techniques which may then be used to refine the results of this analysis.

Throughout the cost-effectiveness analysis, ERT is the baseline reference since most SRT systems will evolve from ERT operations. This approach has two significant benefits:

(a) calculations of the incremental difference between SRT and ERT are more accurate than if the SRT values had been developed "from the ground up" and

(b) using input data from a specific ERT company, the SRT operating options available to that company can be projected and used as a guide in making conversion decisions.

The analysis assumes an instantaneous or overnight change from ERT to SRT followed by steady-state operating conditions and is not concerned with transient phenomena. However, the cost analysis takes into consideration startup costs involved in converting from ERT to SRT.

It should be realized that there is a distinct difference between the cost-effectiveness of SRT and the cost-effectiveness of the CCS which controls the SRT system. Discussion in this section is concerned only with SRT effectiveness; CCS effectiveness is discussed in subsequent sections of this report.

4.2 SUMMARY OF ANALYTICAL APPROACH

The three-step approach used to analyze SRT cost-effectiveness is summarized here (the detailed analysis is presented in Potter, Task 3: Systems Analysis, 1978, and Carberry and Simpson, 1977). The first step was to develop a model of the service supplied, the next step was to determine the demand that could be generated by such a service, and finally, a model was developed of the costs and revenues of such a service. The process is represented schematically in Figure 4-1.

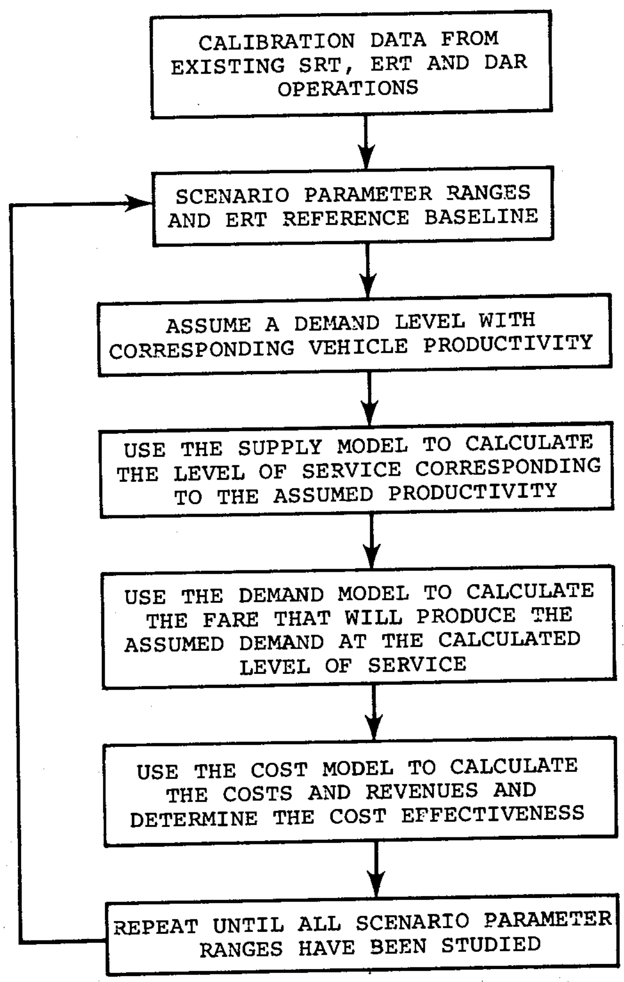


FIGURE 4-1

OVERVIEW OF METHOD FOR CALCULATING SRT EFFECTIVENESS

The cost-effectiveness analysis starts with a definition of the scenario; e.g., the service area size and the taxi fleet size. In this study, four basic scenarios were considered -- see Figure 6-1.

4.2.1 Supply Model

An extensive literature search for DRT supply models revealed six alternatives. Of these, the Flusberg and Wilson (1976) descriptive supply model was selected for two reasons: first, the asymptotic values given by this model are realistic, and second, the model has been calibrated by data from DRT programs and appears to give accurate supply predictions. Key input variables to the supply model are the scenario fleet size, scenario service area, and the assumed productivity in passengers per taxi-hour; the principal output is the level of service corresponding to the assumed productivity -- i.e., the ratio of the time from phone call to arrival at destination divided by the time to make the same trip by automobile.

4.2.2 Demand Model

The key parameters affecting the demand for SRT service are the fare structure, the level of service provided, the uncertainty of the service (or lack of reliability as measured by the average absolute value of the difference between the time the passenger expected to be picked up and the actual time the passenger was picked up), and external parameters (such as the attractiveness of alternative transportation modes and the possible effect of gasoline prices). A multivariant demand function was developed for these four factors and calibrated with demand elasticities available from the literature. It must be recognized that the available information on these demand elasticities is very limited; a reasonable estimate can be made of demand elasticity with respect to fare; a less reliable estimate can be made for the demand elasticity with respect to level of service; demand elasticities with respect to uncertainty and external parameters are, however, no better than educated guesses.

Nevertheless, the model has to incorporate these important factors if for no other reason than to be able to define the sensitivity of the analysis to changes in their values.

Key input parameters to the demand model are the assumed productivity and the corresponding level of service; the principal output is the average fare which will create the assumed productivity at the corresponding level of service.

4.2.3 Cost Model

ERT operating costs per hour were used as the reference cost, and incremental costs were added to this to determine SRT costs. All costs are based on 1976 value dollars for consistency. To avoid confusing ERT profits with profits from SRT, it was assumed that the ERT company was at a break-even operating point before conversion to SRT (if the ERT company was making a profit, then this amount could simply be added to the incremental SRT profit to come up with the total company profit).

Key input parameters to the cost model are the assumed productivity and the average fare that will create this productivity. From the fleet size and productivity the costs can be calculated, while the productivity and fare parameters yield revenues.

Since all financial data is presented in 1976 dollars, it will be necessary to adjust for inflation to obtain current-year or future-year data. An implicit assumption in this approach to analyzing cost-effectiveness is that all costs and revenues will increase at a uniform inflation rate. There is no assurance that this will actually occur, and in fact, it is likely that labor costs and fares will inflate more rapidly than the CCS costs since electronic-equipment costs have, historically, tended to reduce relative to other costs. Thus, the assumption of a uniform inflation rate is conservative.

Figure 4-2 shows the estimated cost of computer and digital communication hardware as a function of the maximum number of taxis in operation. To this must be added the cost of personnel (it takes longer to book SRT requests than ERT requests, though digital communication offsets this somewhat), the increased mileage cost of operating a SRT vehicle (it

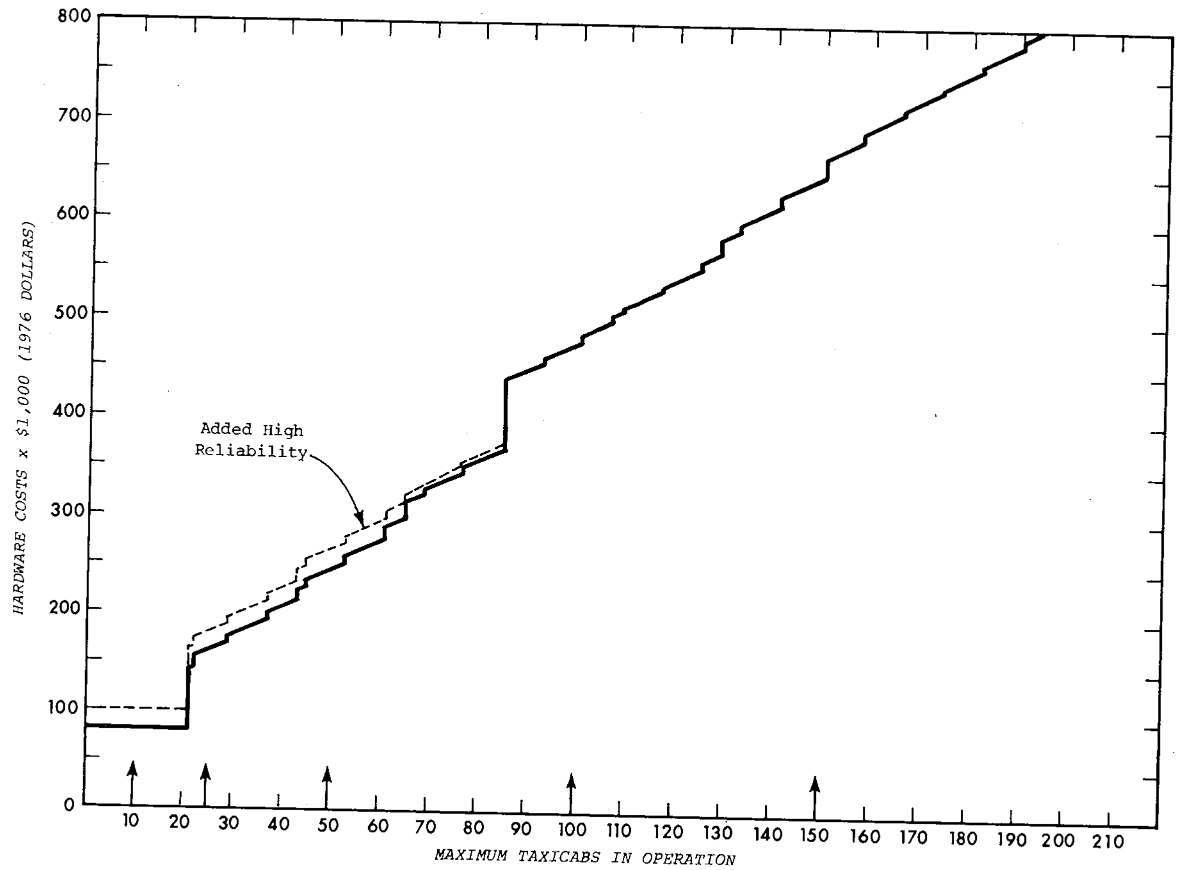


FIGURE 4-2

COMPUTER AND DIGITAL COMMUNICATIONS ESTIMATED HARDWARE COST

averages more miles per shift than an ERT vehicle), facilities costs, and startup costs; these are shown for a 50-taxi system in Table 4-1. A five-year depreciation schedule was used for the electronic equipment with no salvage value, a somewhat conservative assumption. The estimated capital costs for computer, digital communications, and startup amount to $0.42 (or 36 percent) out of the total cost of $1.16 per taxi hour shown in Table 4-1.

TABLE 4-1

50-TAXI FLEET
ESTIMATED INCREMENTAL COST INCREASE
OF SRT OVER ERT

	Total Monthly Cost	Per Taxi	Per Taxi Hour
Computer and Peripherals	$ 4,638.00	$ 92.78	$ 0.21
Digital Communications Equipment	3,929.00	78.59	0.18
Control Room Personnel Increment	9,577.00	191.54	0.44
Amortized Startup Cost	582.00	11.64	0.03
Increased Mileage Wheel Cost	6,525.00	130.50	0.30
Total Incremental Cost of SRT over ERT	$25,251.00	$505.05	$ 1.16

NOTE: Taxi in-service hours per year: 260,000
Passengers carried per year: 1,300,000

In this cost analysis, the taxi company absorbs the full cost of converting to SRT (except that the government's cost in developing the concept, the generic control software, and demonstration costs are not included). Thus, any startup assistance or other types of subsidy would increase the cost-effectiveness of SRT.

4.3 COST-EFFECTIVENESS RESULTS AND POTENTIAL COST SAVINGS

The cost-effectiveness computer program permits a large number of alternatives to be considered; in fact, the program can be run for any ERT company that is contemplating conversion to determine the cost-effectiveness of SRT. In order to present the results in a comprehensible form, the scenarios were constrained to a medium city (Scenarios I and II, population 90,000 to 500,000), a small city (Scenario III, population 18,000 to 90,000), and a large city (Scenario IV, population over 500,000) -- these scenarios are described in Section 6.1. To further summarize the presentation of results, the alternative values of each of the parameters were restricted.

4.3.1 Parameter Interrelationships

Figure 4-3 shows a three-dimensional view of a medium city's estimated SRT profitability as a function of productivity and fleet size following overnight conversion from ERT to SRT. It utilizes an isometric projection so that the shape of the surface is visible.

The figure shows that the maximum increase in profits following conversion from ERT to SRT is achieved by reducing the number of taxis in service and operating at a productivity that is only modestly greater than the three passengers per taxi hour achieved in ERT. Such high profits, however, will not be realizable in practice because of competition and/or regulation of fares. Furthermore, the fleet size should not be reduced to the point required for maximum profit because this would cause a serious deterioration in the quality of service. Rather, a compromise operating point (see point A shown by an asterisk on Figure 4-3) is required between all of the relevant parameters, which might typically be about 60 taxis in SRT service (compared with the original 80-taxi ERT fleet), a productivity of five passengers per taxi-hour (compared with 2.72 in ERT service), and a profit increase to be shared between drivers and the company of $0.50 per ERT-hour. (Use of the parameter "profit increase per ERT-hour" is helpful because it provides a direct comparison of overall company profits -- to get total SRT fleet increase in hourly profits simply multiply the increase per ERT-hour by the original ERT fleet size, which is a constant for the various SRT fleet sizes considered.)

4.3.2 Profit and Fare

Figures 4-4 (medium city), 4-5 (small city), and 4-6 (large city) show the estimated increase or decrease in profits achieved by "overnight" conversion from ERT to SRT as a function of the reduction in fare and for various reductions in fleet size.

It can be seen in all three figures that as the fleet size is reduced, SRT can be operated profitably at a lower fare. For example, in Figure 4-4 the compromise operating point shows that in a medium-size city SRT can achieve a 30-percent fare reduction and additional profits of $0.50 per ERT-hour, equivalent to 7.5 percent of costs. The capital

LEGEND

* = Typical Compromise Operating Point, Fare is 71% of ERT, LOS is 136% of ERT

⊙ = Point of Minimum Fare 45% of ERT, while system at zero increase in profits

Scenario Parameters Held Constant:
Service Area = 50 Sq. Miles
Original ERT Fleet = 80 Taxis in Service
Elasticities: Fare = -1.
Level of Service = -0.5
Uncertainty = -0.5
Lumped Parameters = 0.
Proportion of Hail and Stand = 0.15
Mean Trip Length = 3.06 Miles
ERT Productivity = 2.72 Pass./Taxi-Hr.

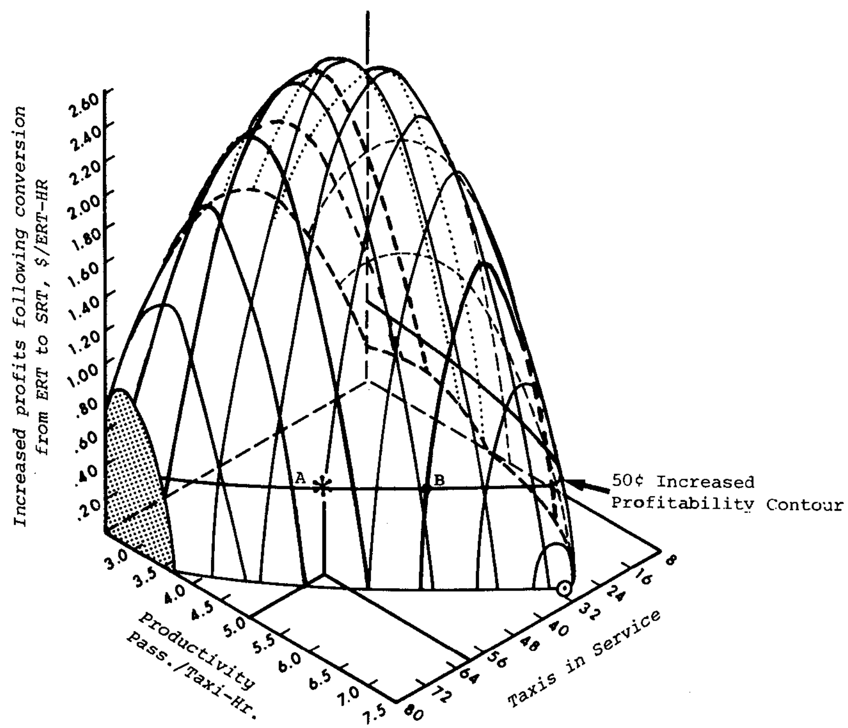


FIGURE 4-3
THREE-DIMENSIONAL VIEW OF ESTIMATED PROFITABILITY AS A FUNCTION OF PRODUCTIVITY AND FLEET SIZE FOR A MEDIUM-SIZE CITY (SCENARIOS I AND II)

Scenario Parameters Held Constant:
Service Area = 50 Sq. Miles
Original ERT Fleet = 80 Taxis in Service
Proportion of Hail, Stand and Subscription = 0. and 0.15
Average ERT Fare = $2.50/Passenger
Fare Elasticity = -1.
Level of Service Elasticity = -0.5
Uncertainty Elasticity = -0.5
Lumped Parameter Elasticity = -0.
Proportion Baseline CCS Cost = 1.

LEGEND

* = Typical Compromise Operating Point, Productivity is 5 Pass./Taxi-Hr.

⊙ = Point of Minimum Fare at Zero Increased Profits

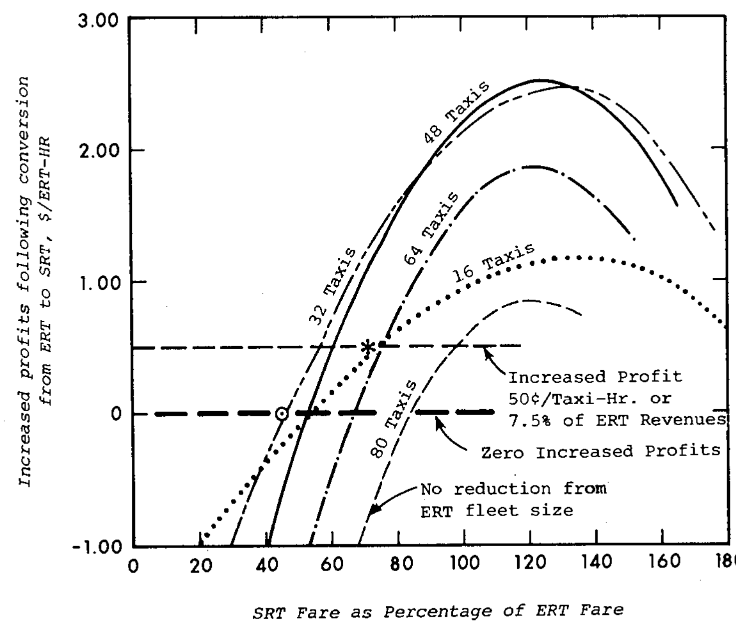


FIGURE 4-4
ESTIMATED PROFITABILITY AS A FUNCTION OF FARE AND FLEET SIZE FOR A MEDIUM-SIZE CITY (SCENARIOS I AND II)

Scenario Parameters Held Constant:
Service Area = 50 Sq. Miles
Original ERT Fleet = 15 Taxis in Service
Proportion of Hail, Stand and Subscription = 0.
Average ERT Fare = $2.50/Passenger
Fare Elasticity = -0.5
Level of Service Elasticity = -0.5
Uncertainty Elasticity = -0.5
Lumped Parameter Elasticity = -0.
Proportion Baseline CCS Cost = 1.

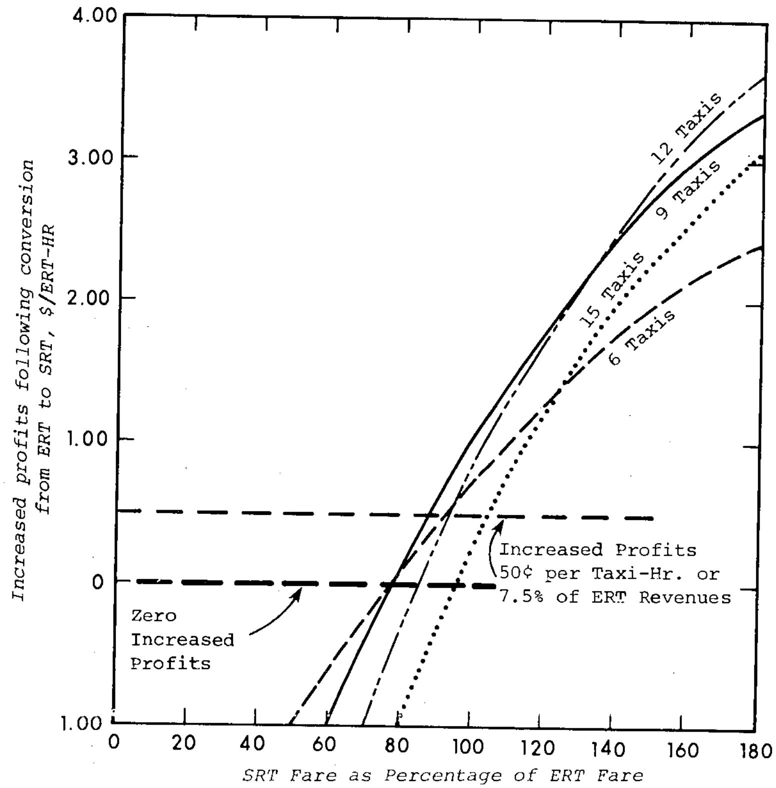


FIGURE 4-5
ESTIMATED PROFITABILITY AS A FUNCTION OF FARE AND FLEET SIZE FOR A SMALL CITY (SCENARIO III)

Scenario Parameters Held Constant:
Service Area = 125 Sq. Miles
Original ERT Fleet = 800 Taxis in Service
Proportion of Hail, Stand and Subscription = 0.3
Average ERT Fare = $3.60/Passenger
Fare Elasticity = -1.5
Level of Service Elasticity = -0.5
Uncertainty Elasticity = -0.5
Lumped Parameter Elasticity = -0.
Proportion Baseline CCS Cost = 1.

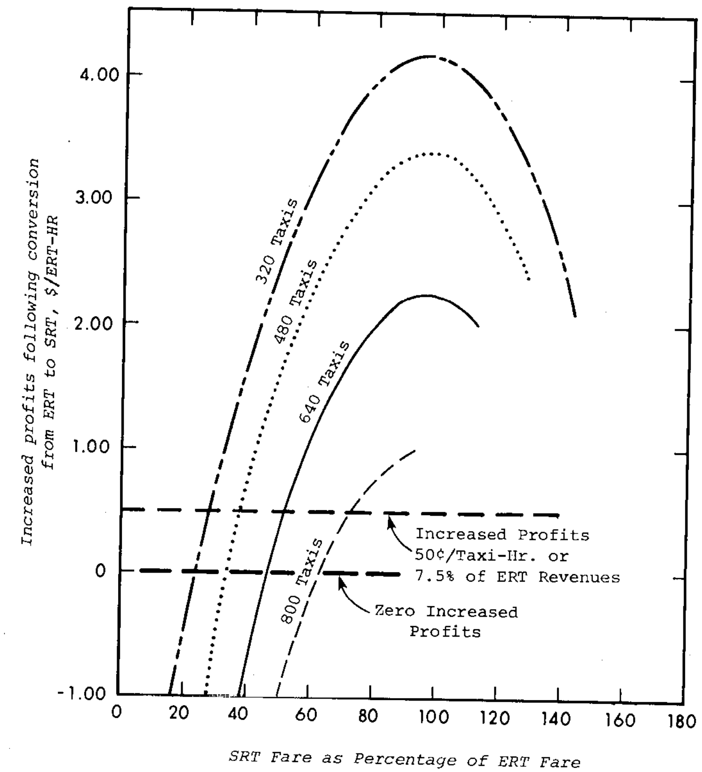


FIGURE 4-6
ESTIMATED PROFITABILITY AS A FUNCTION OF FARE AND FLEET SIZE FOR A LARGE CITY (SCENARIO IV)

investment costs (see Section 4.2.3) are also on the order of $0.50 per ERT-hour, indicating an attractive return on investment (ROI) at the compromise operating point. Standing orders from commuters going to a station or other passenger groupings may permit even higher productivities and lower fares than the compromise operating point.

For the small cities, on the other hand, Figure 4-5 shows that any significant reduction in the SRT fare below that of the ERT fare quickly results in a reduction in profits. A prudent businessperson would be unwise to make a conversion from ERT to SRT based on the modest potential benefits and the high risk involved in a small city. Rather, in a small city, if SRT is to be implemented, it may be necessary to consider some form of subsidy -- i.e., in effect a DAR service.

Profitability of SRT in a large city may be most attractive (as shown by Figure 4-6). Substantial reductions in the fare can be achieved while still retaining satisfactorily increased profits. In fact, if the fare is reduced to on the order of 40 percent of the ERT fare, the new operation will probably resemble a downtown jitney service during the peak periods.

4.3.3 Fleet Size and Conversion Time

The analytic model assumes an "overnight" conversion from ERT to SRT. Consequently, the projected SRT operation has a smaller fleet size than the original ERT system; Figure 4-3 shows that if productivity is increased without a reduction of the number of taxis in service, then the taxi company would suffer a decrease in profits.

In practice, it is expected that a prudent taxi company will gradually increase the percentage of SRT; the entire conversion will take months or even years; "overnight" conversion of the entire fleet from ERT to SRT operation would be economically hazardous as well as disruptive to the service provided to the public. (This is discussed further in Section 8.3.3.) During the conversion period, overall ridership market for SRT will grow so that there should be little if any reduction in fleet size. Moreover, by cautious transition, even if there were a temporary reduction in fleet size, employment could be trimmed by normal turnover and later increased as the market for SRT builds.

4.3.4 Sensitivity to Uncertainty Estimates

In the preceding analysis, the demand elasticity with respect to uncertainty was held constant at -0.5 and the potential effect of lumped external parameters, such as automobile disincentives or changes in other modes of transit, was held at zero. Because of the lack of good calibration data for the demand elasticity with respect to uncertainty, it is appropriate to consider the effect of variations in this parameter upon the cost-effectiveness and viability of SRT. Figure 4-7

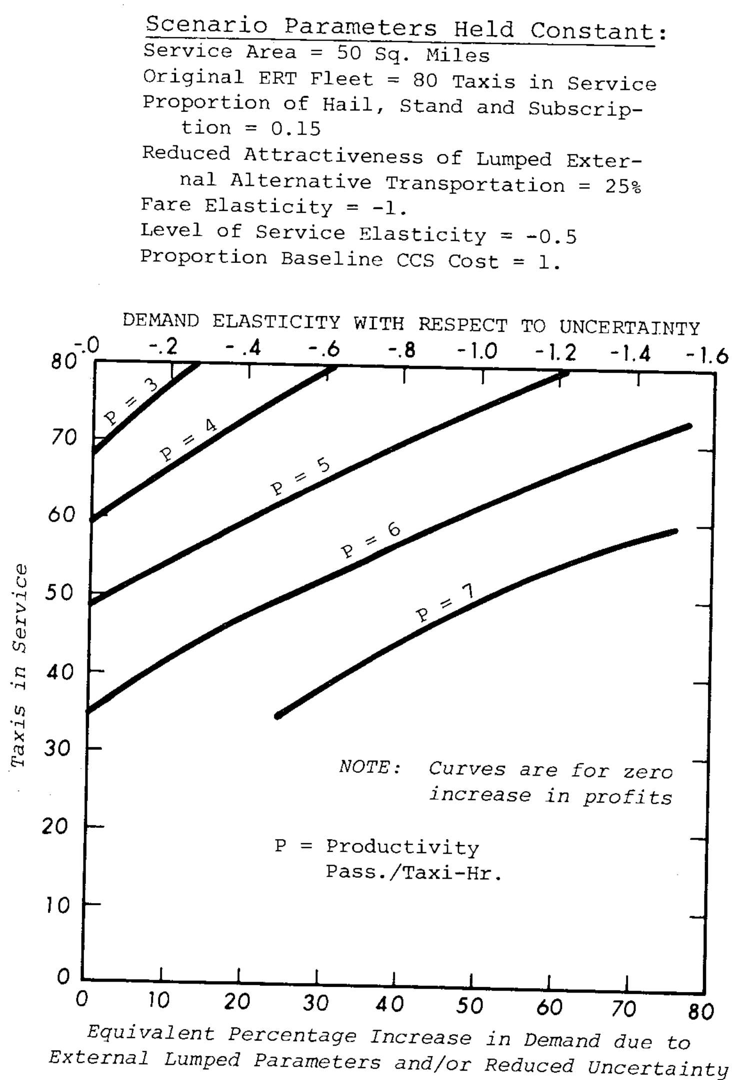


FIGURE 4-7
SENSITIVITY OF DEMAND CAUSED BY UNCERTAINTY ON TAXI FLEET SIZE AT ZERO INCREASE IN PROFITS AS A FUNCTION OF PRODUCTIVITY FOR A MEDIUM-SIZE CITY (SCENARIOS I AND II)

shows this effect in terms of the number of taxis in service for a medium city environment at no increase in profits and constant productivities.

It is evident that the key impact of any error in estimating the demand elasticity with respect to uncertainty will be to modify the fleet size required for a viable SRT operation. This serves to emphasize the need to convert from ERT to SRT slowly so that the correct SRT fleet size for viable operation can be established without significant risk.

4.4 Increased Taxi Ridership

Will SRT increase taxi ridership? This is an important question since an objective from the government's point of view for a transit system is increased ridership. An examination of Figure 4-3 indicates that the taxi company's "operating point" on the curve determines not only the taxi company's profitability but also whether taxi ridership will increase or not with SRT. For example, if the taxi system operates as an ERT fleet of 80 vehicles with a productivity of 2.72, the ridership is estimated to be 218 riders/hour. However, if the taxi system is a SRT fleet of 40 vehicles with a productivity of 4.00 (corresponding to a private company's objective of maximum profitability), the ridership declines to an estimated 160 riders/hour. This decline is due to the reduction in the level of service at this SRT operating point (in this case, the fare reduction is not sufficient to counteract the effects of the reduced level of service).

However, as previously noted, this operating point is probably unrealistic since competition and/or regulatory bodies would limit profits. If the profitability increase is limited to a more realistic $0.50/ERT-hour, the ridership increases to an estimated 300 riders/hour for a fleet of 59 SRT vehicles with a productivity of 5.00. Thus, this "more responsible" operating point allows both increased ridership and limits company profits.

4.5 Fleet Size and Cost-Effective Automation

When is automation cost-effective? This is an important question since automation must be perceived as advantageous by the taxicab industry before it will accept the cost of introducing this technology into their operations. The cost of introducing automation on a per-vehicle basis should decrease as the fleet size increases. This was demonstrated analytically in the Task 3 Report (Potter, B.E., et al, June 1976). For a 50-vehicle fleet, the cost is estimated to be $1.16 per taxi-hour for introducing automation into an SRT fleet over an ERT fleet (see Table 4-1). However, from a taxicab operator's point of view, the impact of these innovations must show themselves in terms of improved profits. As shown in Figure 4-3, point B represents a 50-vehicle SRT fleet with a productivity of 6.00 passengers per taxi-hour (this is the productivity necessary to keep the profitability at $0.50). The ridership remains at very nearly 300 riders/hour. Thus, a 50-vehicle SRT fleet appears to be a fleet size that will allow automation to be introduced in a cost-effective manner. This checks with an independent study (Multisystems, Inc., Benefit-Cost Analysis of Integrated Paratransit Systems, Vol. 5, May 1978) which showed that for paratransit systems above 32 vehicles, automation is beneficial.

5.0 EXPLANATION OF AUTOMATED CONTROL OF SHARED-RIDE TAXI OPERATIONS

It has now been shown that SRT provides a needed service and is economically viable in medium and large cities. This section explains why existing manual dispatching methods constrain implementation of SRT and how computers will solve this problem. The credibility of this solution is illustrated by descriptions of several DAR and taxi computer systems. Recent advances and trends in computer technology and computer cost reductions indicate that the benefits of computer control will continue and improve.

5.1 LIMITS ON HUMAN CONTROL PERFORMANCE AND NEED FOR AUTOMATION

Three significant technical problems -- dispatch efficiency, uncertainty, and communications throughput -- have restricted the non-computerized application of SRT. The need to use computers to control SRT fleets will be apparent from the discussions below.

5.1.1 Dispatch Efficiency

SRT operations use two methods of manual dispatching. In the first, the dispatcher offers a trip by radio to the drivers and the first driver to respond (i.e., bid) wins the job (e.g., at Black and White Taxi Company, Little Rock -- Hall, private communication, Dec. 1977). The responsibility for efficient routing thus falls upon the driver who must bid only for those trips which fit the tour he/she is planning. This process has obvious deficiencies. For example, the driver who wins the job may be a less desirable choice than some other driver who was not as quick to bid. Moreover, the ability of the driver to organize his/her work requires a high level of decision-making which not all drivers possess. Thus, this first manual technique of trip assignment has efficiency limitations -- though it has the advantage that it can be applied to large fleets.

In the second technique, trips are assigned to the individual drivers by the dispatcher (e.g., at Royal Cab Co., Davenport -- Cherry, private communication, Dec. 1977). To do this, the dispatcher must know the approximate location and planned tours of all of the vehicles in the fleet. Though this method inherently has a much greater potential for optimization than the first method, it becomes limited by the mental capability of the dispatcher at about 20 shared-ride vehicles or about 100 requests per hour (Heathington, 1974). Though fleets of over 30 SRT's using central control have been reported (Somers, D., private communication, December 1977), this probably is close to an upper bound. Confirmation of these limitations is provided by observation of DAR operations, which suggests that the efficiency of human dispatchers starts to decline above 50 requests per hour, even when the dispatchers are very efficient and use visual aids such as maps and colored magnetic markers (Fielding, 1976, TRB. Paratransit, S.R. 164, p. 49).

The complexity of shared-ride dispatching arises from the three-dimensional nature of the problem. The trips for each of the passengers and the routing of vehicles occupy two dimensions -- e.g., they can be displayed by the dispatcher on a map of the service area. The scheduling or timing of the vehicles for each passenger's expectations of pickup and delivery time introduces the third dimension of time which cannot be visually represented except by writing the times opposite the stops on the map. Thus, though the dispatcher can visually identify patterns of routing, the timing of pickups must be done in the dispatcher's head. When it is realized that a typical fleet of 40 SRT's involves a pickup or delivery assignment decision about every 12 seconds, the inadequacy of humans for efficient control of large fleets and the need for automation becomes apparent.

Timing of the pickups and deliveries is even more critical for integration of transit and paratransit; synchronized transfers are the essence of its attractiveness. Thus, in integrated transit systems, human dispatch capabilities are more limiting and implementation of computerized control more essential.

Verification of the higher efficiency of computer control over manual control has been obtained in actual operations. Results (USDOT, Haddonfield Final Report, Oct. 1974, Table 3-1 and personal communications,

E. Ziegler, 1977) indicate that the Haddonfield and Rochester automated control systems operated somewhat more efficiently than the earlier manual control systems despite the fact that the fleet sizes are small enough (under 20 buses) for efficient manual control. Since randomly-occurring perturbations (e.g., vehicle breakdowns, employee absences) tend to detract from automated control more in a small system than in a large system, the advantages of automated control become greater as the fleet size is increased. Because of the similarities between a CCS for Dial-A-Bus and SRT, the same conclusion -- i.e., that a CCS is more efficient than manual control for all but the smallest operations -- applies also to SRT.

5.1.2 Uncertainty

Since the routing of SRT's is dynamically changed as new requests for service are received, the uncertainty of the actual pickup time for each passenger is greater in SRT than in ERT operations. This potentially negative factor can be overcome by calling the passenger by telephone to: (a) apprise the passenger of any significant change to the committed pickup time, and (b) advise the passenger shortly before the vehicle arrives so that the passenger can be ready to board when it does arrive.

Such telephone callbacks are too expensive to implement routinely if humans make each call. Computer control, on the other hand, can make callbacks automatically at virtually no additional cost, because all of the necessary information has already been entered into the computer system (see Sections 6.6.3 and 7.1.6 for more detail). The computer's ability to minimize the perceived uncertainty (and minimize the anxiety of the waiting passenger) will be an important asset for SRT.

5.1.3 Communications Throughput

When an ERT is dispatched, the driver is generally given only the pickup address; the passenger supplies the delivery address after pickup. SRT dispatching, on the other hand, requires that the driver be given both pickup and delivery addresses for each passenger so that the stops can be made in the most efficient sequence. Thus, SRT communications throughput must accommodate twice the number of stops as ERT.

Many taxi radio channels are already near maximum capacity and additional radio channels generally are not available. During conversion from ERT to SRT it will often be necessary to improve the utilization of the channel in order to accommodate more messages. This can be accomplished with digital communications, which increases the message-carrying capacity of a radio channel by a factor of from two to four (see Section 6.6.1) -- more than adequate to convert from ERT to SRT.

Use of digital communications has other significant benefits. The dispatch data is already stored in a computer system and its transmission to the driver can be accomplished without a human intermediary, effecting significant manpower and cost reductions. Also, the data displayed to the driver is virtually error-free, thereby avoiding occasional confusion caused by human fallibility and again improving the cost-effectiveness of the system.

5.1.4 Need for Automation

To accommodate SRT fleets larger than 20 vehicles (the average taxi fleet size is 41 vehicles), it is apparent from the above discussion that the requirements of dispatch efficiency, uncertainty, and communications throughput dictate the use of a computer control system. Once the decision to automate has been made, additional benefits become available though by themselves they may not justify the computerization:

(a) Accurate and reliable service of deferred and standing orders which the computer automatically stores and retrieves at the proper time.

(b) Billing of welfare and other organizations which pay for taxi service; such time-consuming functions are presently a source of major frustration to many taxi companies.

(c) Checking for duplicate orders from the same passenger which, without a computer, sometimes are not noticed and result in two vehicles servicing the same request.

(d) General computing services such as payroll, accounting, maintenance, and personnel records.

(e) Management information in real time and in statistical reports, yielding a currently unavailable insight into operations.

(f) Virtual elimination of favoritism, kickback payments, and "skimming" by dispatcher-driver collusion.

(g) Ability to answer waiting-passenger's inquiries about status of service accurately and quickly.

5.2 DESCRIPTION OF SOME EXISTING COMPUTER-CONTROL SYSTEMS

A successful SRT automated control system has not yet been implemented. The first and only SRT automated control system attempted thus far was that of Royal Cab in Davenport, IA. It was discontinued due to the financial limitation of the company to fully finance the development (as described in Section 5.2.3). However, a number of examples of related DAR and ERT computer-control systems have been placed into continuous and successful operation, lending credence to the technical feasibility of automating SRT.

5.2.1 Rochester/Haddonfield Dial-A-Bus Demonstrations

As part of its program for integrated transit and paratransit service, UMTA funded development of computer technology in Haddonfield, NJ, which was subsequently continued and expanded in Rochester, NY. The Rochester control system is the most sophisticated attempted to date and incorporates many of the functions required for SRT.

Rochester's control center is shown in Figure 5-1. The order-taker enters the passenger's request directly into the computer via a keyboard and cathode ray tube (CRT) display (also called a visual display unit [VDU]). The computer responds with the estimated pickup time and, if the passenger is satisfied, the trip is confirmed; from that point on, it is scheduled automatically.

Communication between the computer and the driver is accomplished by digital communications; a display and keyboard on the bus are shown on Figure 5-2. The driver can communicate directly with the computer and is permitted to make some modifications to the computer-assigned tour so as to improve its efficiency and can also update the computer

FIGURE 5-1: ROCHESTER DAB CONTROL CENTER WITH FULLY-AUTOMATED SCHEDULING AND DIGITAL COMMUNICATION DISPATCH

FIGURE 5-2: ROCHESTER DIGITAL COMMUNICATION TERMINAL WITH FULL KEYBOARD IN BUS

for any unexpected delays, changes in the expected number of passengers, or other perturbations. The driver's ability to participate in the decision-making process and to interact to improve his/her assignments is a significant motivator for high driver-standards.

The earlier Haddonfield demonstration did not include digital communications (see Figure 5-3), and so drivers were only able to interface with the computer via the dispatcher. This proved to be a limitation because the dispatcher was a communications "bottleneck," which sometimes caused delays when drivers had to wait for instructions.

5.2.2 Ann Arbor Transportation Authority

The Ann Arbor Dial-A-Bus computer system (see Figures 5-4 and 5-5) is a computer-aided control system -- i.e., in Ann Arbor the assignment of a trip to a vehicle is determined by the control staff, whereas this decision is made by the computer in Rochester. On the other hand, the Ann Arbor system emphasizes the synchronized transfer of passengers between the DAB and fixed-route services, controlling a combined fleet of about 100 vehicles. Part of the Ann Arbor minibus fleet is shown in Figure 5-6. Since the inauguration of computer control in Ann Arbor, over a million passengers have been processed. Computer control has become totally accepted by the control staff and by the drivers. It is interesting to note that the union drivers readily accepted digital communications since this relieved them from the need to write their stops on a sheet of paper and also minimized errors. Figure 5-7 shows the vehicular digital communications equipment used by the Ann Arbor system.

5.2.3 Taxi Computer Operations

The Yellow Cab Company of Los Angeles, CA, used a computer system for dispatching a fleet of 500 taxis for several years and was able to demonstrate economies from computer technology even while the company was beset by other unrelated problems of major dimensions (Davidson, J., private communications, 1977). The Los Angeles system is primarily a booking and sorting computer program whereby the requests are entered

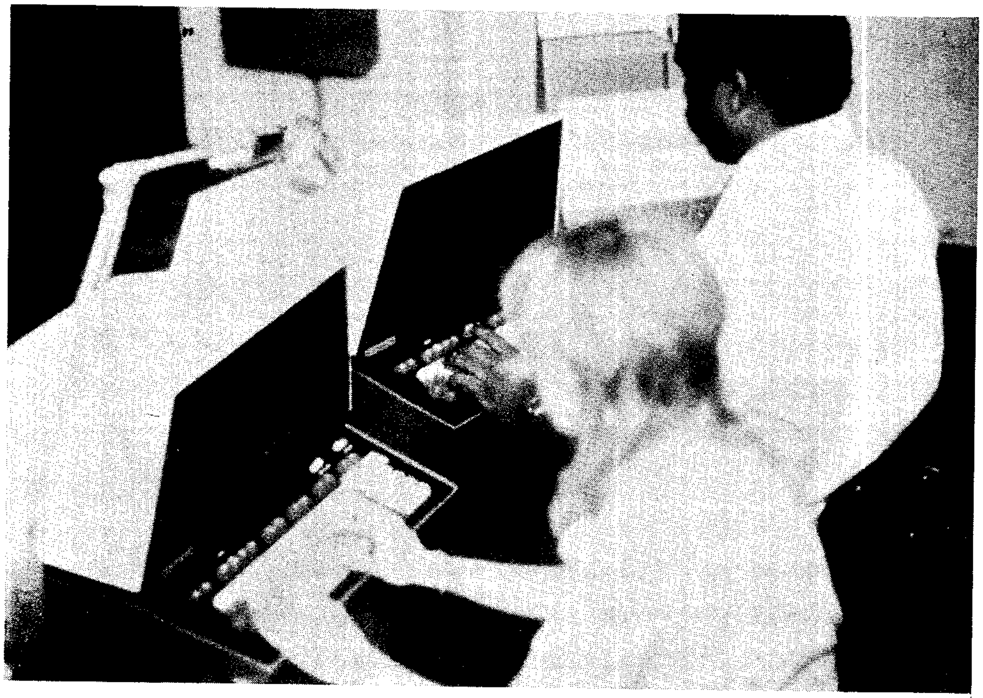


FIGURE 5-3: HADDONFIELD DAB CONTROL CENTER WITH FULLY-AUTOMATED SCHEDULING AND VOICE DISPATCH

FIGURE 5-4: ANN ARBOR DAB CONTROL CENTER WITH COMPUTER-AIDED CONTROL AND FULL DIGITAL COMMUNICATION

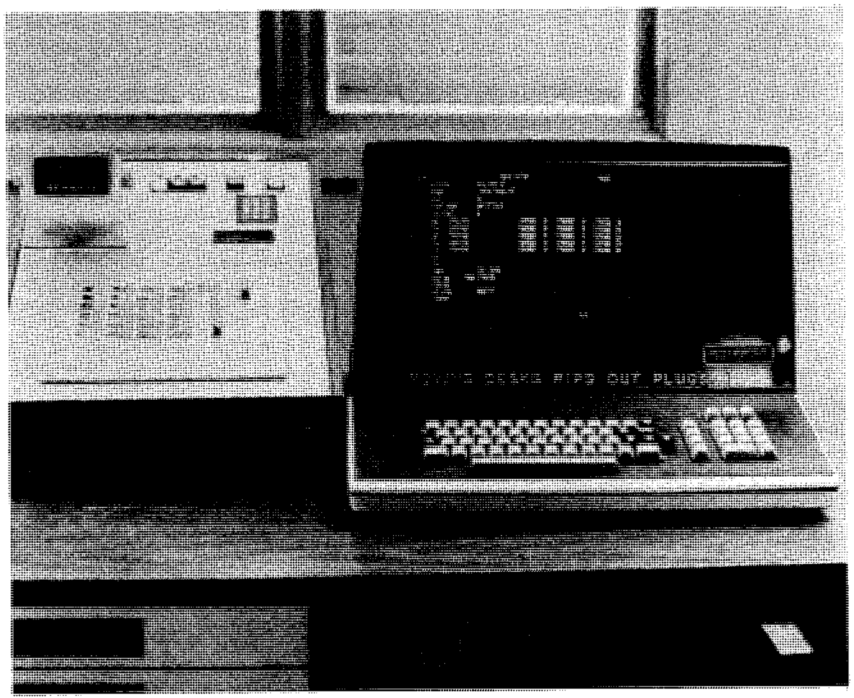


FIGURE 5-5: CLOSE-UP OF ANN ARBOR CRT TERMINAL SHOWING ALTERNATIVE VEHICLES FOR A TRIP ASSIGNMENT DECISION

FIGURE 5-6: ANN ARBOR'S MINIBUS FLEET WHICH FEEDS ARTERIAL FIXED-ROUTE BUSES

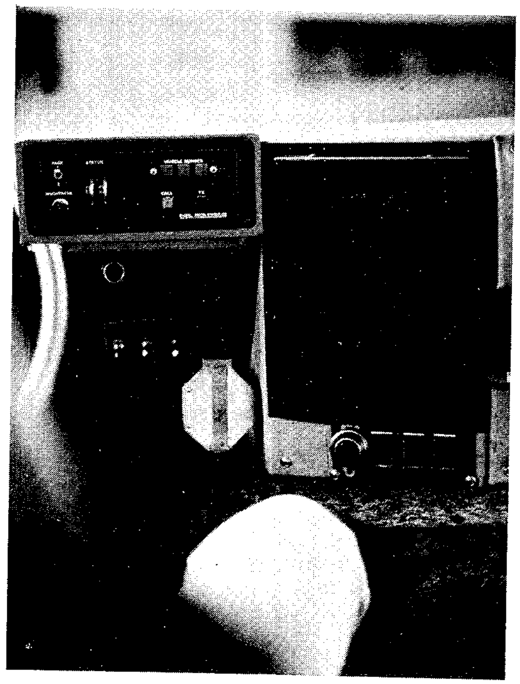


FIGURE 5-7: ANN ARBOR DIGITAL COMMUNICATION UNIT IN VEHICLE: Eight-stop display is on right; driver-to-computer status communicator is on left

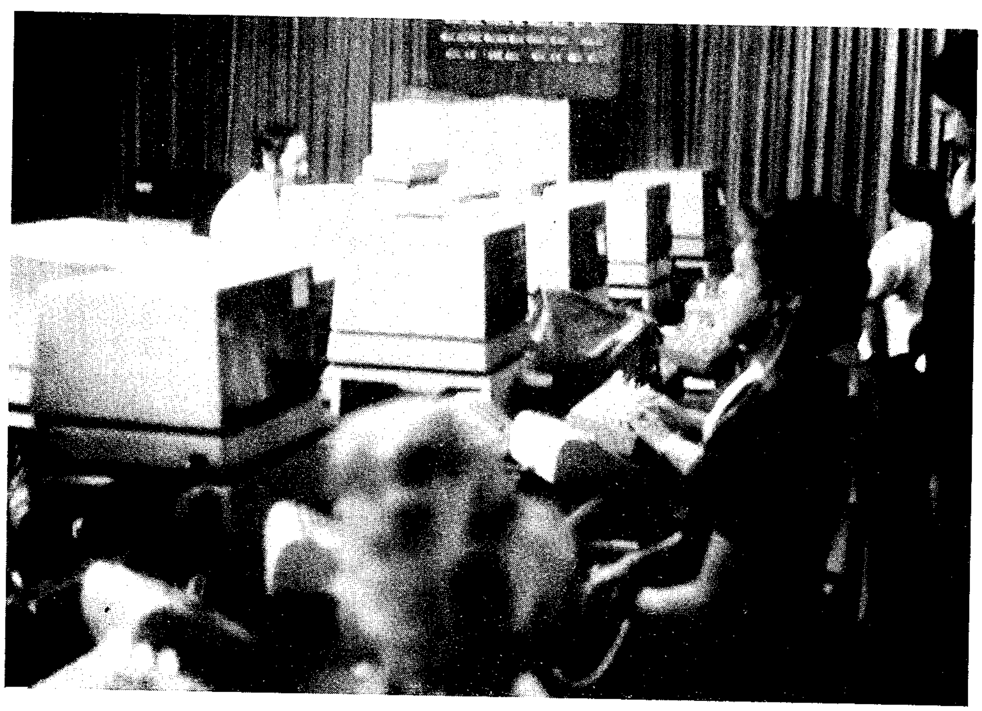


FIGURE 5-8: YELLOW CAB OF LOS ANGELES CONTROL CENTER WITH COMPUTER BOOKING AND DISPATCH FOR 500 TAXIS: Dispatchers are on left, telephone answerers on right

into the computer and then assigned to the dispatcher covering the appropriate areas of the city. Trips are offered to taxi drivers on the basis of their position at various stands throughout the city or, if there are no taxis at the stand, then the taxis in the vicinity of the pickup bid for the trips. Though relatively unsophisticated compared with the other systems described above, the Los Angeles computer system handled a large number of requests per day and was of great assistance in producing statistical information required by the city. In the control center shown in Figure 5-8, the order-takers are on the right and the dispatchers are on the left.

To date, the only SRT computer-control system attempted has been in Davenport, IA, where the Royal Cab Company introduced an IBM System 3/6 based unit shown in Figure 5-9. The programs were developed by the taxi company owner and his wife from 1970 to 1973. Despite many obstacles, the computer system was operated for periods of several hours in 1973, and improvements of over 50 percent in productivity were noted (Cherry, private communication, December 1977). However, the functional capability of the system was limited by computer size -- the computer was inadequate to update files to maintain a one-to-one correspondence between the real-world and the computer's image of the world. Since this project was funded by private sources, the cost of obtaining a more powerful computer and the additional programming was economically infeasible, so development was discontinued.

A number of other automatic control systems for ERT have been implemented in various cities and seem to be operating effectively after initial startup problems were resolved.

5.3 STATE-OF-THE-ART FOR COMMERCIAL SHARED-RIDE TAXI OPERATIONS

Advances in computer technology have continued to enhance computer power while concurrently reducing costs. Section 4 shows that, at today's prices, such computer systems are cost-effective. Some of the current and near-term state-of-the-art features of computer systems suitable for SRT are discussed below.

FIGURE 5-9: THE ROYAL CAB COMPANY'S SHARED-RIDE TAXI COMPUTER SYSTEM

5.3.1 Computational Capability

Two examples of typical minicomputer systems used for dispatching are shown in Figures 5-10 and 5-11. Minicomputers available today have the computational capacity of large-scale computer installations of five and ten years ago. It is now possible to perform all of the required calculations for automated SRT control on a minicomputer costing an estimated $50,000 for 50 taxis, and $100,000 for 100 taxis. In addition to accommodating the SRT control process, many minicomputers can perform background calculations simultaneously with the SRT control (whenever there is a fraction of a second of spare unused computing capability) to perform background programs such as accounting, maintenance, and personnel records. These supplemental programs are often available to owners of the computers from computer user groups at nominal cost.

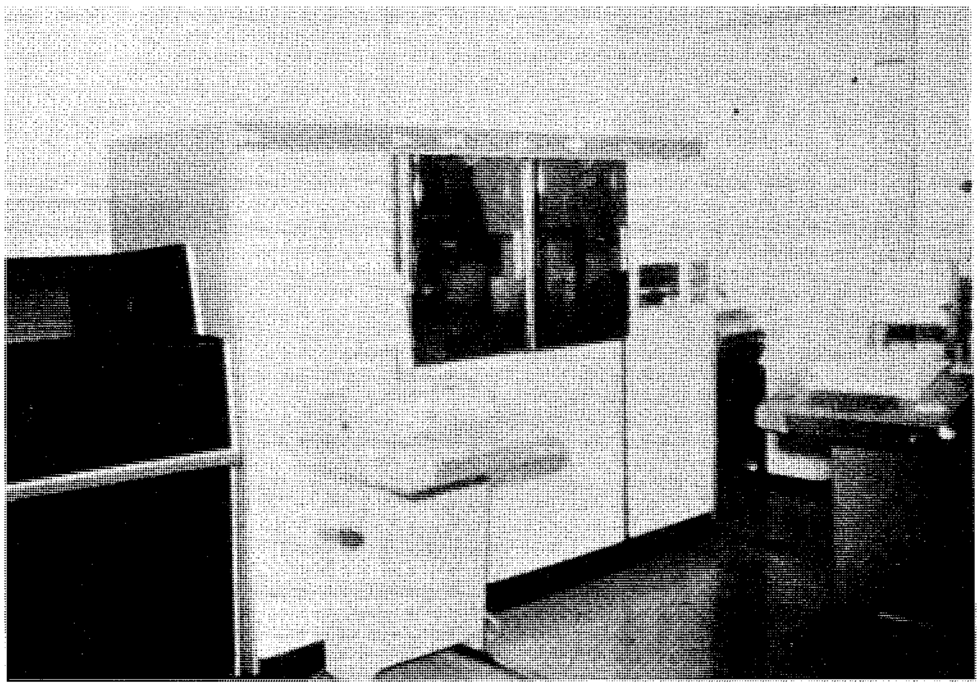


FIGURE 5-10: COMPUTER SYSTEM USED TO CONTROL HADDONFIELD. Left to right: printer, disc cabinet, two tape units, mini-computer, card reader, and two TTY's in foreground

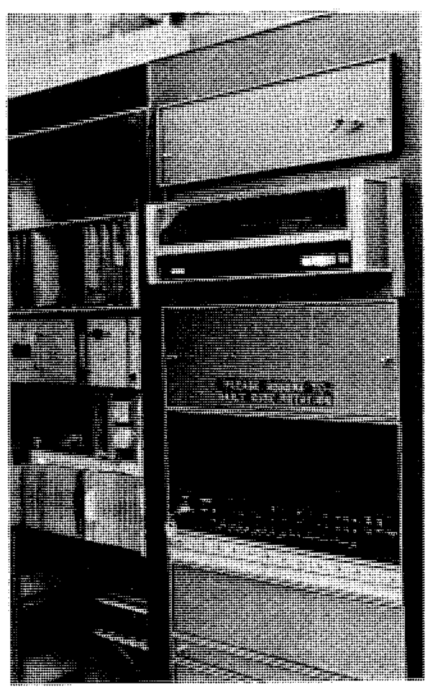


FIGURE 5-11: ANN ARBOR COMPUTER SYSTEM. On right, top to bottom: disc unit, computer and communications multiplexer

The cost of computing capacity continues to decline. Microcomputers are being developed which, in a few years time, may have the capability of today's minicomputers but at a fraction of the cost. Already, for example, microcomputers are being used as inexpensive communication controllers by retrofitting taxi radios for combined vehicle identification, automatic first-bidder selection, faster dispatching, radio discipline, private communication, and emergency functions (Potter, 1977, p. 3).

5.3.2 Memory

A similar evolution is occurring in memory devices. It is now economically feasible to maintain complete street address files for large cities on moving-head disc packs. Disc memories for a 50-taxi fleet cost about $26,000 -- i.e., about half the cost of the computer and core memory -- and proportionately less for larger fleet sizes.

In addition to the decline in the cost of memory, the speed of access continues to improve. A few years ago it would have been necessary to go to the much more expensive fixed-head disc memories in order to achieve acceptable terminal response time; now moving-head discs are acceptable for a SRT-CCS.

5.3.3. Digital Communications

Widespread use of interactive digital communication systems by the police has fostered technical improvements. Equipment suitable for SRT can be purchased off-the-shelf. Cost per mobile unit has not declined as rapidly as in the computer and memory areas, though some reductions have been noted. For example, digital communications equipment which used to cost about $4,000 per taxi has now declined to between $2,000 and $3,000 per taxi. Though this is still relatively expensive, it is anticipated that costs will continue to decline as they have in other areas of electronic technology.

5.3.4 Man-Machine Interfaces

The ability of computers to communicate with humans via a CRT display and keyboard is now a routine phenomenon, as evidenced by airline booking terminals, banking transaction terminals, air traffic control, and text-editing systems. Recently, the cost of color displays reached the point where they are economically feasible peripherals for a SRT-CCS -- they now cost about $8,000. These color terminals have the capability to display the routing and scheduling of vehicles in real-time so that the dispatcher can monitor the pattern of vehicle assignments that have been made. A light-pen placed against the CRT screen permits the dispatcher to make any necessary reassignments or reorganizations quickly and easily without having to go through complex keyboard instructions.

This CRT display capability is important for the SRT-CCS because a sufficient number of unique situations are encountered which cannot yet be programmed into a generic computer system -- for example, existing algorithms do not accommodate preplanned periodic tours, taxi-fleet management, or starter tours for new taxis entering service without prior notification. The dispatcher's ability to monitor and, if desired, to overrule computer decisions is an important asset because: (a) it makes the success of SRT independent of immediate development of complete automation, and (b) it gives to the operator a feeling of still being in control. Moreover, interaction between the human and the scheduling terminal of this type will enhance the development of the computer system in the future because it makes possible an intimate understanding of what is going on in the computer system from which can be deduced new methods, improvements, and enhancements of automation.

PART II: COMPUTER CONTROL SYSTEM REQUIREMENTS

In Part I of the study it was shown that there will be a significant growing demand for SRT, that the services supplied and the role of SRT will be important, that the system is cost-effective, and that an overview of the technology involved indicates that it is technically feasible. Part II now develops the necessary systems, engineering, and operational requirements of a SRT-CCS in greater depth. These requirements are the starting point of the CCS design needed to implement the concept.

6.0 COMPUTER CONTROL SYSTEM ANALYSIS AND SYSTEM REQUIREMENTS

6.1 SCENARIOS

The first step in developing the CCS requirements is to identify representative contexts for which the requirements can be specified. These contexts are provided by scenarios which define the environment in which the CCS must operate. The number of scenarios is kept to a realistic minimum to avoid an excessively complex set of requirements.

6.1.1 Prototypical Cities

The three prototypical city sizes shown in Table 6-1 were established on the basis of analysis of the population limits at which significant changes would be needed in the CCS configuration (Fielding, Task 2: Concept Development, 1977, Section 7). For example, because of the increased impact created by a computer failure in a medium-city taxi fleet, the CCS configuration to achieve the higher reliability needed in a medium-size city is different from that in a small city; and, whereas a medium-city taxi fleet can be accommodated on a one-computer generic configuration, a large-city taxi fleet needs a nongeneric system involving more than one computer or at least an extended-capability single computer.

TABLE 6-1

CHARACTERISTICS OF PROTOTYPICAL CITIES

Size of city	Small	Medium	Large
Examples	Redding/ Enterprise	Birmingham and Tucson	Philadelphia and Detroit
Population range (persons)	18,000 to 90,000	90,000 to 500,000	> 500,000
On-peak-hours demand, passengers/hour	< 50	50 to 250	> 250
Population density (persons/sq. mi.)	1,000	4,000	8,000
ERTs/1,000 persons	0.3	0.4[1]	0.8[1]
Prototypical ERTs in service	15	80	800
Prototypical service area (sq. mi.)	35	50	125
Prototypical population	35,000	200,000	1,000,000
Transit alternatives	None	Few	Several

[1]Rosenbloom, 1968, p. 404, 433.

6.1.2 Relevant Scenario Characteristics

Within prototypical cities, over 40 characteristics were identified which might be expected to affect CCS requirements, such as population density, quality of service, terrain, regulations, fare structure, etc. (Fielding, Task 2: Concept Development, 1977, Table 7-1). Analysis of these characteristics determine that only three of them had major impact on defining the scenarios:

(a) Peak Hourly Ridership — the size (and hence the cost) of a CCS must be tailored to the throughput required of it. This characteristic corresponds closely to the three city sizes identified for prototypical cities.

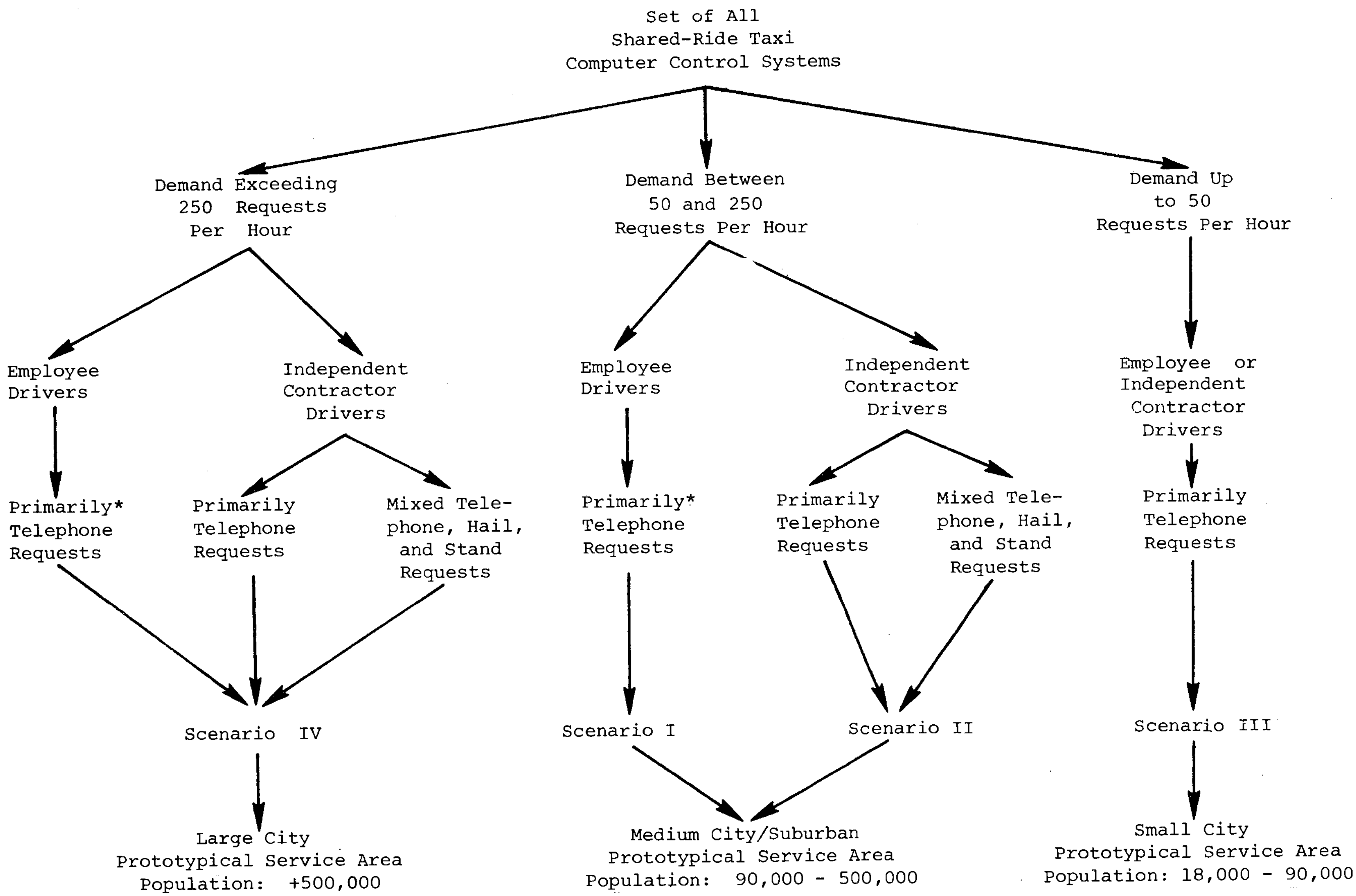
(b) Organization -- CCS requirements vary significantly between taxi companies which employ the drivers and those companies where drivers are independent contractors. This is important because independent contractors may refuse any dispatch assignment and may determine their own start and quit times -- behavioral factors which significantly impact the CCS functional requirements.

(c) Hail and Stand Policies -- Control techniques vary significantly depending on whether the computer knows about a passenger in advance of boarding (i.e., via a telephone request) in which case the computer can optimize the routing, or only at the time of boarding, in which case the degree of computer optimization is severely limited.

6.1.3 Scenario Descriptions

The way in which these three characteristics impact the prototypical cities is shown schematically in Figure 6-1. If all combinations were considered, the three prototypical cities, two organizational factors, and two hail-and-stand factors would result in 3 x 2 x 2 = 12 scenarios. Figure 6-1 shows that the number of combinations can be reduced to only four scenarios by appropriately combining those criteria which do not result in significantly different scenario conditions (Fielding, Task 2: Concept Development, 1977, Section 7.0).

6.1.3.1 Scenario I -- The CCS accommodates up to 250 requests per hour, corresponding to a fleet of about 50 shared-ride taxis. (Note that analysis shows a fleet of 50 SRT's has equivalent passenger-carrying capability to a fleet of about 100 ERT's [McLeod, M.G., 1972, p. 110]). Drivers are employees of the company and subject to normal employee discipline. Requests are made primarily by telephone. Drivers must get authorization from control before accepting any stand or hail passengers. The computer displays the fare for all trips and keeps a tally. Prototypical areas for Scenario I (see Figure 3-2b) are medium-sized cities and suburban areas with populations between 90,000 and 500,000.



*Note: Alternative where employee drivers carry hail and stand passengers in SRT mode is not generally feasible because of potential for driver theft.

FIGURE 6-1
SCHEMATIC OF FACTORS DISTINGUISHING SCENARIOS
AND CORRESPONDING PROTOTYPICAL SERVICE AREAS

6.1.3.2 Scenario II -- The capacity, fleet size, and prototypical service area are similar to Scenario I. Drivers, however, lease their taxis from the company or own their own taxis. The taxi company may be owned by the drivers as an association or cooperative, or it may be owned by others. As independent contractors, drivers are not subject to the same degree of control as employees, and can accept hail and stand passengers without prior authorization from control. Zonal fare methods can be used without risk of theft (since independent contractors keep all revenues) and also permits normal fare collection in the event of computer malfunction.

6.1.3.3 Scenario III -- The CCS need accommodate only up to 50 requests per hour or a fleet of about 10 taxis. This is within manual control capabilities, but an inexpensive computer system might improve dispatcher, driver, and overall productivity. It would also handle routine record-keeping, reporting, and business functions. Control should be via computer-aided graphics due to the high frequency of perturbations experienced in the control of small operations. Drivers in small operations are usually employees, but independent contractors are also feasible because almost all requests will be by telephone. Prototypical service areas are cities with populations between 18,000 and 90,000.

6.1.3.4 Scenario IV -- An inexpensive CCS will start to reach saturation at about 250 requests per hour; above this throughput, a more powerful computer or multiple computers will be needed. The number of combinations of configurations and capacities in which the taxi companies may want these larger systems defies development of a generic CCS. The exception to this is the case in which the service area is divided into several regions, each one of which is equivalent to Scenarios I or II (Figure 3-2b). Prototypical service areas for Scenario IV are cities with populations exceeding 500,000.

6.2 GENERAL CHARACTERISTICS

The general characteristics required of the SRT-CCS are summarized in Table 6-2. These were translated into specific requirements (see Section 7.0) and incorporated into an analysis plan (Potter, Task 3: Systems Analysis, 1978, Appendix B) which guided the system analysis and resulted in the system requirements described in this section.

6.3 FUNCTIONS

6.3.1 Top-Down Modular Approach

Current on-line/real-time system-design practices dictate the use of a top-down structured approach to specify the functional requirements as a necessary preliminary to later effective design of structured programs. IBM's HIPO (Hierarchy, plus Input, Process, Output) documentation method was selected because it has the necessary top-down structure, is widely used and clearly documented (e.g., Katzan, 1976), does not constrain software implementation alternatives, and can be easily understood by management and operations personnel as well as by the technical staff. HIPO documentation, especially at the top levels, specifies "what" the system must do rather than placing specific limitations on "how" it must be done.

The hierarchy of functions required for a comprehensive SRT-CCS is shown in Figure 6-2. This particular decomposition of the system was chosen so that, to the degree possible, each function stands alone, and can be changed without a cascading effect throughout the system. This stand-alone capability is made possible in general by selecting functional boundaries which permit communication between functions via the data bases. Also, where feasible, UMTA's DAR functional organization was incorporated to take advantage of existing designs and documentation.

6.3.2 Multiple-Service Capability

It is important to realize that each function and subfunction defined by the HIPO process basically communicates between the external world and a file or between a file and the external world; in other words, the functions act independently. It is, therefore, feasible for

TABLE 6-2

REQUIRED CHARACTERISTICS OF COMPUTER CONTROL SYSTEM

1. Results in negligible risk of implementation.

2. Results in the automated dispatch of SRT.

3. Results in minimal site dependency.

4. Allows for performance of the following services:

   - exclusive-ride taxi (ERT)
   - shared-ride taxi (SRT)
   - dial-a-ride (subsidized SRT)
   - hail-a-ride and stand
   - subscription (or periodic)
   - integration with fixed-route transit as part of an integrated paratransit system
   - intercity transportation feeder (bus, rail, and airline limousine)
   - service for the transportation-handicapped
   - goods movement (priority and deferred)
   - supplement to fixed-route transit
   - jitney
   - fixed-route deviation
   - fixed-route service (low-density routes)

5. Accommodates the operational strategies and implementation constraints of the identified scenarios (see Section 6.1.3).

6. Provides the required services to each addressed market segment (Fielding, Task 2: Concept Development, 1977) with a consistently high level of user acceptablity.

7. Is cost-effective, reliable, and readily maintainable, with adequate fail-safe recovery and backup ability (both computer-assisted and manual backup modes).

8. Demonstrates a high degree of hardware/software compatibility and modular standardization.

9. Is sufficiently specified and documented.

10. Has sufficient flexibility to insure that the manufacturing community can respond competitively to specifications.

11. Has sufficient flexibility to accommodate adjustments indicated from operational experience.

12. Is sufficiently flexible to adjust to future improvements in equipment and technology.

13. Supports, to the extent that is practical, marketing, safety, accounting, and other indirectly beneficial services.

14. Accommodates Management Information System (M.I.S) requirements.

15. Does not exceed the capabilities of typical driver and dispatch center personnel.

Note: Appendix B in Potter, Task 3: Systems Analysis, 1978, is a comprehensive discussion of how the above criteria were applied to the process of evaluating candidate CCS functions.

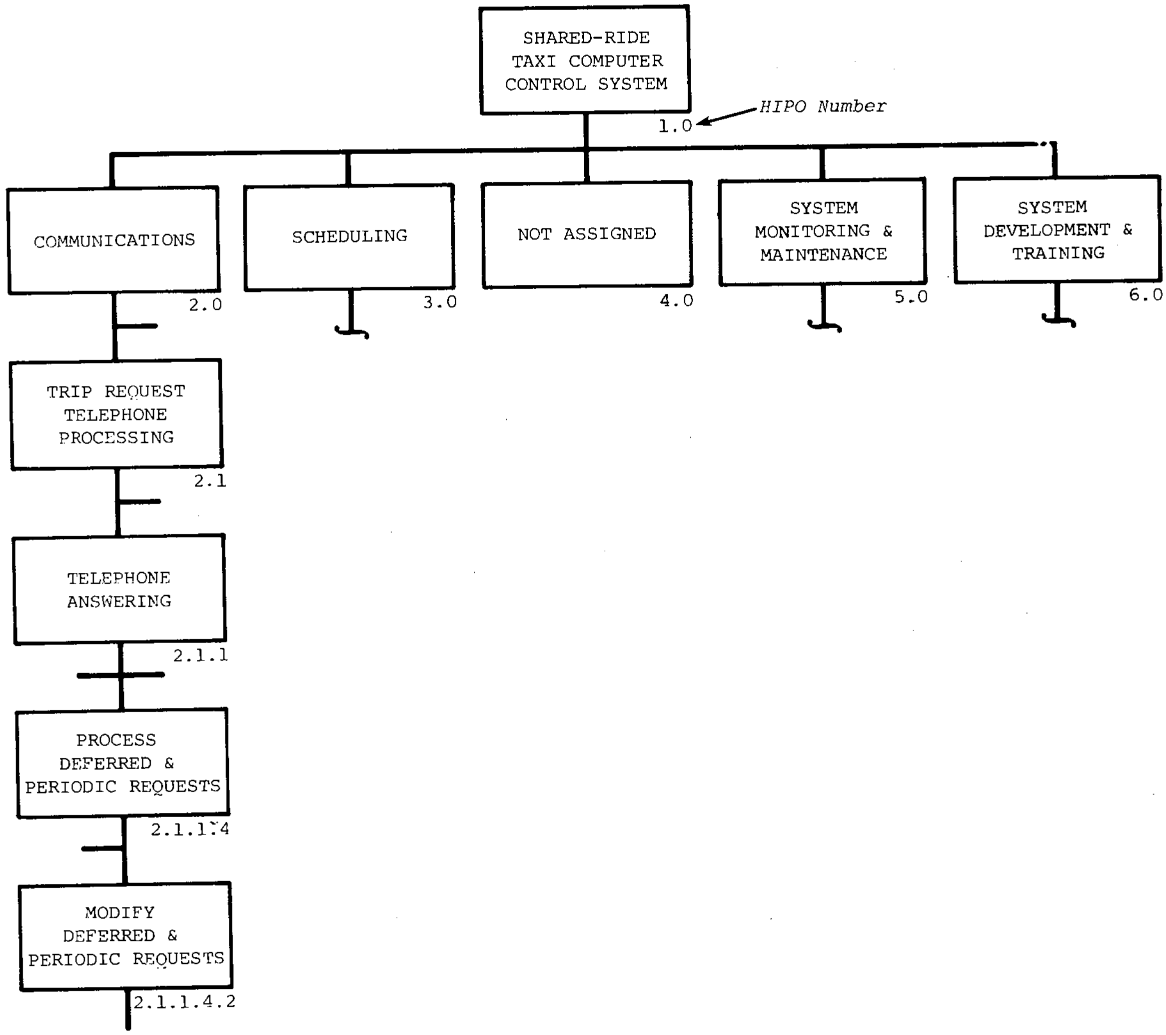


FIGURE 6-2

TOP-LEVEL FUNCTIONAL BREAKDOWN AND EXAMPLE OF FUNCTIONAL HIERARCHY TO FIFTH LEVEL

the functions to be multitasked (i.e., for the computer to perform tasks on a priority basis) and, in effect, to have several functions running concurrently. Moreover, an effective SRT system must permit several different modes of service to be operated concurrently; this is illustrated in Figure 6-3, which shows how some multiple-service features may be used concurrently in a typical operating environment. A detailed discussion of these modes of service is presented in Potter, Task 3: Systems Analysis, 1978, Section 7.3.1.

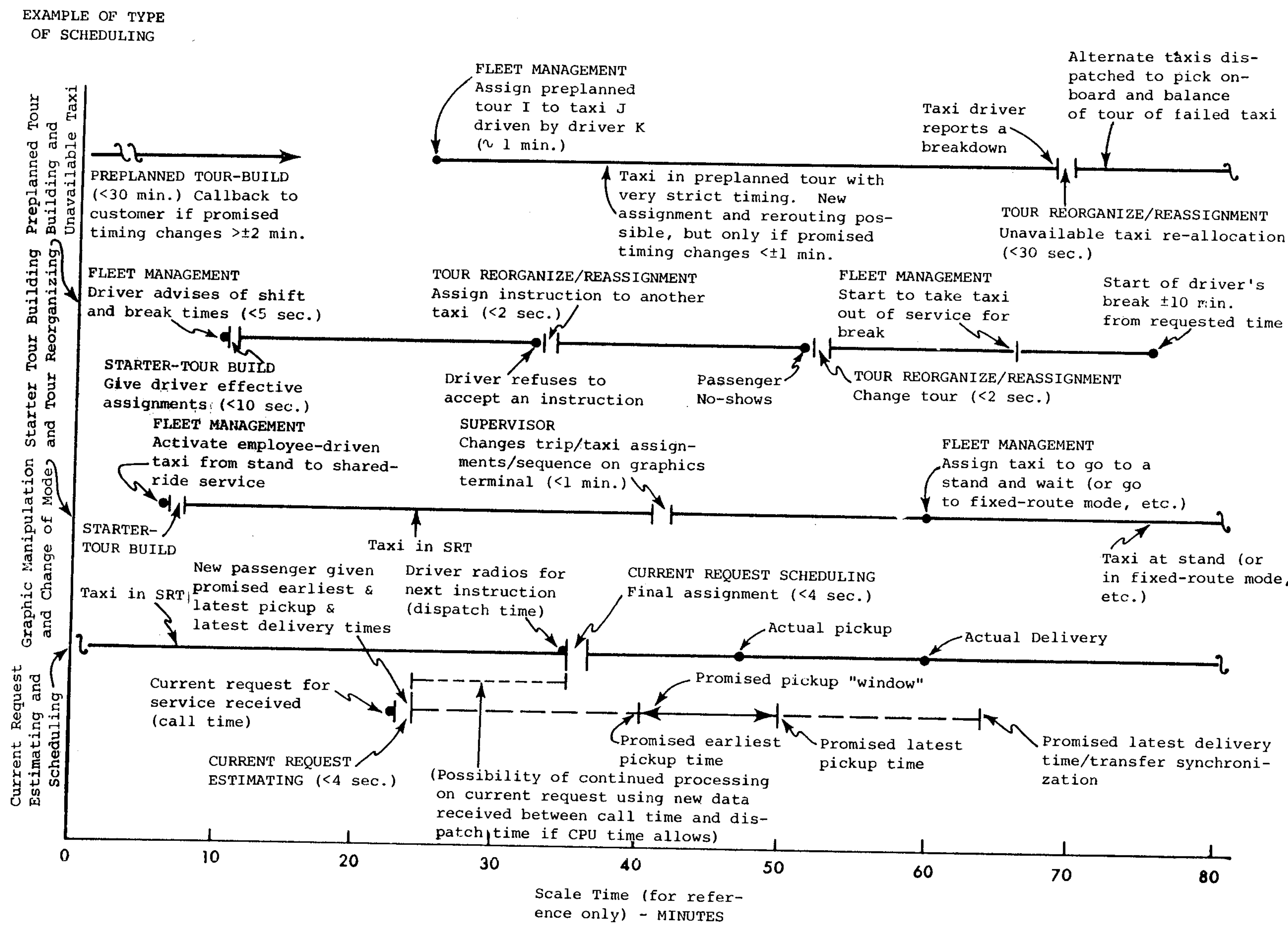


FIGURE 6-3

CONCEPTUALIZATION OF SOME KEY FUNCTIONAL CAPABILITIES
NEEDED CONCURRENTLY FOR A SHARED-RIDE TAXI COMPUTER CONTROL SYSTEM

6.4 COMPUTATIONAL LOAD ANALYSIS

6.4.1 System Considerations

The computation load or stress upon the computer central processing unit (CPU) is an important factor in defining the type of computer needed and, hence, the cost of a CCS. The analytical relationship between computational stress and cost-effectiveness, and other interrelated factors such as tour development models and their conversion to computer transactions, CPU time to perform a transaction, delay in information transfer to terminals, and computer saturation conditions are shown in Figure 6-4.

6.4.2 Assignment Algorithm and Tour Profile

CPU stress is directly related to the type of assignment algorithm and the manner in which the tours develop. This study uses the algorithm developed by MIT and applied in the Rochester DAR program. More experience and computational data is available for this than for any other algorithm.

Tour development is defined in terms of passenger pickup and delivery sequence (tour profile), passenger load, and wait- to ride-time ratio, all of which have a significant effect on CPU stress. Peak-hour and constant-flow profiles were selected as representing the normally encountered operating extremes; most DRT systems operate somewhere between these extremes. The peak-hour tour profile approaches a many-to-few condition such as is encountered when SRT is feeding a fixed-route transit system; all passengers are picked up within a relatively short interval and then travel to a common destination area where they are similarly delivered within a relatively short interval. The constant-flow tour profile maintains a consistent passenger load level and corresponds to the many-to-many type of service.

It is assumed that peak-hour tour profile passengers are all booked in advance of their tour's commencement. On the other hand, constant-flow tour-profile passenger bookings tend to occur shortly before service is required and can be studied by varying the time "window" in which they book trips prior to pickup.

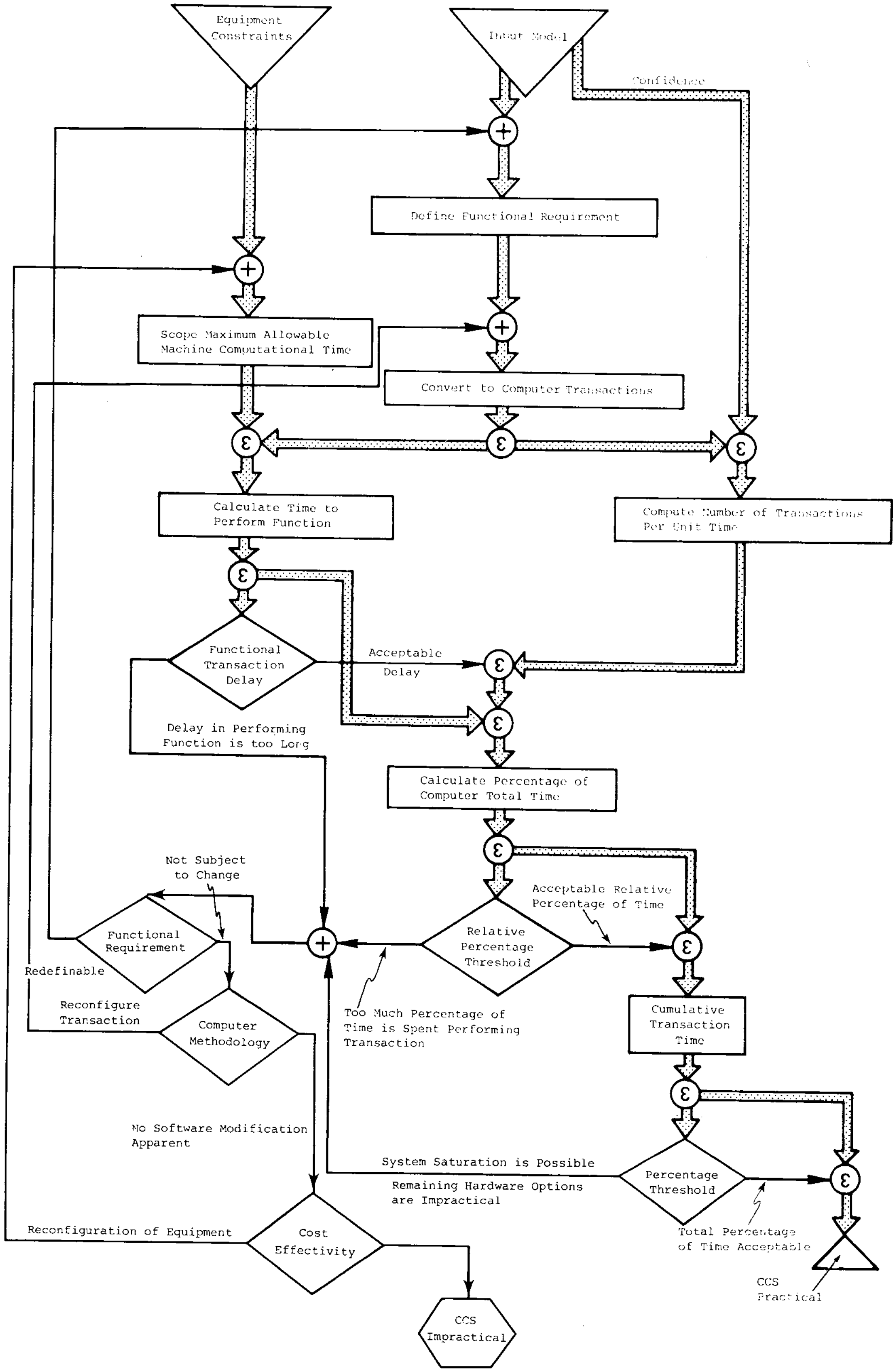


FIGURE 6-4

EFFECT OF THROUGHPUT ON SYSTEM DESIGN

6.4.3 Computation Time

The MIT algorithm employs the trip-to-tour assignment method shown in Figure 6-5. The word "algorithm" means the rules by which each of the calculation steps are made by the computer. The algorithm's purpose is to find the best taxi and the best position to insert a new trip into that best taxi's list of stops. In essence, the MIT algorithm investigates all possible combinations in which the new trip can be inserted into each taxi's tour. The table insert in Figure 6-5 shows there are 15 possible combinations for this one-taxi example. The process is repeated for each taxi in the fleet.

For each possible insertion of a new trip in each taxi's tour, the computer calculates the penalty effects caused by the insertion. This penalty includes the extra wait- and travel-time of the previously booked passengers, the delays for the new passengers, and the extra distance traveled. It remembers the new-trip insertion that causes the minimum penalty, and this becomes the chosen insertion for the new trip. (This is a simplification of how the MIT algorithm works -- see Wilson, March 1976, for more complete details.)

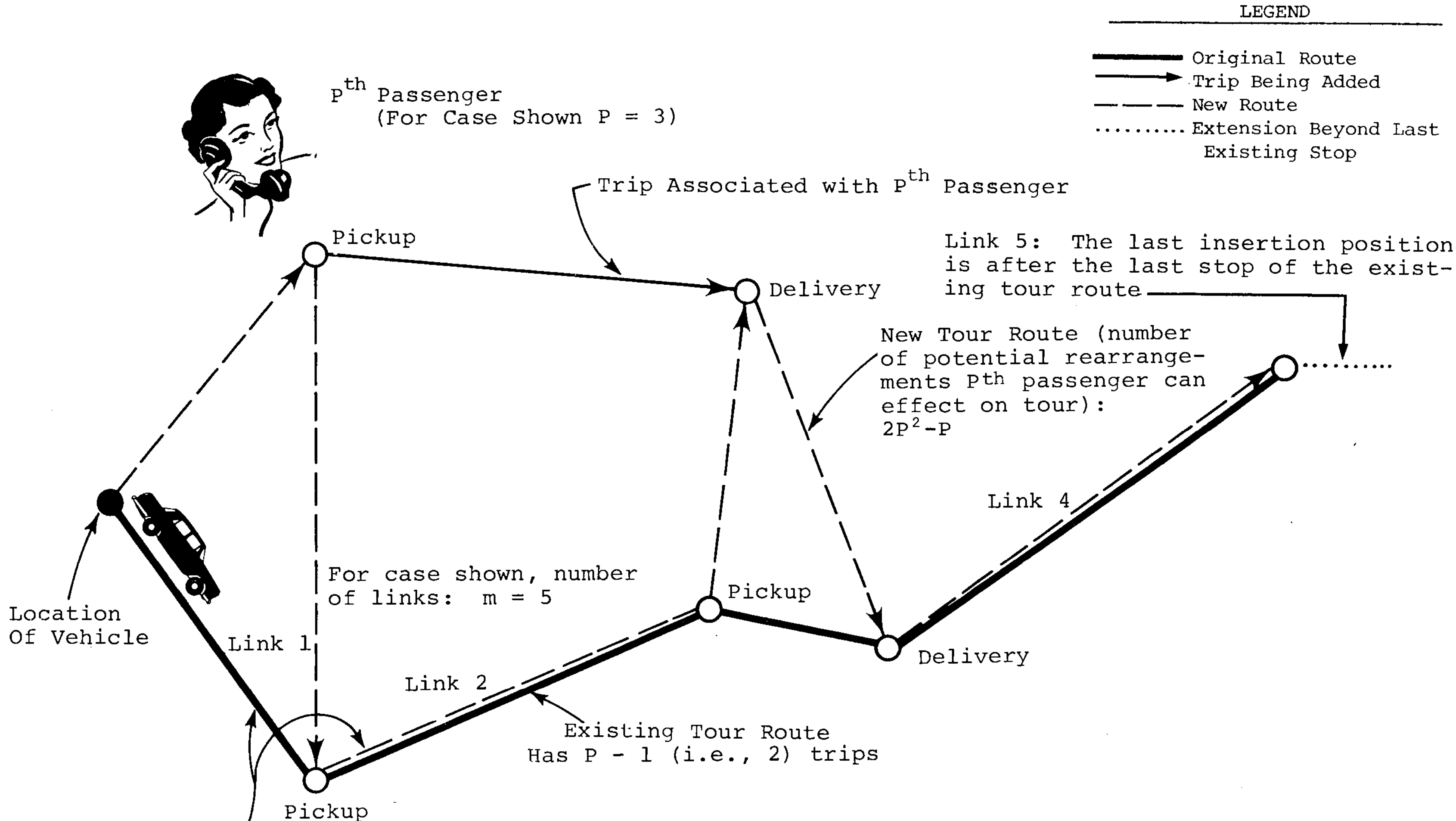
The "computation" time needed for the computer to find the best choice is the product of:

(a) The number of insertion combinations (as illustrated in Figure 6-5 and discussed above) <u>times</u>

(b) The time taken by the computer to calculate a single trip-insertion. This time was obtained by measurements of the Rochester DAR program which uses the MIT algorithm (Connolly, private communications, 1977).

In order to verify that the computation time derived by this method is realistic, it was compared with the actual measured computation time of the Rochester DAR program as shown in Table 6-3. The closeness of fit between the derived and measured values demonstrates the validity of this approach.

The computation time shown in Table 6-3 is for the large, fast computer (Digital Equipment Corporation's PDP-10KL) used for the Rochester DAR. To convert the PDP-10KL computation time to a typical inexpensive, slower minicomputer, computer speed comparisons (benchmarks) were obtained



Combinations Possible					
Pickup Insertion Link	1	2	3	4	5
No. of Delivery Insertion Combinations	5	4	3	2	1
No. of Combinations = 5 + 4 + 3 + 2 + 1 = 15					
$2P^2 - P = 18 - 3 = 15$					

FIGURE 6-5

TOUR-SCHEDULING GEOMETRY

TABLE 6-3

COMPARISON OF DERIVED AND MEASURED SCHEDULING COMPUTATIONAL TIME AS A FUNCTION OF TRIP NUMBER

Trip Number (P^{th} Trip)	Derived Time for Computation ($0.008\ [2P^2 - P]$)	Least Mean Square Curve Fit to Actual Measured Time of Rochester DAR/MIT Algorithm Excluding Constant Term as Determined by TSC*
	(seconds)	(seconds)
1	0.008	0.017
2	0.048	0.060
3	0.120	0.129
4	0.224	0.238
5	0.360	0.359
6	0.528	0.527
7	0.728	0.732
8	0.960	0.978
9	1.224	1.268
10	1.520	1.599
11	1.848	1.987
12	2.208	2.423

*Note that subsequent to these timing tests, it is understood that further enhancements were made to the Rochester DAR algorithm programs, and that reductions in search time may have been achieved. Then, the analysis may be conservative since it is calibrated from the original (pre-improvement) timing data.

(using FORTRAN Program HANOI -- DEC, private communication, June 1977). It was determined that the minicomputers would take about 2.2 times longer than the PDP-10KL to perform this type of calculation.

6.4.4 Transaction Throughput

Various transactions occur between human operators and the computer -- e.g., trip booking, cancellation, information requests. The approximate number of times that each transaction occurs per trip booking was obtained by estimates of SRT operating conditions. The time to perform these transactions was based upon Rochester DAR measurements taken by TSC (Connolly, private communication, 1977). All data were then scaled from the PDP-10KL upon which the measurements were taken to the CCS minicomputer using the 2.2 benchmark scale factor. For example, Table 6-4 shows the contribution of each transaction to CPU load for a 25-taxi operation under the most stressing of operational circumstances -- high productivity (average of 10 passengers per hour) and long average wait times. The CPU load (throughput) with the constant-flow tour-profile is 67.66 percent.

The CPU is almost fully utilized at the computational load created by 25 taxis. Since the computer load increases as a third-order polynomial function of passenger demand (i.e., load is proportional to demand x demand x demand -- Potter, Task 3: Systems Analysis, 1978), faster and far more expensive computers would be required to accommodate larger operations. To avoid these costs, a "field-control" method, which reduces the computational load, was introduced. Field controls permit inexpensive minicomputers to control fleets of over 70 SRTs, instead of the 25-SRT limitation without field controls.

TABLE 6-4

TRANSACTION THROUGHPUT*

Function	Number of Transactions**	Percent of CPU Time for 25-Taxi Fleet Example	
		Constant Flow Tour Profile	Peak-Hour Profile
Cancellation	0.1	0.25	0.31
Information Request	0.1	0.10	0.12
Tour List	0.4	1.72	1.28
Communications and Link Control	2.8	5.56	6.92
Booking	1.0	59.43	24.86
Fleet Status	1.0	0.60	0.74
ALL FUNCTIONS		67.66	34.23

*Note: This throughput table assumes no field control, 40 percent stacking factor, and a 50 percent overhead.

**Expressed as a fraction of the number of bookings

6.4.5 Field Control

In essence, a field control is a "filter" which rejects obviously unlikely trips and/or vehicle assignment alternatives before the algorithm considers them. In other words, field control reduces the "field" of trips and/or vehicles considered by the algorithm. Several techniques employing simple proximity and/or directivity filters are available to accomplish field control though determination of the optimum field control process was beyond the scope of this study.

In addition to field control, the concept of stacking was introduced. The "stack" is simply a list of active vehicles whose sequence has been determined on the basis of vehicle utilization; the least utilized vehicles will be considered first. Each vehicle in the stack is processed by the field control and then by the MIT algorithm, until the first acceptable vehicle which has an objective function below a threshold value is found; if no objective function is found below the threshold level, then the vehicle which has the lowest objective function is selected. (The "objective function" is the summation of all the penalties incurred as a result of the insertion of a new trip into a particular vehicle tour; the "threshold" level is a value of the objective function where the penalties are low enough that further search is unnecessary.) The ratio of the average number of vehicles processed before a selection is made to the total number of vehicles in the stack is called the stacking factor.

6.4.6 Central Processing Unit Load

Analysis shows that when field controls limit the field to 30 percent of the fleet or 20 taxis (whichever is less) and when a stacking factor of 40 percent is applied, major improvements are achieved in the fleet size that can be accommodated by a typical inexpensive minicomputer. (Of the two elements, field control is more important than stacking as a means of reducing CPU load.) Using these field control and stacking factors, and assuming a conservative peripheral overhead of 50 percent, a single minicomputer can control an active fleet of 70 vehicles even under maximum stress conditions as shown in Figure 6-6 (i.e., 7.5 passengers per taxi-hour productivity and a wait time which is three times

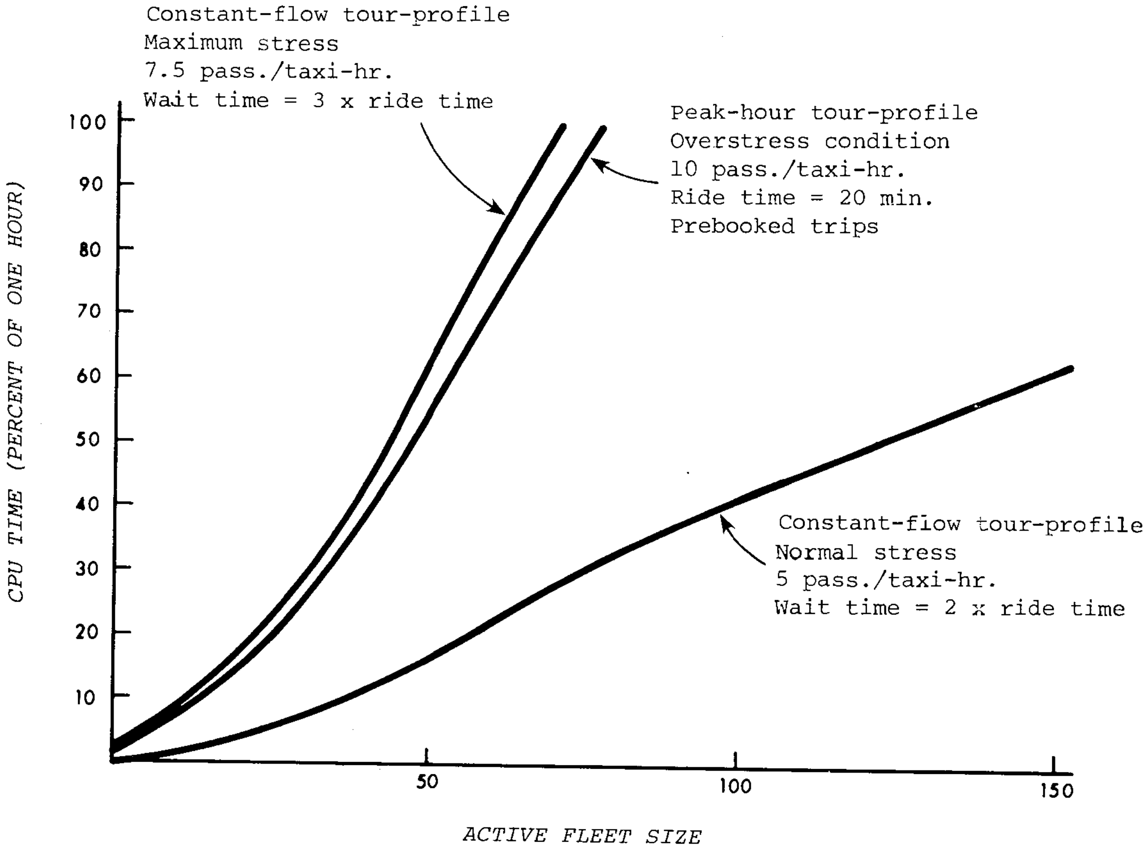


FIGURE 6-6

PERCENT CPU TIME REQUIRED AS A FUNCTION OF FLEET SIZE
USING FIELD CONTROLS AND STACKING

the ride time -- the higher the ratio of wait to ride time, the more trips the computer must investigate in making a new trip assignment and, therefore, the greater the computational stress).

It is concluded that by proper application of field control and stacking, the computational requirements of SRT can be constrained to fit a typical, inexpensive minicomputer. However, it must be noted that such field controls and stacking have not been applied in practice, and should receive a high priority for verification during system design.

6.5 MEMORY

A CCS of the type needed for SRT has two levels of memory (storage), main (core) memory and secondary (disc) memory. (In addition, peripheral units such as terminals and printers incorporate small amounts of specialized memory for their operation.)

Main memory is more than 100 times more expensive than disc memory, but access time is 10,000 times shorter. Thus, effective design requires that only those parts of the program and data base which are being used or are used frequently should be in main memory. Everything else should be stored on disc.

Overlays (i.e., sections of code which are loaded from disc to main memory areas and "overlay" other sections of the same program's code no longer needed) are used so that program or data segments can be temporarily transferred from disc to core when a task requiring these segments is being processed. When the task is interrupted or complete, the overlay area is made available for other tasks. In the core of an interrupted task, the state of the task is remembered so that when the interruption is resolved, the task may be completed. In this way several tasks -- e.g., transactions from several terminals and vehicles -- may be processed with such short delays that the computer appears to be performing them concurrently. The operating system (OS) supplied by the computer manufacturer must be sufficiently powerful to permit this type of multitasking operation -- a common feature on most recent minicomputers.

The decision concerning whether to store each type of data in core or on disc involves a tradeoff between the cost of the core storage vs. the time needed to repeatedly transfer it from disc to core. In many cases the decision is relatively easy to make, but some types of data required extensive evaluation. For example, it was determined that the best allocation of memory for the list of customers assigned to a taxi tour is to store about half of the data in core and the other half on disc. This and other tradeoffs yielded a balanced system configuration with between 24 to 30 disc accesses per trip booking.

6.5.1 Main Memory

Program and management functions will occupy about 58 16-bit kilowords of core storage for the smallest SRT-CCS as shown in Table 6-5. This will grow relatively slowly with fleet size.

Data storage in main memory, on the other hand, grows with fleet size at the rate of approximately 640 16-bit words per taxi. This is shown in Figure 6-7 for a single-computer system up to a 75-taxi fleet, and for two computers above this size.

6.5.2 Disc Memory

Recent improvements in the access time of moving-head discs has made them suitable for a SRT-CCS. (In the past -- e.g., for the Haddonfield DAR system -- a more expensive but faster fixed-head disc was required.) Concurrently with speed improvements, costs have declined to the point where moving-head disc storage is not a critical cost consideration.

The principal disc-memory design factor is the size of the street address file. A conservative estimate based on the comprehensive files used for the Rochester DAR system is 350,000 bits per square mile -- this includes block address ranges, zone identification, key street

TABLE 6-5

BASIC CORE STORAGE USED FOR PROGRAM AND MANAGEMENT FUNCTIONS

Function	Storage (16-Bit Kilowords)
Operating System	22
System Management	8
Resident Programs	24
Unallocated	4
TOTAL	58

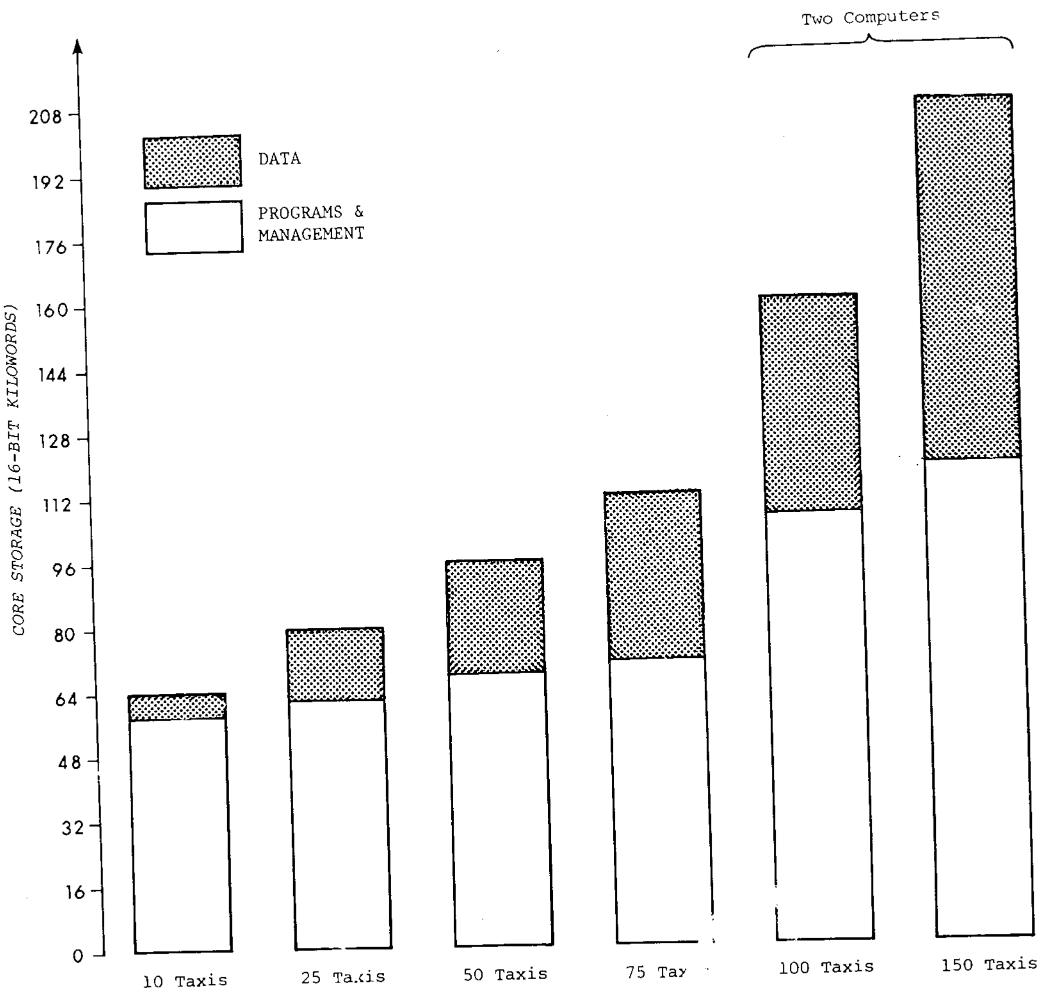


FIGURE 6-7

MAIN MEMORY REQUIRED AS A FUNCTION OF FLEET SIZE

intersections, alternative spelling, and building names, and has a map coordinate accuracy of one-half block. Recently announced inexpensive moving-head discs with storage of 40 to 80 million bits per disc indicate that storage for service areas exceeding 100 square miles will not present significant technical or cost difficulties.

Since disc accesses are sequential, the access-time load on the disc increases with fleet size. This is shown in Figure 6-8 where the disc access time for worst-case operating conditions limit a single disc unit to a fleet size to about 70 taxis (the same limit as a single minicomputer) though under normal operating stress a single disc unit can accommodate a far larger fleet. Multiple disc units (including controllers) can be used to expand capacity in a dual-write/duplex-read

Average disc access time = 0.038 sec.
Maximum number of disc accesses per booking = 30

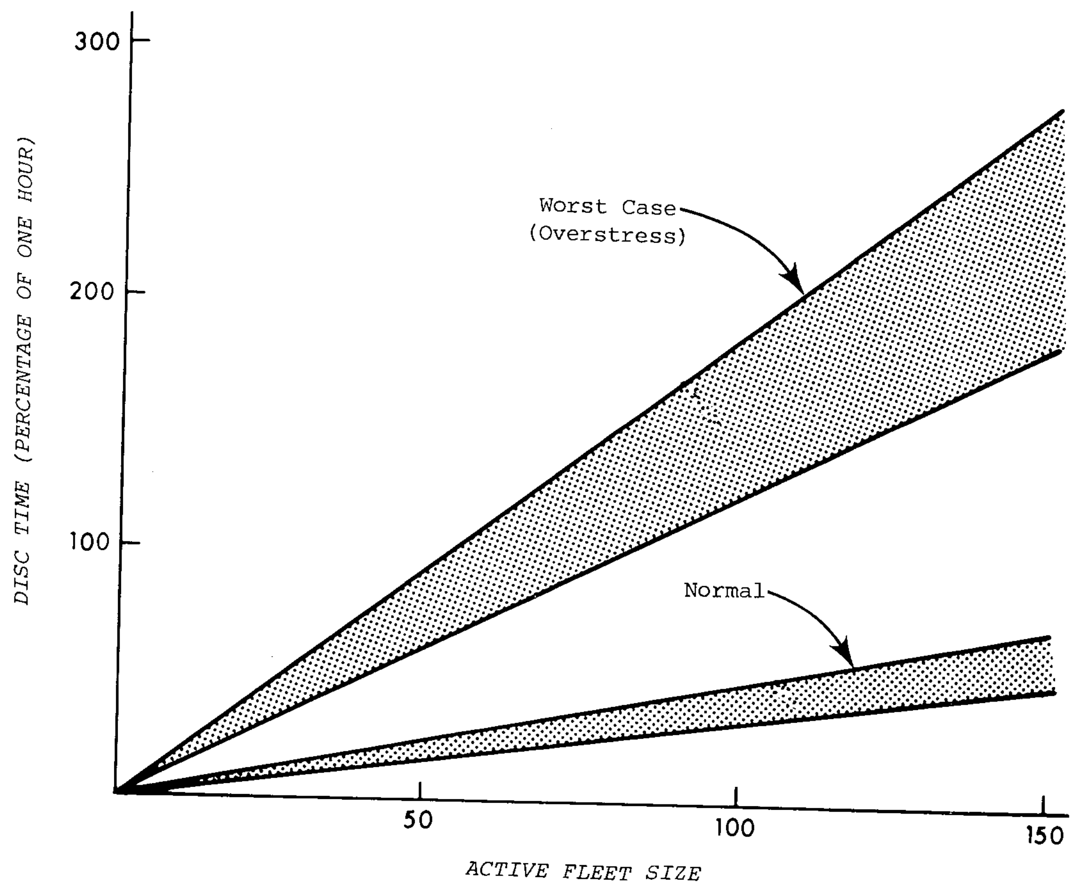


FIGURE 6-8

DISC ACCESS LOAD AS A FUNCTION OF FLEET SIZE mode (i.e., all discs units are written identically but can be accessed independently for read-only data). This has the advantage of redundancy in the event of a disc failure though the dual-write requirement limits the increase in capacity to less than direct proportionality to the number of the disc units.

6.6 COMMUNICATIONS

6.6.1 Radio Communications

Analysis showed that existing ERT duplex (or half-duplex) radio equipment of the type currently in use by most taxi companies will be adequate for conversion to SRT digital communications. Above a fleet size of 20 SRT's, voice communications will saturate the channel; it was shown in Section 4 that small SRT operations will not usually be economically viable. Thus, almost all SRT-CCS's will utilize digital communications.

While reuse of existing taxi radio equipment (which in general is not designed for digital communications) imposes constraints on the transmission rate, these constraints are not critical, and the cost-savings are significant. The estimated duration for various messages is shown in Table 6-6. Allowing for overhead, retransmission, and occasional voice communications, at least 50 and probably 70 SRT's will be controlled via a duplex channel (Potter, Task 3: Systems Analysis, 1978, Section 4.4.2).

TABLE 6-6

COMPUTED DIGITAL TRANSMISSION MESSAGE DURATIONS

Signal Description	Time (Seconds)
Vehicle to Base Message	0.85
Base to Vehicle Line of Display	1.35
Acknowledgment	0.65

6.6.2 Telephone Communications

The telephone system by which customers call in their trip requests will be similar to existing taxi telephone equipment -- no significant changes are needed except that operators will wear headsets so that their hands are free to use the CRT terminal keyboards.

6.6.3 Automatic Callback

Automatic callback will inform customers of:

(a) the imminent arrival of their taxi,

(b) any changes to the pickup time they were told to expect when the booking was made,

(c) the exact pickup time if the request is booked well in advance.

The logic for auto-callback is shown in Figure 6-9. This includes re-making the auto-callback if the customer's telephone is busy or not answered and transferring the call to a human operator if the passenger does not hang up after the automatic message.

Legislation regarding computer-initiated telephone messages is in its infancy. There are indications that "junk" telephone messages now being generated automatically for sales promotion will result in legislated restraints -- the California Public Utilities Commission has already enacted a temporary ban (L.A. Times, Jan. 11, 1978). This legislation will impact the design -- at a minimum, it is anticipated that the customer must be given the right to deny permission for auto-callback. Nevertheless, the benefits of improved reliability, shorter taxi dwell time (time spent by the taxi waiting for the customer to board), and more efficient deferred-assignment algorithms outweigh potential obstacles.

6.7 TERMINAL RESPONSE

The time required for a terminal to respond to an operator's instruction must be acceptably brief. For example, when booking a request, the computer must calculate and then display the estimated pickup time while the customer is still on the telephone. Delays of more than 2 to 3 seconds for this type of response are noticeable, and a delay of over 5

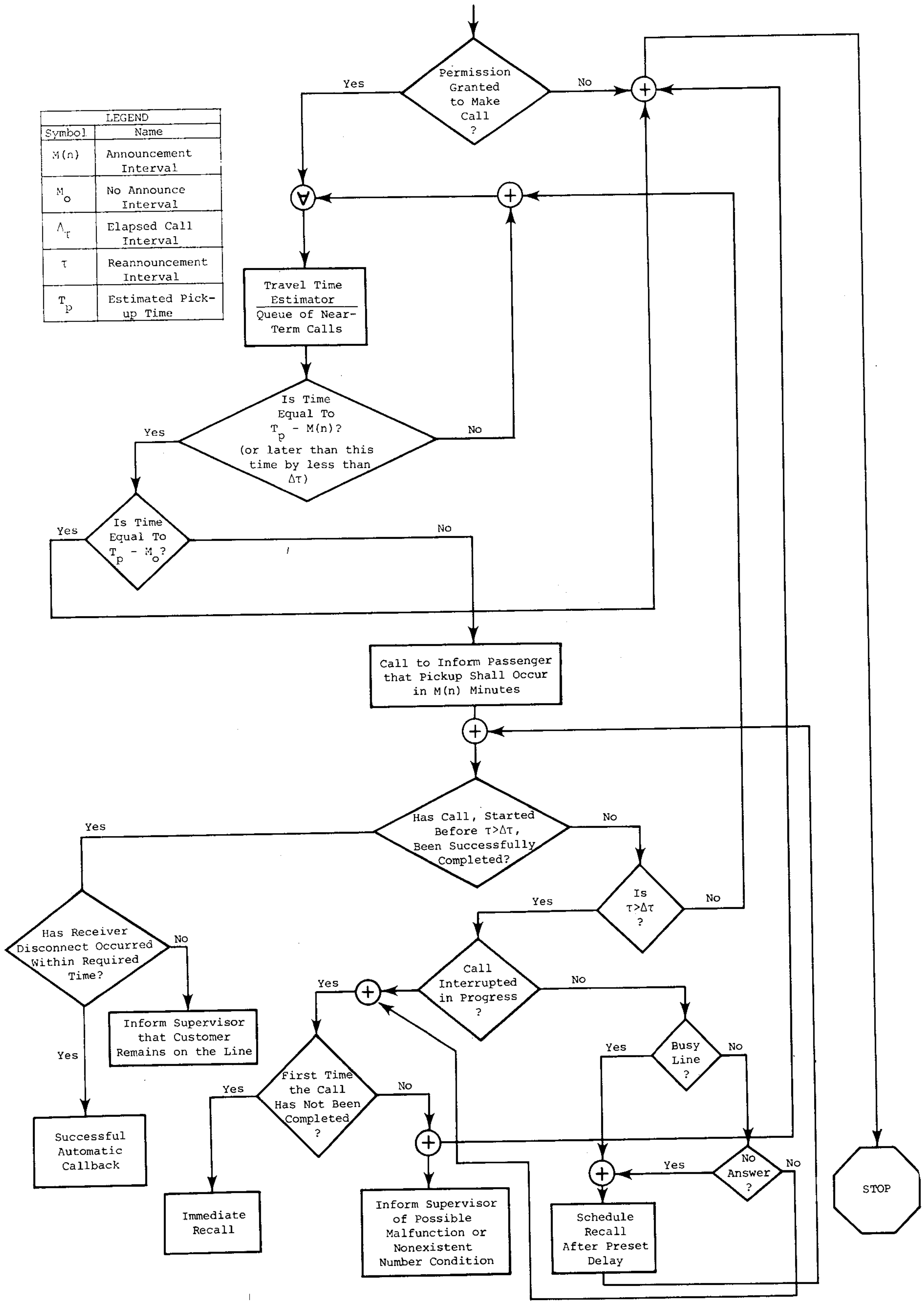


FIGURE 6-9

AUTOMATIC CALLBACK PROCESS

seconds is objectionable. If no more than 10 percent of responses take longer than 3.5 seconds, the system is considered acceptable (Martin, 1973, p. 322).

Using the Rochester DAR system as the basic foundation, Figure 6-10 shows terminal response time for booking (the longest CRT-terminal transaction) as a function of SRT fleet size, with and without field controls. It is apparent that without field controls the response time quickly becomes unacceptable. Non-field-control solutions to this problem include faster memory storage devices such as a moving head disc or increasing the main memory size to reduce program overlay swapping; such solutions would significantly increase the cost of the CCS and would again become limiting at somewhat higher fleet sizes.

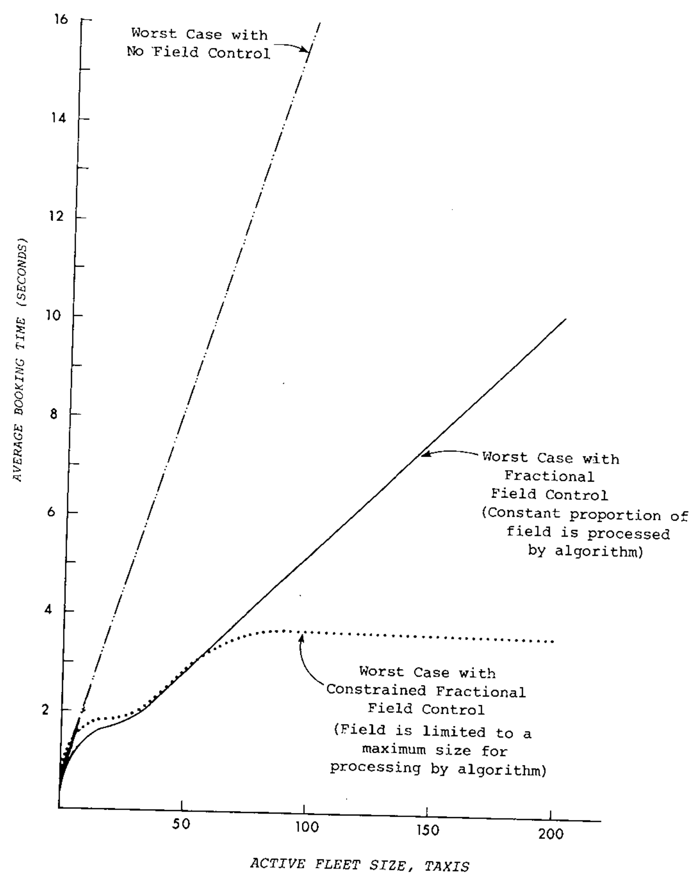


FIGURE 6-10

TERMINAL RESPONSE TIME FOR BOOKING REQUESTS

Field controls that limit the algorithmic search to a fixed fraction of a total search are effective up to a fleet size of about 50 taxis. Above this fleet size, the field controls must constrain the search to a maximum number of alternatives -- in this case, a constrained search equivalent to a full search with a 20-SRT fleet. This is a relatively conservative estimate of the field-control potential and should be easily realizable in practice.

It is concluded that constrained fractional field controls will permit acceptable terminal response times for larger fleets than can be accommodated on a single minicomputer (see Figure 6-6).

6.8 RELIABILITY

Reliability of the post-experiment system must be high. An annual system failure of 11 per year (5,000 hours operation per year) is reported by Kinney (1973). These will primarily be in the electromechanical components: the disc drive (average 5 failures per year) and printer (average 4 failures per year). By using two independent disc drives and the monitor console local printer as backup to the line printer, the annual failure rate of the system can be reduced from 11 to only slightly more than two.

With use of electromechanical backup described above and software-managed auto-switchover in the event of device failure, a reliability of 99.5 percent availability (25 hours downtime per year) is a minimal requirement based on the data presented by Kinney (1973) and Sohn (1975). Experience with the Ann Arbor, Santa Clara, and Yellow Cab of Los Angeles control systems confirms this conclusion (private communications, Potter, Siersema, and Davidson, 1977).

The system must have a semiautomatic warm-start capability requiring less than one minute to implement. This was found to be feasible and a valuable feature in the Santa Clara system. Any loss of records must be automatically noted so that the operators can make appropriate corrections.

In the event of a computer failure, the reversion to manual control should be smooth and create minimum inconvenience to the customers. All current, deferred, and periodic bookings previously accepted by the CCS must be dispatched without loss of quality of service. The Haddonfield and Rochester DAR programs demonstrated that reversion can be accomplished in under two minutes after it has been determined that the computer cannot be restarted. A similar 2-minute maximum reversion time is required for SRT.

7.0 ENGINEERING REQUIREMENTS

Effective system design requires that hardware and software be considered jointly as was done in Section 6 above. At the engineering level of this section, however, CCS hardware and software requirements must be identified separately because of their essential difference -- for example, hardware is purchased primarily off-the-shelf while software is programmed for the specific application.

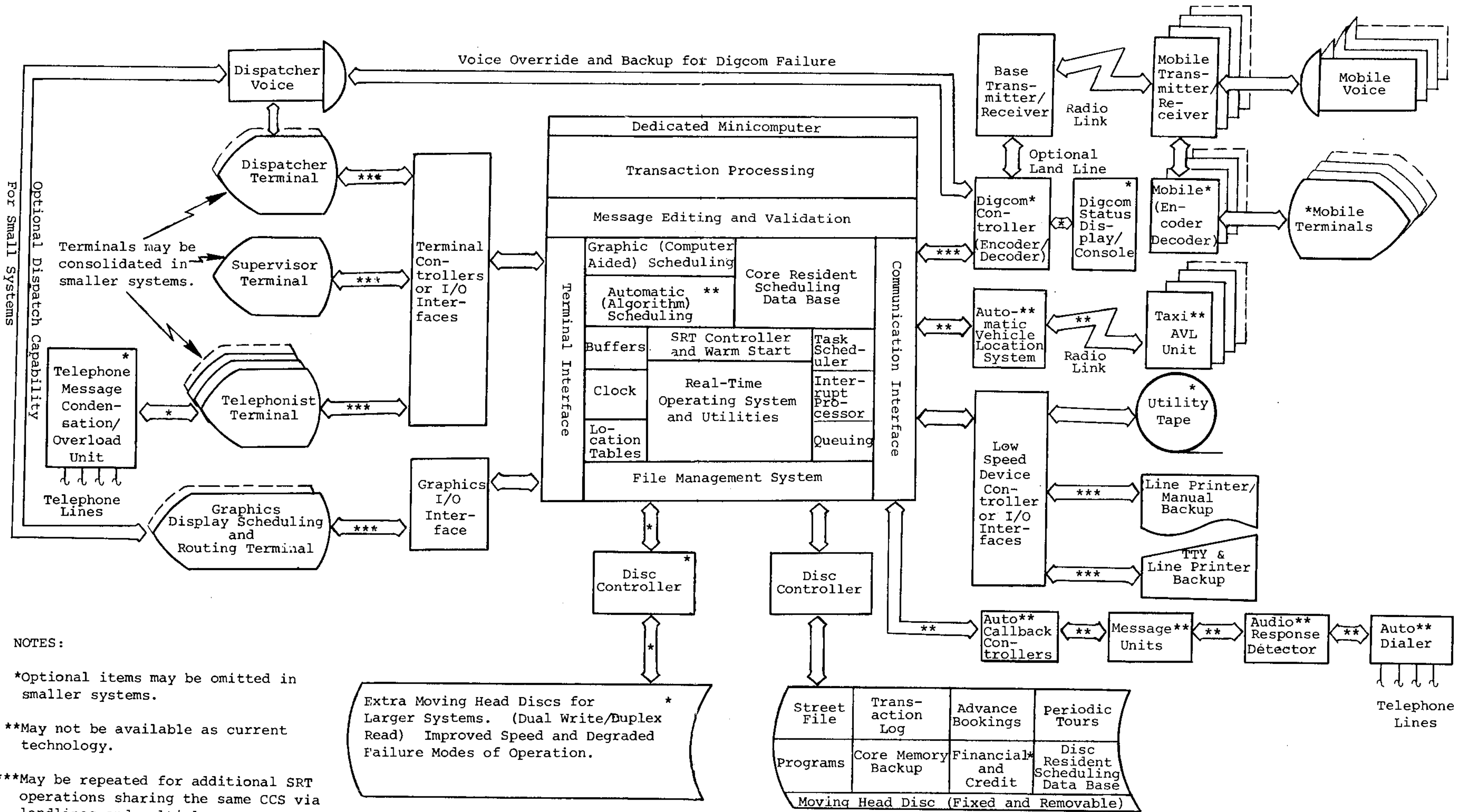
7.1 HARDWARE REQUIREMENTS

7.1.1 Configuration

A schematic of the comprehensive CCS configuration is shown in Figure 7-1. This would be suitable for medium-scale operations such as Scenarios I and II. For smaller systems, such as Scenario III, various parts of the configuration can be omitted as shown by the asterisks, while for larger systems, multiple computers will be needed (Harris, Task 4: Systems Requirements, 1978, Figure 5-4).

The "basic" configuration is typical of current on-line/real-time interactive systems except for the unique SRT features -- i.e., digital communications, graphics, automatic vehicle location (AVL), and auto callback. The equipment required for the basic configuration is readily available from a range of manufacturers and can be purchased competitively and at relatively low cost.

The cost analysis (see Figure 4-2 and Table 4-1) shows, for example, that a production CCS capable of accommodating over 5,000 passengers per day and over 50 taxis is estimated to cost about $260,000 (1976 dollars) for all hardware including digital communications (but assuming a voice-radio system already exists). The cost of equipment is based on 1976 quoted prices which have been increased 20 percent to allow for site-specific system engineering and coordination and further include 15-1/2 percent per annum interest for a five-year lease-purchase, 1976 contract maintenance prices (which average to about 1 percent per month), and 4-1/2 percent for insurance and property tax. This cost corresponds to a monthly payment of about $8,600, or $172 per taxi. For larger systems,



NOTES:

*Optional items may be omitted in smaller systems.

**May not be available as current technology.

***May be repeated for additional SRT operations sharing the same CCS via landlines and multiplexer.

FIGURE 7-1

SCHEMATIC OF CONFIGURATION FOR COMPREHENSIVE SHARED-RIDE TAXI COMPUTER CONTROL SYSTEM economies of scale result in lower CCS costs per taxi, respectively reducing to \$158 and \$147 for 100- and 150-taxi fleets. After the fifth year from date of purchase, the monthly per-taxi cost of equipment (only the cost of maintenance, insurance, and property tax henceforth being borne) ranges from about \$50 for a 50-taxi fleet to less than \$40 for a 150-taxi fleet.

The cost of each item described below varies with the fleet size, and needs to include installation, maintenance, engineering, taxes, financing, insurance, and depreciation costs. This cost information is presented in Potter, Task 3: Systems Analysis, 1978, Section 6.

Requirements for each major hardware component of the CCS have been prepared and the top-level hardware configuration control diagram is shown in Figure 7-2. A summary of hardware component requirements is presented in this section. (Correlation between the operational requirement, functional requirement [HIPO], software module, hardware component requirement, and personnel is shown in Harris, Task 4: Systems Requirements, 1978, Table 5-1.)

7.1.2 Central Computer

Any inexpensive minicomputers meeting the requirements in Table 7-1 are suitable for the CCS. They have low cost, and are available from several suppliers. They are multiprogrammable machines with powerful operating and disc file-management systems, and multipass optimizing FORTRAN compilers. (This will permit programs to be written in UMTA specification language and translated into FORTRAN.) Main memory must be expandable to 128 16-bit kilowords. A high direct-memory-access (DMA) rate and accommodation of communication interfaces is needed for chained computers in a large-fleet, Scenario IV environment.

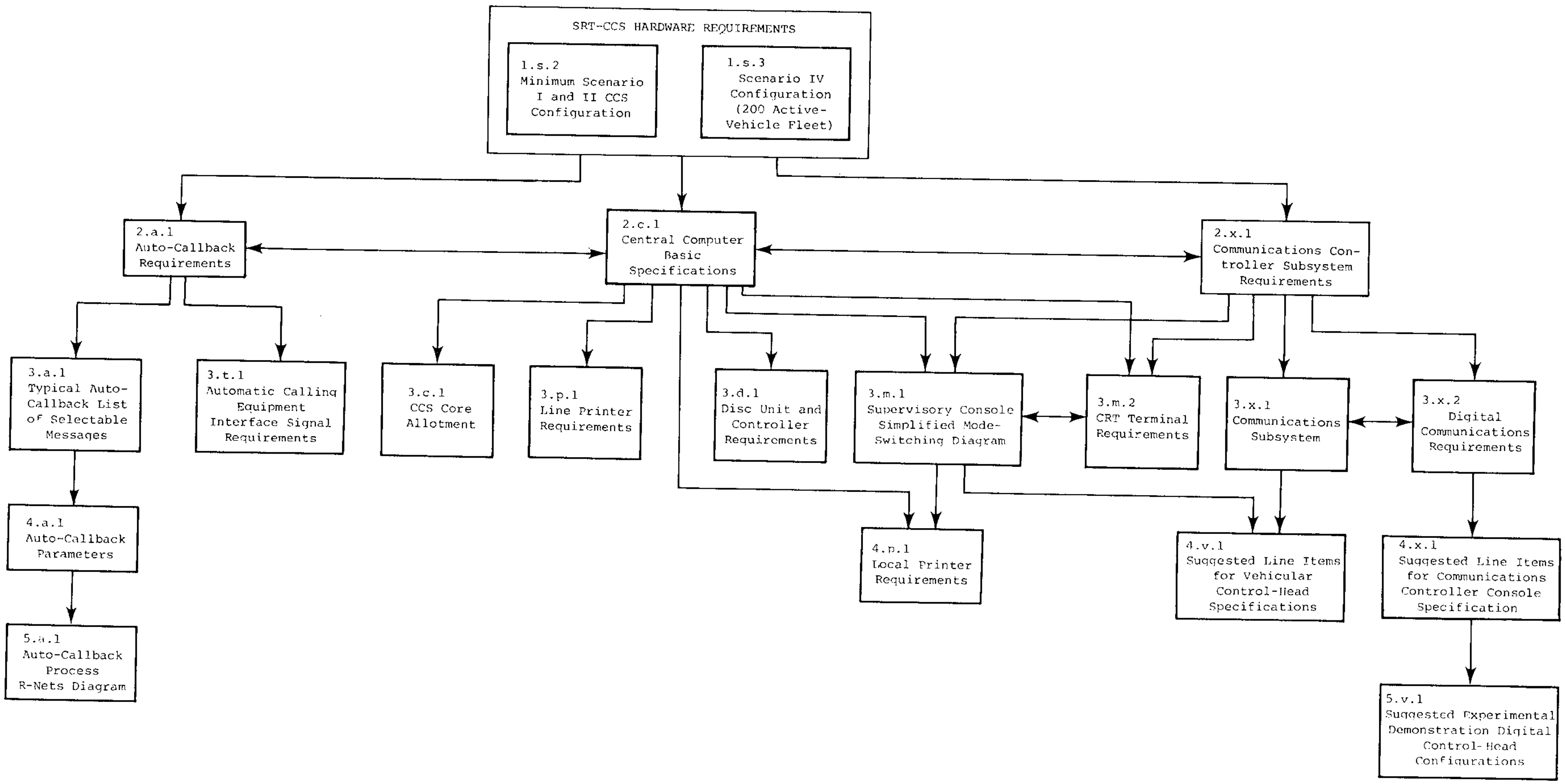


FIGURE 7-2

HWRE. NO. 1.s.1 ORGANIZATION OF HARDWARE REQUIREMENTS

TABLE 7-1

CENTRAL COMPUTER BASIC REQUIREMENTS
(2.c.1)

- 16-bit word length with 8-bit processing and addressing
- Four general purpose registers, minimum
- 32K-word memory with ability to deploy up to 128K-words
- DMA-rate of 1.0 Mbyte/second, minimum
- Accommodation for communication interface to allow multiple computer "chain" operations
- Asynchronous operation
- 16-level auto priority, minimum
- Multiprogramming and spooling
- High-speed interrupt, without requirement for poll
- Power failure detection and automatic restart
- Real-time clock
- 0.7 microsecond maximum cycle time; 1.5 microsecond maximum add time; 12.0 microsecond maximum multiply or divide time
- Documented OS, FORTRAN IV programmable (operating language, communications and disc buffers, and FORTRAN compiler to occupy no more than 22K-word core)
- Capability of startup and control from any USASCII terminal as well as TTY

7.1.3 Disc Unit and Controller

New moving-head disc units described in Table 7-2 have recently been announced. These new discs are adequate for a SRT-CCS and eliminate the need for a faster, but considerably more expensive, fixed-head disc. The new disc units have an average random access time of 35 millisec, which assures reasonable terminal response time, though care must be taken in detail design and coding to use less than 30 disc accesses per booking (see Figures 6-7 and 6-9).

The new disc units have up to 5-megaword capacity, which effectively removes capacity as a design constraint. Such a unit can easily store address data for over 100 square miles.

TABLE 7-2

DISC UNIT AND CONTROLLER REQUIREMENTS
(3.d.1)

Controller Capacity	Up to 4 disc units with simultaneous seek on all other units when anyone is transferring data
Disc Unit Description	19-inch rack, mountable, removable cartridge
Disc Capacity	5M-byte, minimum
Disc Transfer Rate	256K-bytes/second, minimum
Maximum Seek Times	12.5 milliseconds, track to track 50 milliseconds, average random 90 milliseconds, maximum
Average Latency	17.5 milliseconds, maximum
Addressable Records	4,000, minimum Large records to be written by linking sectors 2K-word, minimum size of maximum allowable record
Input/Output	Under DMA control
Desired Price Dependent Options	35 milliseconds or less, average random seek time Ability to mount removable and fixed-head disc on same spindle

7.1.4 CRT Terminals

Two types of CRT terminals -- basic alphanumeric and color-graphic with alphanumeric -- will be required as shown in Table 7-3. These are so-called "intelligent" terminals which perform many editing and control functions and communicate with the central computer with "bursts" of data. This minimizes the central computer's communications with the terminals and permits it to attend to overall control of the system.

Free-form entry can be applied, such as a Primary Action Code (PAC), which is used in the Rochester and Haddonfield DAR systems, the

TABLE 7-3

CRT TERMINAL REQUIREMENTS (3.m.2)

<table>
<tr><th>REQUIREMENT</th><th>ALPHANUMERIC TERMINAL</th><th>COLOR GRAPHICS TERMINAL</th></tr>
<tr><td>Power</td><td colspan="2">115 VAC/60 HZ
150 Watts, Maximum</td></tr>
<tr><td>Operating Environment</td><td colspan="2">Temperature: 60°F to 90°F
Humidity: 10% to 80%</td></tr>
<tr><td>Usable Display Size (Diagonal Length)</td><td colspan="2">17 to 21 inch</td></tr>
<tr><td>Alphanumeric Display Format</td><td colspan="2">80 character by 24 line (1,920 characters)
USASCII uppercase 64 character subset</td></tr>
<tr><td>Internally Generated Refresh Rate</td><td colspan="2">30 per second, minimum</td></tr>
<tr><td>Data Input/Output Configuration</td><td colspan="2">EIA RS-232(c)
Three (3) I/O Ports
Full I/O channels to central computer and for interconnection as part of distributed processing chain
Interconnection to local hard-copy device (mode selection from keyboard: print only, display only, print/display)
Independent computer-controlled printout on local hard-copy device through computer I/O channel</td></tr>
<tr><td>Data Input/Output Rate</td><td colspan="2">9,600 baud
16-bit word structure (USASCII 8-bit character format compatible with 16-bit architecture acceptable)</td></tr>
<tr><td>Keyboard</td><td colspan="2">Stand alone (with up to 5 feet of cable)
<u>Minimum Configuration</u>:
Standard USASCII Section
Display Control Section: cursor arrow keys, cursor blink, insert line, delete line, insert character, delete character, roll up, roll down
Software Control Section: up to 20 user-defined functions shall be provided with a minimum of 8 software latchable keys</td></tr>
<tr><td>Memory</td><td>At least 16K-bytes available to perform other than specified display functions</td><td>At least 40K-bytes available to perform other than specified display functions</td></tr>
<tr><td>Color</td><td>N/A</td><td>At least 5 distinct grades</td></tr>
<tr><td>Interactive Input/Output</td><td>N/A</td><td>Light pen, mouse, joystick, RAND tablet, or other suitable means</td></tr>
<tr><td>Number of Directly Accessible Elements</td><td>N/A</td><td>7 x 10⁴ minimum (number of elements per character or symbol not to exceed 9)</td></tr>
<tr><td>Other Requirements</td><td>None</td><td>Canned-vector and symbol-generation package</td></tr>
<tr><td>Desired Price-Dependent Options</td><td>Upward field kit installable compatibility with Color Graphics Terminal
Full USASCII 128-character subset display</td><td>None</td></tr>
</table>

Los Angeles Yellow Cab system, and the airlines via IBM's Programmed Airlines Reservation System (PARS). Form entry used in the Ann Arbor DAR, Santa Clara DAR, and many on-line business systems is also acceptable since it is only slightly slower than the PAC method and has the benefit of being easier and more accurate for an inexperienced operator to use.

TABLE 7-4

DIGITAL COMMUNICATIONS REQUIREMENTS
(3.x.2)

Delay in Initial Character Generation after Signal Transmission Start	500 milliseconds required
Specification Environment	Rayleigh fading over uniform area 95 percent coverage at 20 db SINAD
Maximum Duration of a Single Continuous Transmission and its Acknowledgment	2 seconds
Length of Single Continuous Transmissions	DISPLAY Transmission (base to vehicle) 4 character identification 32 characters for display (or less for other specified communications -- 32 consistent-character format recommended) 36 characters ACKNOWLEDGE Transmission (base to vehicle and vehicle to base) 4 character identification 1 character acknowledgment 5 characters STATUS Transmission (vehicle to base) 4 character identification 10 character space allocated 14 characters
Transaction (vehicle-stored message) Length	Transactions may include up to 6 DISPLAY Transmissions to be stored in vehicle electronics
Probability of Error	No erroneous characters in at least 99.6 percent of messages accepted for display, a minimum of 95 percent of display transmissions being decoded and displayed at 20 db SINAD*
Number of Automatic Retransmissions of Message which has not been Decoded	3

*This allows an error due to transmission in about two percent of communications transactions and approximately a 10^{-5} usable bit-error rate.

7.1.5 Digital Communications

Digital communications equipment described in Table 7-4 will be cost-effective in all but the smallest operations. Voice communications in shared-ride operations are limited to about 150 passengers per hour (i.e., about 30 taxis in operation) per channel. In addition to making the driver's job more convenient and reducing errors associated with the handwriting of trip information, digital communications will allow for a transfer of information at a rate of more than twice that of voice communications on older radio equipment used in many taxi operations and up to four times that of radio equipment designed to interface with digital communications equipment.

Mobile digital communications units are required to be compact in order to fit into existing taxis. Full keyboards and large displays are not essential. There must, however, be the ability to display about four lines of instructions (or to roll over a single-line display) so that the driver can select best routes and can proceed in an area of radio blackout.

It should be noted that the cost of the computer and peripherals is only slightly greater than the cost of digital communications (see Table 4-1). Thus, from a cost viewpoint, the design of the digital communications system is of paramount importance.

7.1.6 Auto Callback

The queue is generated by a computer search based on the computer's data on each vehicle and each passenger as well as by instructions from drivers and control staff who identify that a callback is needed. (For example, a driver waiting for a passenger could generate a callback to say that the taxi is waiting.) The computer activates calls by advising the auto-callback equipment of the telephone number and message identifier. Feedback from the auto-callback equipment confirms that the call has been completed, that the phone was busy or not answered, or that the passenger has not hung up and thereby indicates a desire to speak with a human operator. The logic for the auto-callback device was shown in Figure 6-9 and the basic engineering requirements are presented in Table 7-5.

Several different technical methods are available to store and play back the messages. For example, a single tape transport per telephone line can store all the needed messages, but its high seek speed is expensive; multiple tape transports can be used, but must be synchronized;

TABLE 7-5

AUTO-CALLBACK REQUIREMENTS

Power	115 VAC/60HZ
Operating Environment	Temperature: 60°F to 90°F Humidity: 10% to 80%
Computer Input/Output	EIA RS - 232(c) Levels maintained at output of 40 foot cable
Telephone System Input/Output	EIA RS - 366
Number of Telephone Lines	Equal to next highest integer above the product of 0.064 and the maximum number of taxis to be dispatched
Total Length of Message	16 seconds
Number of Sequential Message Segments	4: Commencement (fixed format) Preamble (4 message selections) Schedule (16 message selections) Closure (5 message selections)
Allowable Delay in Message Composure	2.5 seconds from receipt of computer command; 0.5 seconds between segments*
Maximum Number of Practical Combinations of Message Selections	156
Vocabulary	100 different spoken words (180 syllables)
Disconnect	Within 2 seconds of customer hang up

*If auto-search tape mechanism is used, this implies that if complete messages are stored, tape registration must be obtained at 1,000 times recording speed; and if sequentially used message segments are stored, tape registration must be obtained at 150 times recording speed.

digitally encoded messages are feasible, but require significant storage; phonetically coded messages require less storage, but may require a degree of interpretation on the part of the listener. This technology is in a period of rapid growth and change, and the optimum method should be chosen during detailed design.

The message will consist of several parts -- for example:

(a) Commencement: "This is Yellow Cab calling."

(b) Preamble: "Your taxi is running slightly ahead of schedule."

(c) Schedule: "It will arrive four minutes from now."

(d) Closure: "Please be ready. If you need more information, do not hang up."

7.2 SOFTWARE

7.2.1 Approach

One of the benefits of describing the system by the HIPO method (see Section 6.3.1) is that it provides a structure for software design and documentation, but does not constrain the design details. This requirements study has taken the HIPO functional decomposition to the sixth level, identifying over 120 HIPO's; the next levels of decomposition will occur in detailed design. (In fact, some of the HIPO's already defined as a necessary part of the requirements really constitute part of the detailed design -- the transition from requirements definition to design is more a gradual process than an abrupt change.)

Each of the HIPO functions will be mechanized by an assembly of software modules needed to perform the function. Over 400 software modules were identified and described (Harris, Task 4: Systems Requirements, 1978). Many of these modules will serve more than one function (though it is important that each module be constructed to serve a specific complete process, so that a cascade of calls from one module to another does not overload memory during multitasking). Thus an operational requirement such as a CRT terminal transaction will initiate one or more functions which will call one or more software modules.

7.2.2. Hierarchy

At the top level, the software requirements are embedded into the functional requirements -- it is not until software modules are defined that the differences between functions and software become apparent.

Figure 6-2 showed the top level hierarchical breakdown into four functional areas. These are further discussed and subdivided in the following sections.

7.2.2.1 Communications (HIPO 2.0) -- These functions shown in Figure 7-3 cover communications which take place between the control center, the drivers, and the customers. Most requests for service are received by telephone. Many of the telephone-answering and trip-booking functions are similar to those used in the Rochester and Ann Arbor DAR systems and the Los Angeles taxi dispatch systems. Driver communications are by

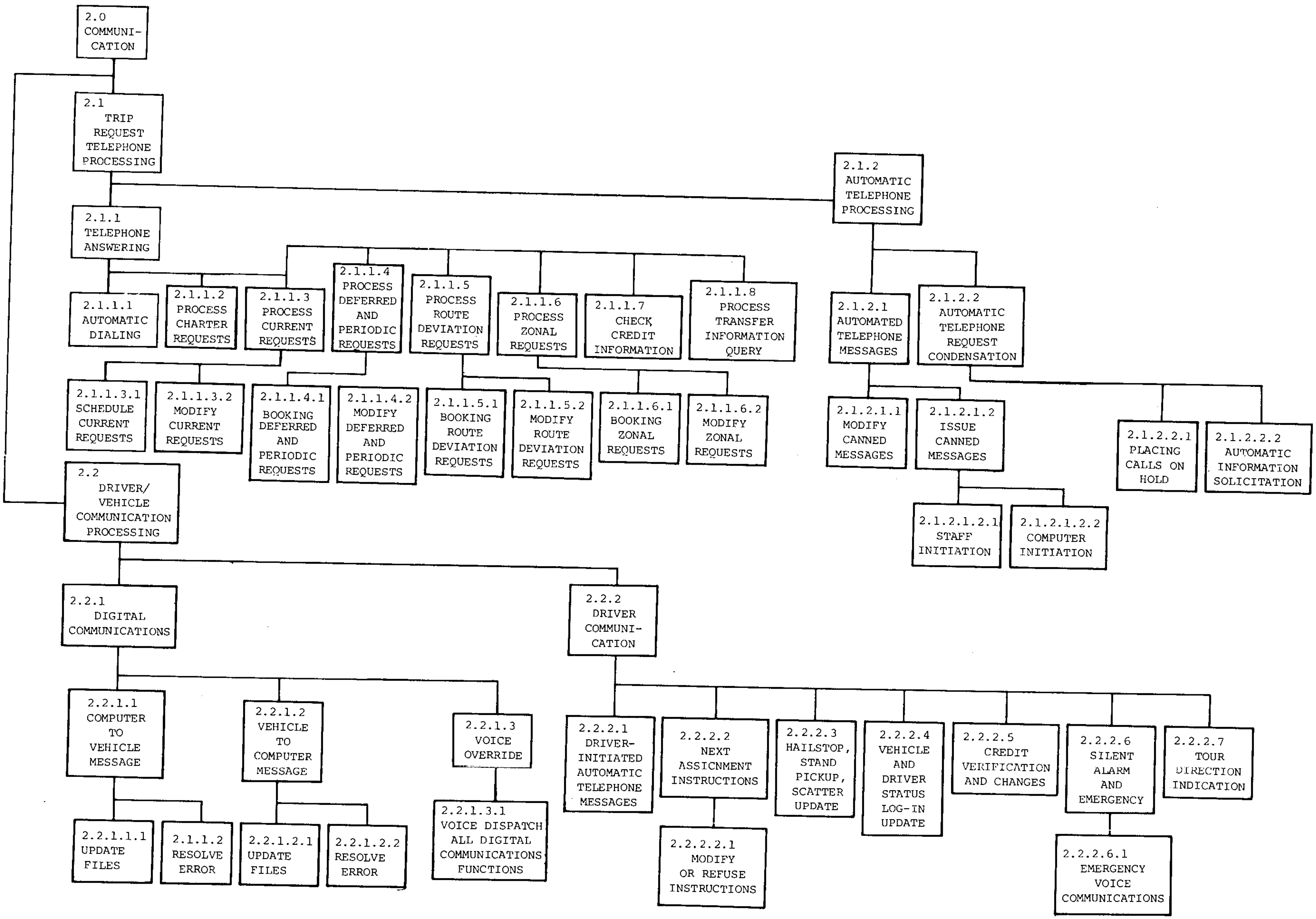


FIGURE 7-3. HIPO HIERARCHY NO. 2, HIERARCHY DIAGRAM FOR COMMUNICATIONS

digital communications and/or voice-radio. A customer callback capability can be activated by the CCS, control staff, or drivers, and relayed to waiting passengers via an auto-dial telephone link and prerecorded messages to advise the passengers of any updated taxi arrival time and also to advise them of the imminent arrival of their taxi.

7.2.2.2 Scheduling (HIPO 3.0) -- The functions in Figure 7-4 incorporate a number of algorithms necessary to control the SRT system. The MIT-developed algorithms include a capability for current-request scheduling, and research is underway at MIT to develop improved versions including a deferred-assignment algorithm (Wilson and Miller, Advanced DAR Algorithms, Phase II Interim Report, July 1977, Chapter III). At this time it is not known if advanced algorithms presently being developed will be able to accommodate all SRT situations or if they will have the speed required for commercially viable implementations. Consequently, a graphic assignment capability which permits effective system monitoring, enhancement of automatic algorithms, and applies proven manual-scheduling methods will be incorporated in the initial implementation. The graphic terminal will show trips, vehicles, timing, assignments, and the objective functions on a CRT so that by use of a light pen the scheduler can make informed decisions. As automatic algorithm advancements are incorporated, the graphics terminal can be relegated progressively to a monitoring and override capability. Vehicle locations used in scheduling will be estimated by an interpolation method similar to the Rochester DAR but with the capability to add more accurate locations from an AVL system. Synchronized transit capability between SRT and other modes of conventional transit is required.

7.2.2.3 System Monitoring and Maintenance (HIPO 5.0) -- Figure 7-5 shows monitoring, maintenance, and control-parameter functions needed to supervise and tune the entire system for best performance. File generation includes the use of census data and dual-independent map encoding (DIME) techniques for street addresses. The street address files can be shared with other users (i.e., several taxi companies can use the same

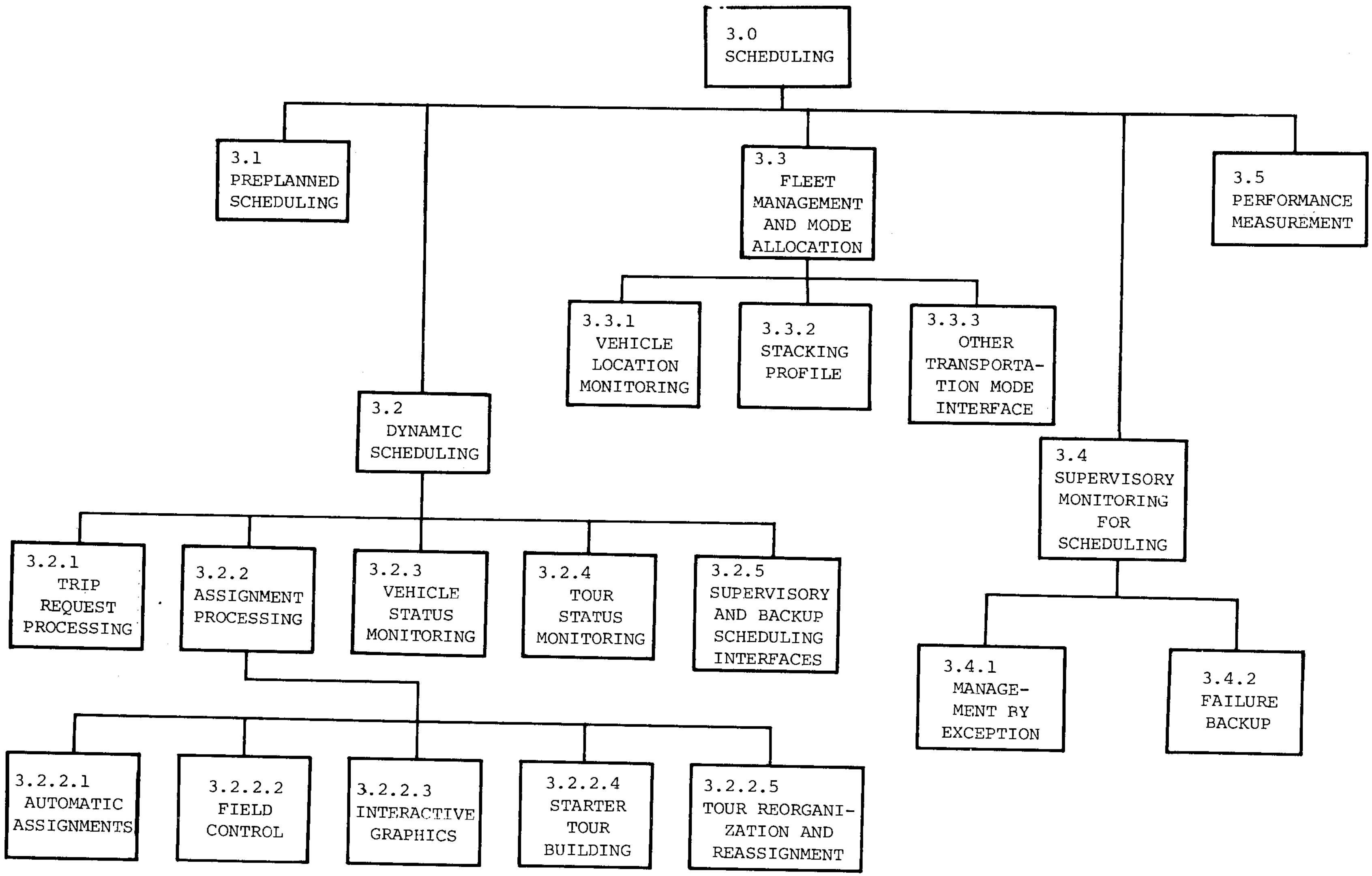


FIGURE 7-4. HIPO HIERARCHY NO. 3, HIERARCHY DIAGRAM FOR SCHEDULING

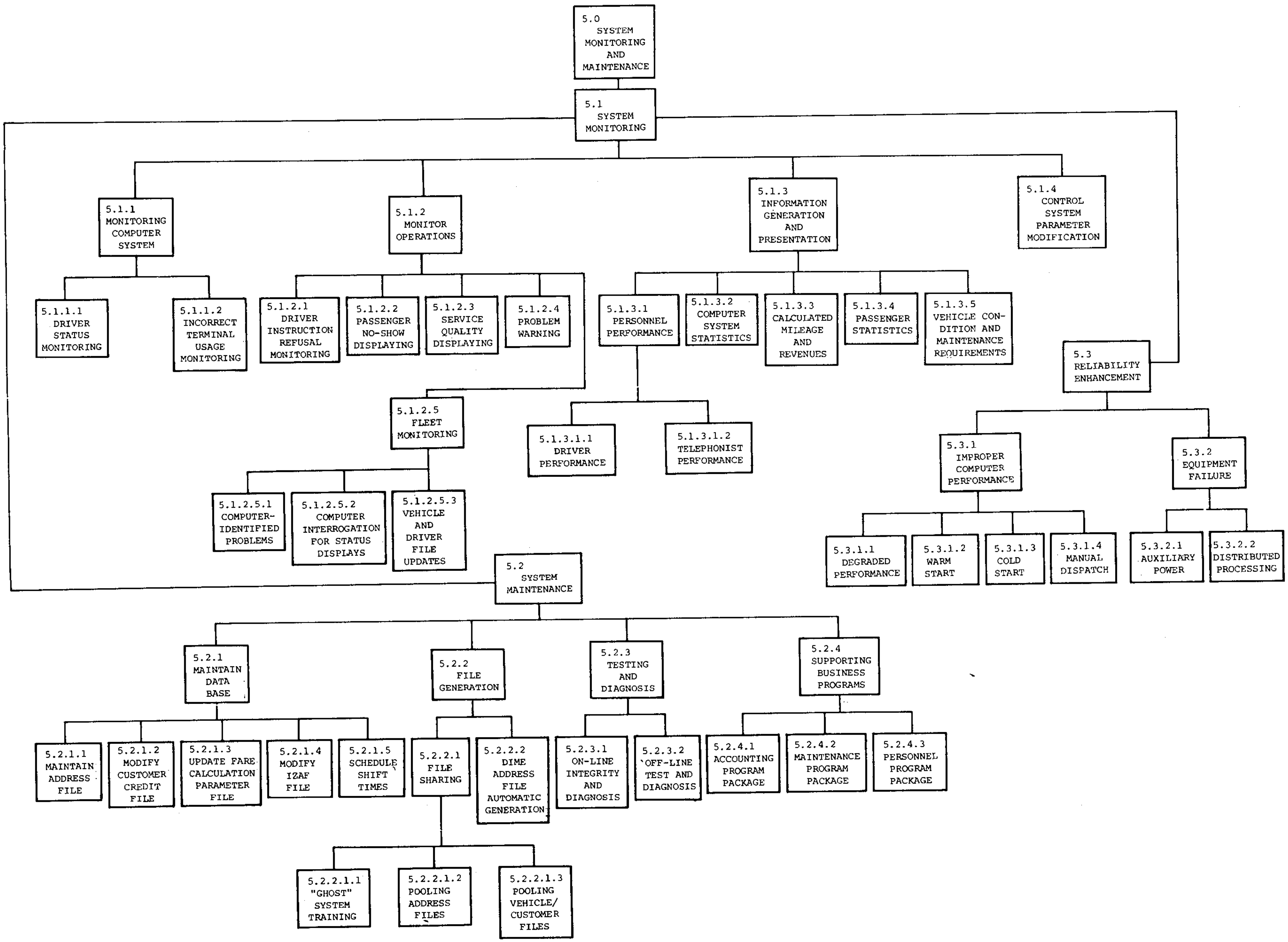


FIGURE 7-5. HIPO HIERARCHY NO. 5, HIERARCHY DIAGRAM FOR SYSTEM MONITORING AND MAINTENANCE

computer), while vehicle and customer files can be restricted. Supporting programs available for use on a background computing basis include conventional business packages available as part of the user group associated with a particular supplier's computer equipment. Reliability-enhancing features are incorporated to permit degraded operation despite various types and levels of failures. On-line and off-line tests and diagnoses will exercise all major elements according to a standard simulation in order to check performance after changes are implemented.

7.2.2.4 System Development and Training (HIPO 6.0) -- Training of new personnel and retraining of existing personnel (see Figure 7-6) will include comprehensive simulations using a "ghost" system in parallel

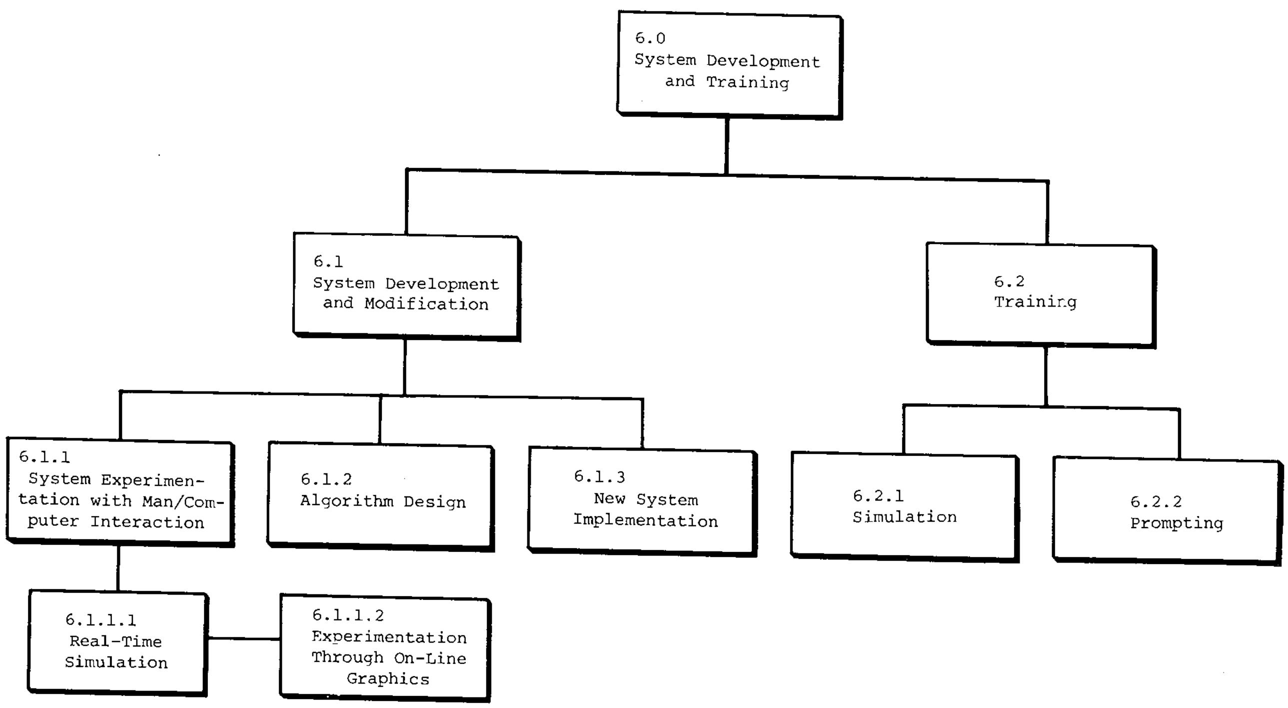
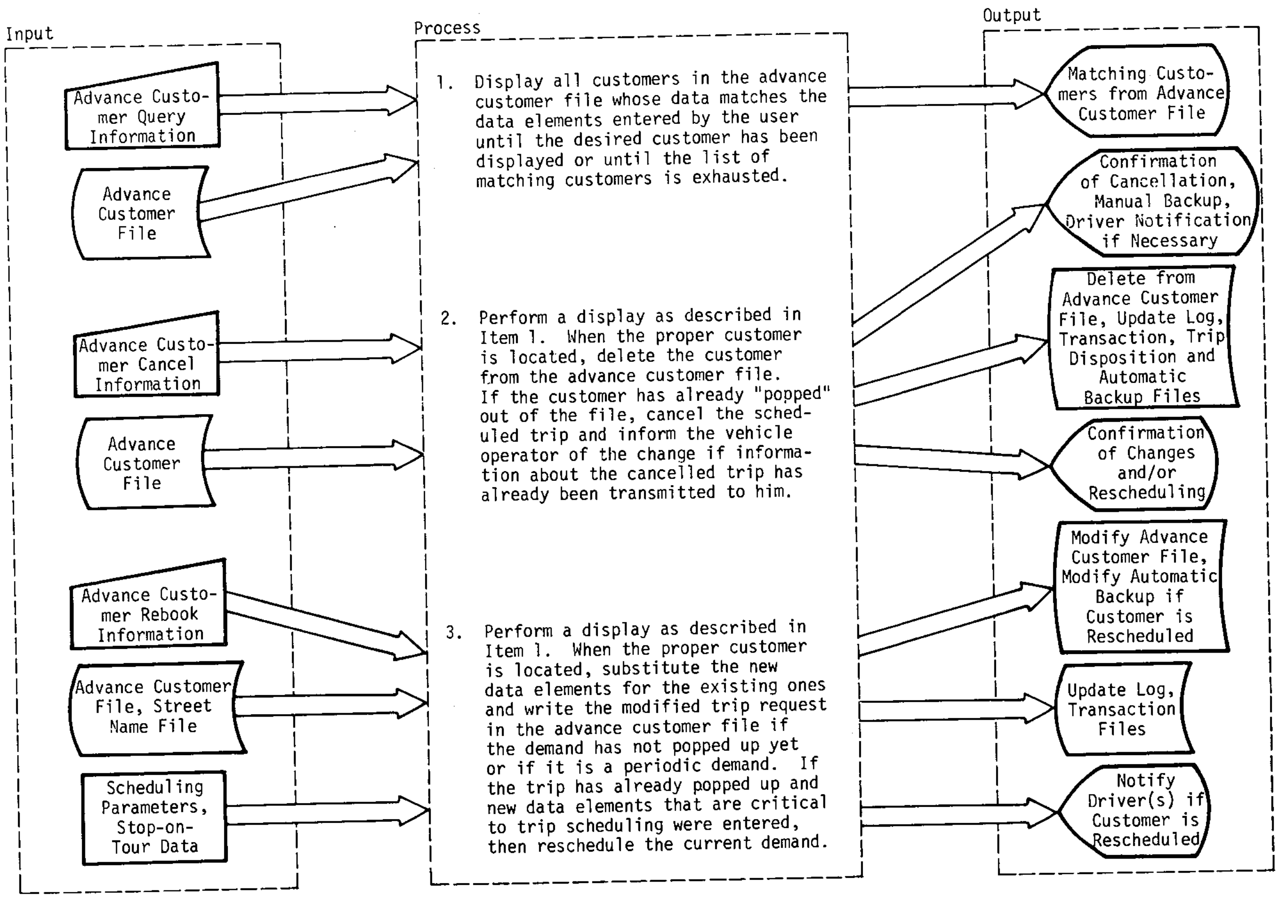


FIGURE 7-6

HIPO HIERARCHY NO. 6, HIERARCHY DIAGRAM FOR SYSTEM DEVELOPMENT AND TRAINING with regular operations. A full set of prompt messages will be available as a training aid which can be suppressed for experienced staff. System development can also be conducted on the ghost system to try out new concepts without interfering with regular operations.

7.2.3 Input-Process-Output

An example of one of the HIPO diagrams developed in this study is shown in Figure 7-7 (the entire set of 138 HIPO diagrams is presented in



1. The search should be restricted to those customers whose demands originated in the advance customer file. This includes demands that have already popped out of the file. If a demand is already scheduled on a vehicle, this should be indicated in the display.

2. The advance customer cancel must completely remove a customer from the system. This involves deleting the entry for the customer in the advance file and removing the customer's scheduled stops if the demand has already popped from the file.

3. The rebook function should allow either the advance file copy of a demand, the currently scheduled copy of a demand or both to be modified. Thus, rebook must be capable of, for example, reassigning the currently scheduled copy of a demand onto a vehicle of the user's choice and modifying the advance file copy of the same demand.

FIGURE 7-7. HIPO DIAGRAM EXAMPLE
MODIFYING A DEFERRED OR PERIODIC REQUEST

Harris, Task 4: Systems Requirements, 1978, Section 2, and a functional description of each is given in Potter, Task 3: Systems Analysis, 1978, Section 2.2.) The indicated processes operate on the input data to produce the output. Control transfers from one HIPO diagram to another are indicated by the arrows at top and bottom of the process block.

7.2.4 Software Modules

The over-400 software modules described in the requirements study (Harris, Task 4: System Requirements, 1978, Section 7) are assembled for convenience into 20 subsystems shown in Table 7-6. These software

TABLE 7-6

SOFTWARE MODULE SUBSYSTEMS

A	System Processing Subsystem
B	Message Processing Subsystem
C	Customer Data Management Subsystem
D	Customer Processing Subsystem
E	Scheduling Subsystem
F	Travel Time Estimation Subsystem
G	Fleet Data Management Subsystem
H	Dispatching and Fleet Processing Subsystem
I	Tour Modification Subsystem
J	Automatic and Manual Backup Subsystem
K	Address Translation Subsystem
L	Day and Time Processing Subsystem
M	String Processing Subsystem
N	Digital Communications Management Subsystem (main computer)
O	Digital Communications Control Subsystem (digital communications controller)
P	Transaction Editing Subsystem (intelligent terminals)
Q	Automatic Telephone Processing Subsystem
R	Graphics Control Subsystem
S	Street Name Data Base Building Subsystem
T	Mobile Terminal Routines

modules are derived from the HIPO diagrams to further define the software requirements. Each software module represents a substantial subprogram or set of subprograms needed to perform or support a specific function. About 30 percent of the SRT-CCS program modules are new concepts developed during the study. The remaining modules are based on the MIT algorithm and software developed in Rochester and Haddonfield. About 25 percent of the modules are functionally identical to their Rochester counterparts. The remaining 45 percent of the total software is similar to the Rochester-Haddonfield software but adapted to the specific circumstances of SRT (Harris, T.W., et al. Task 4 Report: System Requirements, p. 196, August 1978).

Software modules of similar types are gathered together by the subsystems and generally, though not necessarily, modules in a subsystem work together in performing functions defined in a closely related set of HIPO's. It will also be found that programmers should usually be assigned work by subsystem because of the programming similarities of the modules in the subsystems.

8.0 IMPLEMENTATION AND OPERATIONAL REQUIREMENTS

Having identified the system and engineering requirements of the computer system, their impact and interaction with operations and the surrounding organizations are assessed in this Section in order to identify and resolve problem areas. Finally, the steps needed to implement SRT and avoid potential pitfalls are presented.

8.1 OPERATIONAL FEATURES

Certain facets of SRT operations place important requirements on the CCS, while the CCS also places certain requirements on the method of operation. Key aspects of these operational requirements are summarized below.

8.1.1 <u>Fare Calculation Requirements</u>

Three potential fare-calculation methods for SRT are taximeter, computer-calculated formula, and zonal:

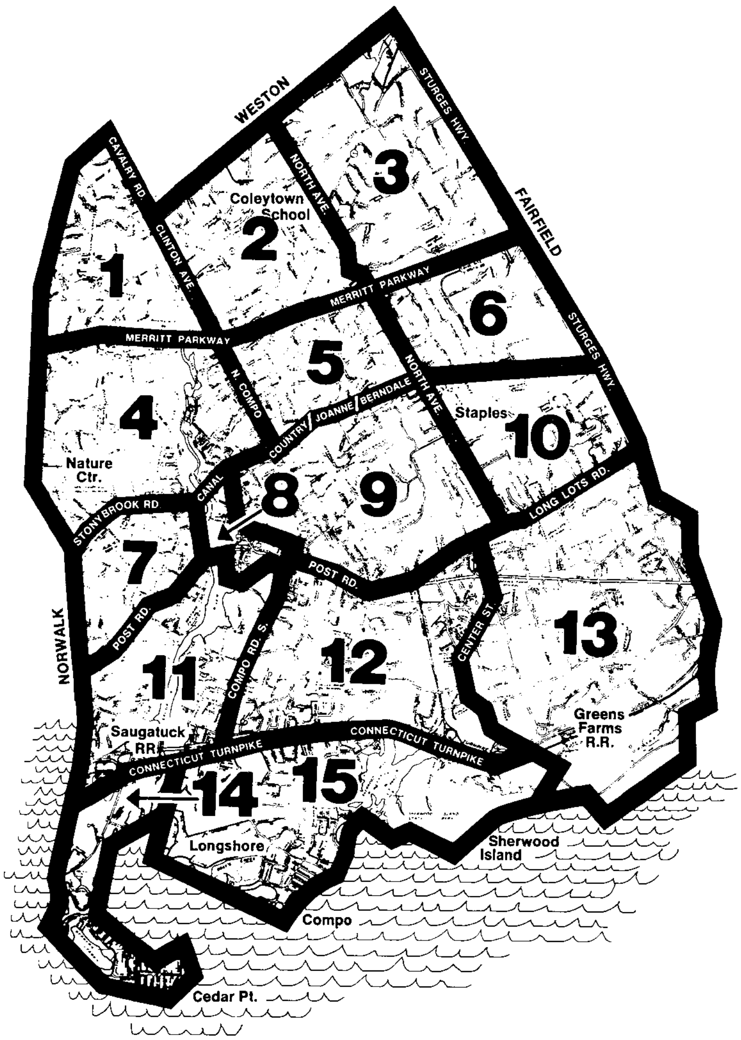
8.1.1.1 <u>Taximeter Fare</u> -- A suitable method of utilizing existing ERT taximeters for SRT fare calculation was not found. The crux of the problem is that ERT taximeters use road distance as a calculation input parameter, and this distance will vary depending on how far other passengers cause the taxi to detour. Consequently, by using ERT taximeters, the same SRT trip taken on different occasions will cost different amounts. Most rate-setting bodies and most passengers would find such fare variations unacceptable. Operating experience confirms this opinion even when the service was partly subsidized (RRC, September 1975, p. 154).

8.1.1.2 <u>Formula Fare</u> -- The computer can calculate each passenger's fare using a formula based on the shortest road-distance -- i.e., excluding detours for other passengers (Au and Baumann, 1975) -- and electronically display the fare for the passengers' information. In this approach, the computer must be fully informed about all passengers; this, in general, is feasible only in an employee-driver operation where management can enforce compliance with procedures. In leased-taxi and driver-owner organizations, the driver is an independent contractor and cannot be forced to comply without losing independent-contractor status within the IRS and Workers' Compensation regulations. Further, when the computer is down, formula fares cannot be calculated -- a backup zonal-fare structure or some other backup alternative must be provided to the drivers.

8.1.1.3 Zonal Fare -- A zonal fare avoids the above problems. The fares are shown on a triangular matrix which can be printed on a sheet of paper as is done in several cities including Westport, CT, (see Figure 8-1), Washington, DC, and Pensacola, FL. For large operations, a small book can be printed. An electronic fare display in the taxi is desirable especially for large operations but is not essential as in the formula-fare case above. Since the driver determines the correct fare without having to advise control of the pickup and does not have to activate a recording meter, the potential for theft is great where the drivers are employees; if the drivers are independent contractors, there is no problem since the fares belong to them.

8.1.1.4 Preferred Fare Method -- It is concluded that the SRT-CCS should incorporate both formula and zonal fare options. A zonal-fare system will be needed in independent-contractor driver situations; for employee-driver operations where fares are turned over to the company, the computer-calculated formula method will be suitable provided high computer reliability has been proved.

8.1.1.5 Interzonal Factors -- The fare considerations have several implications for the interzonal factors (IZF) file (i.e., a computer-stored file of those factors relating to travel between zones in the service area and including a distance correction to the straight-line distance). First, the IZF file must contain additive distance corrections (or "micro-zone" fare data) so that the formula-fare calculation is accurate. Then, to get the travel-time estimate, a multiplicative speed factor is needed. (Note: DAR systems need include only a time-correction factor which is not adequate for SRT since SRT performance



Here's how to figure your fare on the maxytaxy

Find out which zone number you're in and which one you want to go to.

On this price chart, find the zone you're in across the bottom. Then locate the zone you want to reach shown top to bottom on the left. Find the square where both numbers meet and that's the price of your maxytaxy ride. Pay 50¢ for any extra person with you. Elderly fare: 25% off at all times. For example: if you take the maxytaxy from downtown (zone 8) to the railroad station (zone 11) your fare would be $1.00. Call us at 226-7171 if you have any questions about the zone map or fare chart.

Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	$1.00														
2	1.25	$1.00													
3	1.50	1.25	$1.00												
4	1.25	1.50	1.75	$1.00											
5	1.50	1.25	1.50	1.50	$1.00										
6	1.75	1.50	1.25	1.50	1.25	$1.00									
7	1.50	1.75	2.00	1.25	1.75	2.00	$1.00								
8	1.50	1.50	1.75	1.00	1.25	1.50	1.00	$1.00							
9	1.75	1.50	1.75	1.50	1.25	1.50	1.50	1.00	$1.00						
10	2.00	1.75	1.50	1.75	1.50	1.25	1.50	1.25	1.25	$1.00					
11	2.00	2.25	2.50	1.50	1.75	2.50	1.25	1.00	1.50	2.25	$1.00				
12	2.50	2.00	2.00	1.75	1.50	1.75	1.50	1.25	1.25	1.50	1.50	$1.00			
13	3.00	2.75	2.25	2.75	1.75	1.75	2.50	1.50	1.50	1.50	2.00	1.50	$1.00		
14	2.75	2.75	3.25	2.00	2.50	2.75	1.50	1.25	2.25	2.50	1.25	1.50	2.25	$1.00	
15	3.00	2.75	3.00	2.25	2.00	2.50	2.00	1.50	1.75	2.50	1.50	1.50	2.00	1.50	$1.00
Zone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

20% off maxytaxy with maxymony! Buy $25 worth of maxymony for $20 — at our office or ask any driver.

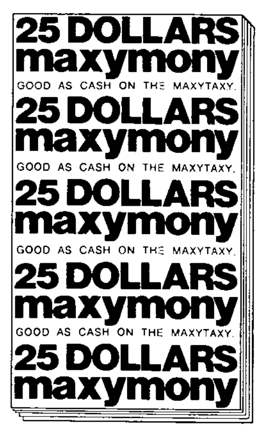


FIGURE 8-1

ZONAL-FARE SYSTEM USED IN WESTPORT

should be measured in terms of non-detour passenger miles.) The zonal-fare table can be integrated with the IZF matrix for data-base economy, provided the IZF zones and the fare zones are chosen to be identical. However, the fare table can be stored on a disc since it is only required once per trip. To assure a consistent data base, the zonal fare elements should be computer-calculated from the distance elements, and the fare tables should be printed by the computer.

8.1.2 Hail-Stop Requirements

In many urban areas a significant proportion of passengers do not telephone for service, but hail a taxi or board at a stand -- the national average for hail and stand riders is 14 percent of all trips (Wells and Selover, 1972), while in some urban areas the proportion exceeds 50 percent. Stand ridership can be particularly heavy at integrated-transit interfaces.

Taxi companies currently operating in a shared-ride mode find hail stops difficult to accommodate with manual SRT dispatching and feel that it is important that the CCS incorporate this capability (ITA Orlando Conference, 1977, reported in Fielding, Task 1: Role Definition, 1977, Appendix B).

The computer has no prior knowledge of hail-stop passengers and cannot make vehicle assignments. Accordingly, the taxi driver must be informed by the computer of the desirable direction and/or destination of planned passengers so that the driver (rather than the computer) can select hail passengers going in the correct direction. Where permitted, the driver can display destination information by roof signs (or by window sign if it is not a safety hazard) thereby permitting passengers to identify an appropriate taxi before hailing it. After an initial period of marketing, the taxi-riding public will become accustomed to the signs as they have to destination signs displayed on buses.

When the driver picks up a passenger not previously known to the computer, the driver must advise the computer of the passenger's destination zone or address. Usually, the driver will not be skilled in rapid keyboard use, nor will a full keyboard necessarily be installed in the taxi; therefore, a simple delivery zone reference rather than a complete address is most appropriate.

8.1.3 Service Reliability

Taxi service reliability is modified in two contrasting ways by conversion to SRT. First, SRT has a greater ability than ERT to accommodate sporadic high-demand rates. In ERT, when the system is overloaded as may occur during bad weather, new requests have to be added to the end of the request queue and consequently have long wait times. In SRT, on the other hand, a higher demand rate can be accommodated by inserting the new requests into existing tours which improves the overall efficiency. Therefore, the new requests are serviced more quickly by SRT than ERT.

The second effect is upon timeliness. Whereas in ERT a specific taxi will generally be available to service a specific customer at a specific time, in SRT the tours for each taxi are continually being changed to accommodate these new requests. Consequently, the uncertainty of pickup time for a specific customer is potentially greater in SRT than ERT under normal system-load conditions. This perceived uncertainty of SRT pickup time can be greatly improved by incorporating the automatic callback subsystem described in Section 6.6.3.

8.1.4 Problem Passenger Requirements

When a public regulatory body considers a requested change from ERT to SRT, one issue is how SRT will control or avoid problem passengers. (A problem passenger is one who is drunk, abusive, or otherwise offensive to other passengers -- under no circumstances should this be interpreted to permit discrimination on the basis of race, color, religion, sex, national origin, or age). Because SRT is a public transit service and because of civil rights legislation, a reasonable policy is that if service is denied to anyone, legally adequate justification must be put on file (Smart, private communication, May 1977). In existing SRT operations, the normal procedure is to place problem passengers in the front seat or to provide them with ERT service. This should generally meet the legal and civil rights requirements of not refusing service to anyone, while minimizing inconvenience to other passengers.

The CCS should provide the capability to assist the staff in identifying potential problem passengers (though all the legal ramifications are beyond the scope of this study, and the operator may choose not to use all of the features in this area). The address file should contain a code to identify locations where problem passengers have previously come from or gone to. The type of problem should be coded so that an appropriate automatic recommended-action message will be presented to the telephonist and also to the driver.

8.1.5 Effectiveness Monitoring Requirements

The key effectiveness measure used in DAR is passengers per vehicle-hour, while in ERT it is revenue per mile. Neither of these is suitable for SRT, and a new criterion must be used: passenger-miles per driver-hour where the passenger-miles are the shortest-route (no detour) miles for each passenger.

Other important measures that must be incorporated in the CCS are percentage of no-shows, wait and ride time, root-mean-square of promised vs. actual pickup time. These measures should be continuously available for display and updated at time intervals not exceeding ten minutes.

8.1.6 Credit Requirements

To fulfill its role, SRT must accommodate user-side subidies and credit passengers. A file of customers who are authorized to receive credit trips should be established, along with the agency or person responsible for payment, their credit standing, and their credit limit.

When a credit passenger utilizes the service, his/her credit must be checked and an invoice number generated. The driver will be required to get a credit-card payment or a signed receipt (waybill) identified by the invoice number. A tabulation of invoices for billing purposes must be generated periodically by the CCS, and traceability to the signed receipts must be auditable. In view of the relative slowness of payment by some user-subsidy providers, this tabulation should tie into the company's accounts receivable statements to assist taxi companies, which often do not have large liquid assets, in securing accounts-receivable financing.

8.1.7 Control-Room Personnel Requirements

Table 8-1 shows the personnel required to staff a SRT-CCS facility per shift -- fractional persons represent extra staff during peak periods on a part-time or multiple-function basis. Personnel requirements decrease as the percentage of hail and stand ridership increases, since these passengers do not communicate with the CCS via control-room personnel. Staffing is predicated on use of management-by-exception graphics terminals. As the degree of automation increases, it will be possible to make some moderate reductions to the personnel requirements in larger systems.

TABLE 8-1

NUMBER OF PERSONNEL REQUIRED PER SHIFT
TO STAFF A SRT-CCS FACILITY

	Percentage of Trips which Are Hail and Stand	Number of Taxis						
		10	25	50	100	150	250	500
Number of Order-Takers	0	0.5	1.3	3.0	7.2	10.7	14.9	27.5
	10	0.5	1.2	2.7	6.5	9.7	13.4	24.8
	20	0.5	1.0	2.4	5.7	8.6	11.9	22.0
	30	0.5	1.0	2.1	5.0	7.5	10.4	19.3
Number of Supervisory and Monitor Personnel		1.0	1.0	1.0	2.0	3.0	4.0	7.0
Total Number of Control Room Personnel	0	1.5	2.3	4.0	9.2	13.7	18.9	34.5
	10	1.5	2.2	3.7	8.5	12.7	17.4	31.8
	20	1.5	2.0	3.4	7.7	11.6	15.9	29.0
	30	1.5	2.0	3.1	7.0	10.5	14.4	26.3

8.2 INSTITUTIONAL CONSIDERATIONS

8.2.1 Organizational Perspective

For development of SRT and integrated transit, there is no such thing as "in the public interest." Every group has its own perspective and will seek to influence the program in its own interest. Knowing in advance which interest groups are likely to be involved in SRT planning and legislation and recognizing their perspective on the program can be beneficial in anticipating potential problems (Fielding, Task 2: Concept Development, 1977, Section 6). A list of groups which may be affected by SRT is shown in Table 8-2, along with their probable perspective on issues that will arise in the planning and implementation processes. Perspectives will range from positive (+) to negative (-) and, in some cases, will be neutral (0) or strongly dependent on the specific site (?).

8.2.2 Integrated Transit Organization

The discussion in Section 3.2.2 indicated that involvement of the private sector is a key factor in keeping the cost of integrated transit down to an acceptable level. This creates a more complex management problem because the fixed-route buses and the demand-responsive services are provided by separate organizations under some form of contractual agreement. Though managerially more complex, it offers the promise of more cost-effective operation because it is possible to contract the DRT portion of the operation to private industry, such as the local taxi company, which can usually provide DRT service at lowest cost. An example of this is Westport, CT, where a federally sponsored demonstration is underway, involving a wide range of integrated transit modes provided by separate organizations, but integrated to effect best utilization of the resources. The program appears to be progressing satisfactorily, and it will be followed with interest by many other communities. Westport's organization is shown schematically in Figure 8-2. The Westport Transit District itself serves as the "transportation broker" for various transit operations which include fixed-route bus, route-deviation bus, subscription bus, ERT, and SRT for limited mobility groups.

It is anticipated that the concept of nonoperating transit organizations such as transportation brokers, transit commissions, and regional authorities will develop in the future to insure that transit and paratransit operators effectively integrate their services and that public funds are allocated to achieve the greatest public good.

TABLE 8-2

PARTICIPATION MATRIX FOR THE IMPLEMENTATION OF SRT SERVICE

	Participation in Feasibility and Initial Studies	Application for Radio Frequency	Continuing Advisory Role	Selection/Creation of SRT Operating Agency	Coordination of SRT with Existing Services	Regulatory Reform	Financial Needs Analysis	Public Funding	System Definition
Private Citizens and Groups	+	0	+	+	0	+	+	+	+
Special Interest Groups	+	0	+	+	0	-	+	?	+
Public Transit Companies	+	+	+	+	?	-	-	-	+
Private Transport Companies	-	-	0	+	-	-	-	-	-
Taxi Companies	+	?	+	+	+	+	+	?	+
Transit Labor Unions	0	0	0	+	?	?	-	-	+
Taxi Labor	0	0	+	+	+	+	+	+	+
Special Transport Agencies	+	0	+	+	?	+	+	+	+
Regional Transport Organizations	+	0	+	+	+	+	+	+	+
Local Government	+	+	+	+	+	?	+	?	+
State Government	+	+	+	0	+	?	+	+	!
Federal Government	+	+	+	0	+	+	+	+	+

Legend: + = Positive   - = Negative
0 = Indifferent   ? = Strongly Site Dependent

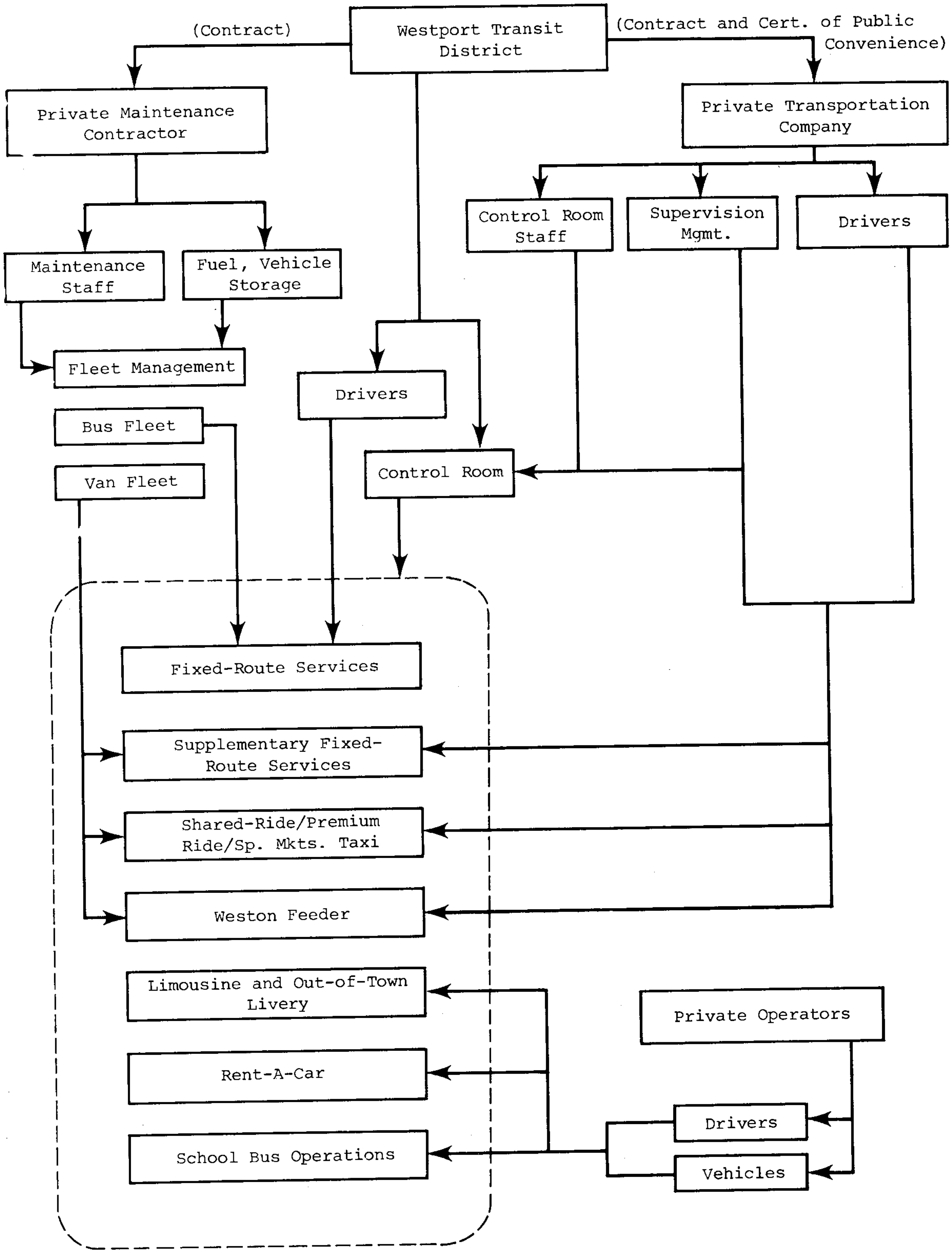


FIGURE 8-2. WESTPORT TRANSIT AND PARATRANSIT DEMONSTRATION PROJECT INTERRELATIONSHIP BETWEEN INSTITUTIONS

8.2.3 Taxi Company Organization

8.2.3.1 Independent Contractor Arrangements -- Some taxi companies have determined that it is advantageous for the drivers to be independent contractors rather than employees. As independent contractors, the drivers either lease the taxis from the company or own their own taxis.

Taxi companies claim several benefits for the independent-contractor arrangement. First, all revenues belong to the driver, so the revenue theft problem experienced in employee-driver organizations is eliminated. Next, the driver is responsible for payroll taxes and Workers' Compensation payments, which in many states now amount to between 15- and 20-percent overhead on direct labor. The drivers tend to obtain better vehicle utilization, often by teaming with other drivers. Finally, many taxi companies have found that the independent contractor has more pride in performance and responds better to the public need (ITA Orlando Conference, 1977, reported in Fielding, Task 1: Role Definition, 1977, Appendix B). Clearly, the CCS must take into account the prerequisites necessary for drivers to qualify as independent contractors as well as an employer-employee relationship.

There are no uniform rulings by the Internal Revenue Service (IRS) and state Worker's Compensation (WC) boards which clearly define the specific circumstances under which a driver is an independent contractor. The key issue is the degree of control over the driver's work. In general (and oversimplifying a complex issue), the independent contractors must have full control over their work; otherwise, they will be reclassified as employees and the taxi company will be liable retroactively for all payroll taxes. Failure to pay these taxes is a criminal offense, and officers of the company are personally liable for the full amount. To qualify as independent contractors, drivers must set their own hours of work and must be able to accept or reject any assignment offered to them. These capabilities should be incorporated into the CCS. When the CCS is sufficiently well defined, pre-approval for the driver to be classified as independent contractors should be sought from the IRS and WC boards.

8.2.3.2 Taxi Company Management Skills -- A potential limitation on the propagation of the SRT concept is that, though many taxi companies are sophisticated and competent to install SRT, some companies can be expected to experience difficulties with the new concepts and technologies involved. These skills could be developed by training seminars designed for taxi management personnel. It is to be expected that those taxi companies which cannot develop the necessary skills will succumb and be replaced by other companies which can.

8.2.4 Regulatory Requirements

In most situations, SRT implementation will require modification or clarification of existing laws and regulations pertaining to the provision of transportation services. Most communities specifically prohibit shared-ride taxis while other communities make no reference to these subjects (Fielding, Task 1; Role Definition, 1977). There is an undeniable case for standardization of regulations. Toward this end, provisions for model ordinances have been developed by the International Taxicab Association in A Compendium of Provisions for a Model Ordinance for the Regulation of Public Para-Transit (1976), and in California, the State Assembly, Office of Research, has published A Model Ordinance on Paratransit Services (1976). These proposed ordinances simplify requirements and state them so as not to impede innovation. Recent efforts to introduce new ordinances have met with inertia and opposition at a local level (E. R. Leyval, private communication, March 1977), and a more sophisticated approach by the taxi industry will be needed to convince local government of the need for change.

8.3 IMPLEMENTATION OF A SHARED-RIDE TAXI SYSTEM EXPERIMENT

8.3.1 Purpose of Experiment

The primary purpose of a developmental experiment will be to confirm that a SRT-CCS is feasible and to obtain preliminary indications concerning its economic and social benefits. Subsequently, several exemplary experiments will resolve the economic and social issues, will show how to implement the system in a variety of scenarios, and will serve as sites where taxi companies and other interested observers can see a SRT-CCS in operation. Having resolved the high-risk technical element and

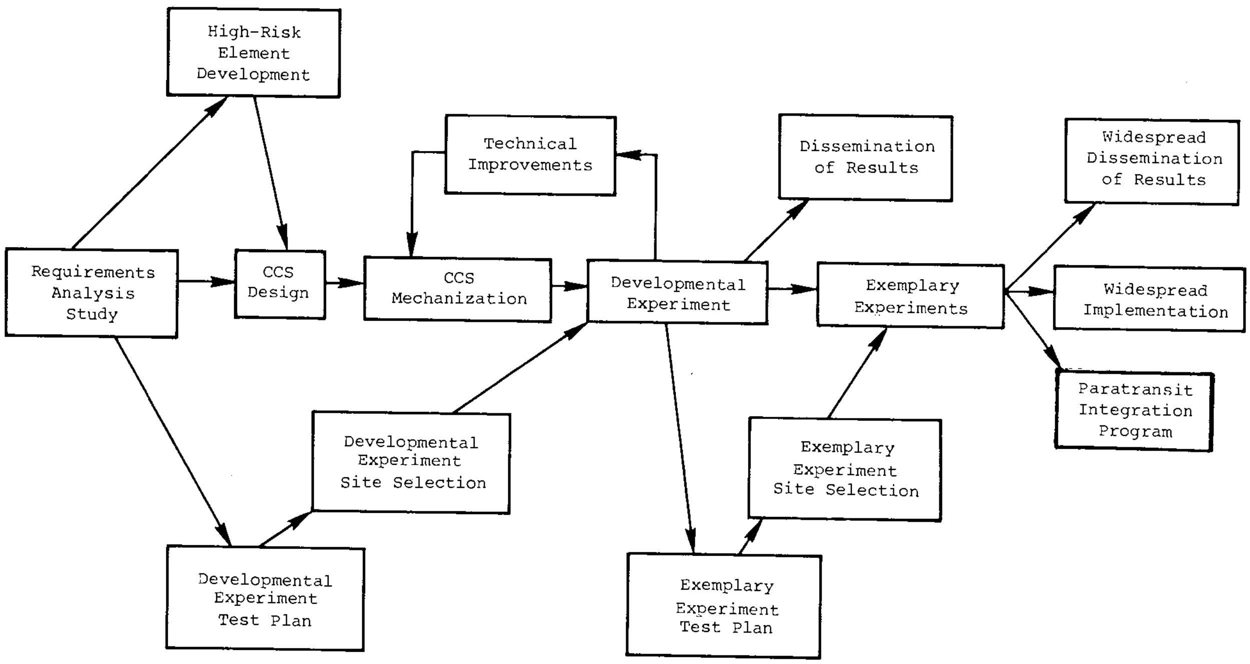


FIGURE 8-3

OVERVIEW OF DEVELOPMENTAL AND EXEMPLARY EXPERIMENT TASKS

established the feasibility of SRT-CCS during the developmental experiment, it is anticipated that taxi companies and communities will compete for selection as the exemplary experimental sites, leading to minimal government expenditure for these exemplary experiments. An overview of developmental and exemplary experiment tasks is shown in Figure 8-3.

Despite extensive study and analysis of SRT-CCS, some problems must be anticipated the first time it is put into operation. Government, industry, and the public will be sensitive to these problems and, therefore, the initial implementation must be clearly defined as "experimental."

Significant differences exist between SRT-CCS and computerized DAR systems which must be recognized in planning SRT experiments:

(a) DAR is a relatively small industry which does not make a profit, whereas the taxi industry is much larger and cannot exist without making a profit. Thus, SRT is much less tolerant of technical and financial problems than DAR.

(b) SRT is a multiple service in which several modes, including ERT and DAR, coexist.

(c) A SRT-CCS must accommodate entry of drivers and vehicles into the system without prior notification and drivers must be given the option of refusing instructions; in such situations the SRT-CCS must make alternative arrangements without major perturbations.

8.3.2 High-Risk Elements

Certain technical alternatives require test of a prototype/breadboard, design analysis, or additional data before decisions can be made. Because decisions in the eight elements discussed below will profoundly influence the CCS design, they have been designated high-risk elements. They must be investigated in advance of design or before the design progresses very far, otherwise considerable redirection and rework of the design will be needed, delaying the project and adding to cost. The eight high-risk elements are:

8.3.2.1 Field Controls -- It was shown in Section 6.4.5 that existing algorithms have a general capability to perform SRT scheduling but not the capacity to handle large fleets or all of the features that are required in multimodal SRT operations. The concept of field controls was therefore introduced to limit the field of alternatives that are investigated by the algorithms, thus reducing the computation load on the computer and permitting a relatively inexpensive minicomputer to be used for SRT. However, the effectiveness of these field controls has not yet been fully investigated or demonstrated.

8.3.2.2 Graphics Terminal -- Since algorithms capable of automatically scheduling all of the modes of an SRT operation do not yet exist, it is necessary to introduce a monitoring and management-by-exception color graphic capability. Graphic scheduling will emulate established manual scheduling techniques. However, SRT graphic capability has not yet been developed, and its testing should include generation of comprehensive data presentations so that terminal resolution, clutter control, and pattern-recognition capabilities can be investigated properly for both monitoring and management-by-exception purposes.

8.3.2.3 Automatic Customer Callback -- Taxi and DAR telephone operators frequently make customer callbacks to apprise them of an impending change in the service that was originally promised, or the imminent arrival of the vehicle. It is well known that this is a good public-relations practice. An automated callback system in which, following authorization by the customer when the trip request is booked, the computer automatically dials the customer and generates the message, has not yet been tested in such an application. Customer acceptance of automated callbacks must be established and also the human engineering and potential legal issues must be resolved.

8.3.2.4 Vehicle Terminals -- Because of the fleet size of typical taxi systems and the high volume of radio communications needed to control an SRT fleet, digital communications will usually be needed. The space available for a digital communciation terminal inside a taxi is relatively small since each seat is a revenue-producing resource. It is therefore important that the digital communications displays be designed within existing taxi space constraints. It is also important to insure that the driver be able to read the digital communication display safely under all lighting conditions and to insure that the system can be operated by essentially all taxi drivers.

8.3.2.5 Microprocessor Scheduling -- The evolution of computer technology will continue in the foreseeable future. Just as the minicomputer of today is more than equal in capabilities to most large-scale computers of ten years ago, today's minicomputer will be surpassed by future microprocessors. Microprocessor systems may even now be able to assist in scheduling and dispatching of small taxi fleets and may serve other useful backup functions. Within five or ten years, a microprocessor control system will probably be available which will perform most or all SRT-CCS functions. Sufficient flexibility to evolve these systems should be incorporated into the system design.

8.3.2.6 Graceful Degradation -- It is inevitable that partial or entire CCS failures will occur. Although they will be infrequent, it is essential that backup alternatives be available. For cost reasons, the backup will generally be by a lower-capability device or manual operation resulting in some performance degradation.

8.3.2.7 Full-Automation Algorithm Development -- Development of full-automation algorithms is a highly technical and creative process; consequently, there is no firm assurance that they will be available by any specific date. Since they are high-risk items, the SRT-CCS must work without these algorithms. Full economic benefits from a CCS, however, cannot be achieved until such algorithms become available since additional personnel are needed to operate the system in less than a fully computer-controlled mode.

8.3.2.8 Supply/Demand Models -- The SRT cost-effectiveness analysis (see Section 4.2) uses the best available supply and demand models. However, calibration of key factors such as level of service and uncertainty is seriously deficient. It was necessary, therefore, to make several gross assumptions in these areas in order to complete the cost-effectiveness analysis. Calibration should be accomplished by analysis of existing DRT operational data, by surveys of potential SRT users and statistical analysis of results, and by calibration from the developmental and exemplary experiments. It is believed that an uncertainty supply model could be developed using queuing models of the type now available for level of service prediction (Orloff, 1975, and Daganzo, 1977).

8.3.3 Evolution to Computer Control

At this time very few taxi companies (about one percent) operate in the SRT mode. Consequently, SRT-CCS implementation in the United States will almost always start with an ERT company and transform it into a SRT company. The procedure will generally be as follows:

(a) Starting with an ERT operation, install the CCS, build the street address data base, and train personnel.

(b) Use the CCS for ERT operation until all systems have been well-tested and personnel are thoroughly familiar with the CCS. Personnel difficulties or CCS failure during this period can be solved by reversion to the original ERT manual control; such reversion should cause no noticeable change in service to the public.

(c) Gradually increase the percentage of SRT operation while adjusting operating parameters in order to maintain profitability.

It was shown in Section 4.3.2 that overnight conversion from ERT to SRT will usually require a reduction in fleet size in order to maintain profitability. By gradually increasing the percentage of SRT over a period of months or even years as the overall demand for SRT increases, it should be possible to maintain the fleet size at an approximately constant level until it is fully converted to SRT and then to increase the fleet size as the demand for SRT gradually increases (see Section 2.2.2). This is shown conceptually in Figure 8-4.

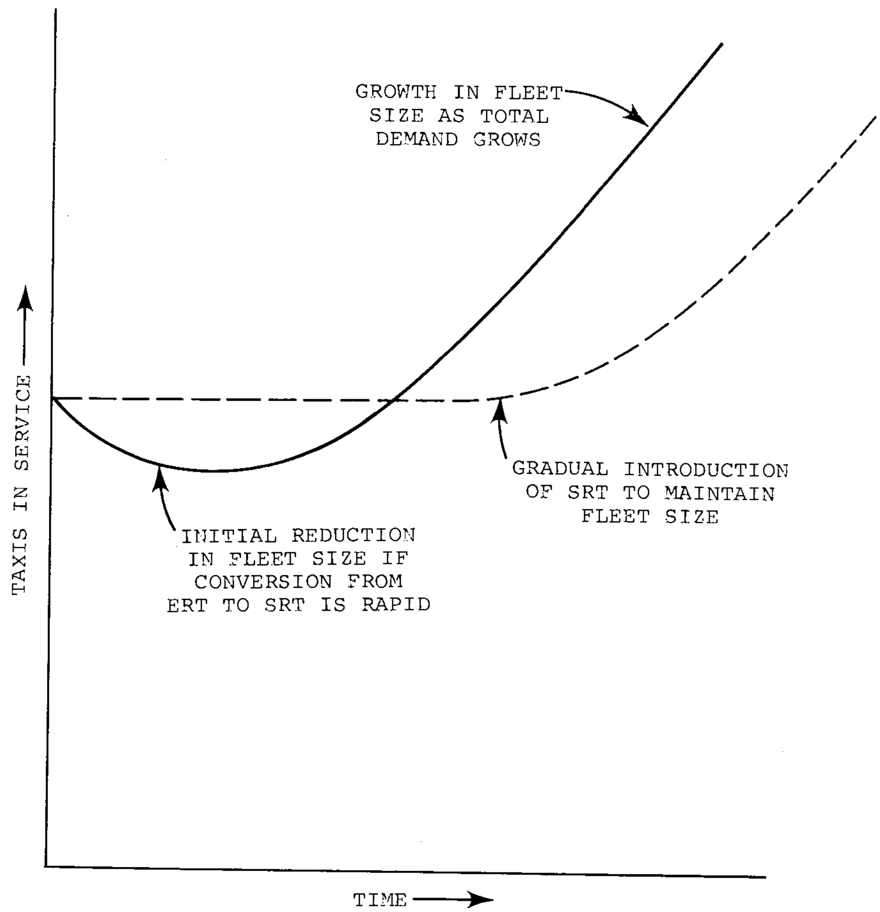


FIGURE 8-4

CONCEPTUAL CHANGES IN FLEET SIZE FOR "OVERNIGHT" AND "GRADUAL" CONVERSION FROM ERT TO SRT

8.3.4 Selection of Appropriate Scenario for Developmental Experiment

In Section 6.1, four scenarios were identified. A process of elimination is used here to select the appropriate scenario for a developmental experiment.

Scenario IV is a big-city environment with fleet sizes of 500 to 1,000 taxis. This will require multiple minicomputer chains which will be nongeneric, and any problems or failures will have serious consequences. Therefore, Scenario IV is not recommended for the developmental experiment.

SRT's operating in a Scenario III environment have been shown in Section 4.3.2 to have marginal economic viability. One of the objectives of the developmental experiment should be to show economic viability in order to attract taxi companies and municipalities to compete for the subsequent exemplary experiments; thereby permitting them to be accomplished at far lower cost to the government. Consequently, Scenario III is a poor choice for the developmental experiment.

The Scenario I environment is a medium-size city with drivers employed by the company. The technology here is similar in many ways to a DAR operation -- for example, the CCS would not have to accommodate hail-stand riders, drivers' schedules would be known in advance, and the drivers would be obliged to accept computer assignments without option. Consequently, a Scenario I experiment would tend to duplicate the government's existing investments in DAR demonstrations and is not recommended.

Scenario II is recommended for the developmental experiment. It will permit the SRT-CCS to be thoroughly tested under realistic conditions while being sufficiently small so that, if problems develop during the experiment, the system can revert to manual operation without major difficulty. The developmental experiment site should be chosen so that some degree of integration of SRT with other modes of transportation can be shown. Authority to implement SRT and integration with transit modes should be confirmed by all of the affected organizations before designation of the site. As shown in Figure 3-2b, the initial Scenario II developmental experiment could take place in a location that permits eventual growth to a Scenario IV environment, though this might add institutional complexities which would interfere with the experiment.

Following the developmental experiment, a determination can be made as to which scenarios and locations are appropriate for exemplary experiments. It is desirable that the exemplary experiments cover a wide range of conditions typical of those which would be experienced by significant numbers of taxi companies. It is recommended that this should include several geographically dispersed Scenario I and II operations and one each Scenario III and IV operations.

PART III: CONCLUSIONS AND RECOMMENDATIONS

9.0 CONCLUSIONS AND RECOMMENDATIONS

The following items are the more important conclusions and/or recommendations identified from Parts I and II of this report and other reports prepared during the study.

9.1 ADVANTAGES AND DISADVANTAGES OF SHARED-RIDE TAXI IMPLEMENTATION

It has been shown above that new travel patterns and other change factors promote use of SRT and that a significant passenger market is projected over the next 20 years. However, the existence of a passenger demand is not by itself a sufficient condition to implement SRT on a widespread basis, since there are many other important considerations.

Table 9-1 lists the advantages and disadvantages of SRT in an attempt to obtain a balanced perspective on the viability of the concept. It is believed that Table 9-1 indicates that the advantages outweigh the disadvantages by a significant margin, and it is probable, therefore, that SRT will receive widespread implementation and will satisfy the predicted passenger market shown in Table 2-2.

9.2 MARKET

Taxi ridership will grow from 3.4 billion (of which one percent is SRT) in 1975 to an estimated 11.8 billion (of which an estimated 84 percent will be SRT) in 1990-1995. The growth in SRT ridership will be caused primarily by a modest population growth, a larger proportion of women workers, more elderly persons, steadily increasing fuel costs, integration of transit and paratransit, moderate auto disincentives, and a ridership switch from ERT to SRT. It is estimated that synergism from SRT and transit integration may contribute to conventional transit ridership increases from 5.9 billion in 1975 to 13 billion in 1990-1995.

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TABLE 9-1

ADVANTAGES AND DISADVANTAGES
OF SHARED-RIDE TAXI

	ADVANTAGES	DISADVANTAGES
A	• Most cost-effective form of public transportation in many low-density areas.	• Relatively expensive compared with high-density conventional transit.
B	• Reduces the unsubsidized taxi-passenger fare.	• Reduces passenger privacy.
C	• Improves the perceived reliability of service* by better accommodation of fluctuating demand.	• Increases the travel time of passengers because of the detours to pick up and deliver others (though premium-fare/premium-service ERT will still be available).
D	• Will complement and feed conventional transit as part of integrated transit systems, thus increasing both taxi and conventional transit ridership.	• Will compete for subsidy funds with conventional transit (though competition should ultimately enhance overall effectiveness).
E	• Benefits from SRT are available to all residents (whereas conventional transit serves only those who live a few blocks either side of the fixed-route).	• Changes to taxi ordinances are needed in most locations (usually old legislation permits only ERT).
F	• Capital intensity of the taxi industry is increased by use of automation to increase productivity.	• Many taxi companies may require financial assistance from UMTA and/or SBA for capital equipment to convert from ERT to SRT.
G	• SRT produces a significant long-range employment increase in lower-skill segments of the labor force (even though SRT increases productivity, the growth in ridership creates a growing need for labor).	• Increases control over taxi drivers, which may force taxi companies from driver-leased to driver-owned taxi (independent contractor) relationships to avoid increasing overhead costs.
H	• May permit financially-marginal taxi companies to continue service and thereby avoid need for equivalent publicly-operated services.	
I		• Will require government support during the experimental phases (since private taxi companies could not absorb the development costs).
J	• Drivers and other employees may demand to share in the increased revenues by wage increases.	• If taxi driver wages are increased faster than national averages (e.g., in an attempt to "catch up" on transit wages), then SRT will become less economically attractive.
K	• Meets an identifiable market demand for the service (expected to reach 10 billion passenger trips per year by 1995).	
L	• Facilitates user subsidies to provide service to target passenger groups (i.e., service to the transportation-disadvantaged).	• Will induce transportation-disadvantaged to travel more, thereby increasing demand for additional subsidies.
M	• Increases the energy-effectiveness of taxi operations (more passengers per taxi-mile).	• SRT should not be considered an emergency aid in a fuel crisis (e.g., an oil embargo) since it takes months or years to smoothly and efficiently train personnel, install computer systems and convert from ERT to SRT.

*Note: Perceived reliability of an SRT system will be considerably enhanced by computer controlled telephone callback to passengers -- a technique referred to in this study as "auto-callback."

9.3 ECONOMIC FEASIBILITY

A taxi company converting from ERT to SRT can maintain or increase taxi company earnings and/or driver wages while reducing fares and improving service reliability in medium and large cities. SRT may not be economically attractive without subsidy in small cities.

An automated control system is cost-effective for a SRT fleet of 50 vehicles or more. However, many taxi companies will find it difficult to raise the startup capital. Thus, government initiatives to support and encourage conversions from ERT to SRT may be needed.

9.4 ROLE OF SHARED-RIDE TAXIS

The role of SRT consists of three elements which can operate simultaneously:

(a) SRT performs the same role as ERT except that, by ride-sharing it achieves higher productivity, better service reliability, and lower fares at the expense of longer travel time.

(b) SRT feeds fixed-route transit increasing both fixed-route and SRT ridership.

(c) SRT companies enter into separate contracts to perform supplemental roles such as a community DAR, small goods movement, and transportation of the elderly and the handicapped.

9.5 TECHNICAL FEASIBILITY

This study provides substantial evidence that the SRT-CCS concept is not only technically feasible and within the present state-of-the-art but also economically attractive for SRT fleets of 50 vehicles or more. Certain technical problem areas have been identified and should be resolved, but they do not appear to be unsolvable or to jeopardize the technical success of the concept.

9.6 RESOLUTIONS OF TECHNICAL PROBLEM AREAS

The following technical problem areas have more risk than the remainder of the CCS and should receive priority prior to or during system design:

(a) Field controls limit the number of alternatives investigated by the assignment algorithm and are needed to keep the computational load within the capacity of an inexpensive minicomputer.

(b) Graphic terminal to facilitate monitoring and human decision-making on a management-by-exception basis is needed because computers presently cannot be programmed to make sensible decisions in every situation.

(c) Automatic customer callback is needed to enhance perceived reliability by advising customers of any changes to their expected pickup time and also of the imminent arrival of their taxi. Customer acceptance, human engineering, and potential legal issues must be resolved.

(d) Vehicle terminals must be designed to fit into the limited space in a taxi (i.e., without reducing passenger-carrying capacity) and for safe readibility under all lighting conditions.

(e) Microprocessor scheduling potential should be incorporated into the design to enhance cost-effectiveness in smaller systems.

(f) A design policy of graceful degradation must be incorporated so that, wherever possible, failure of a single CCS component only causes reduced CCS performance rather than CCS shutdown and reversion to manual operation.

(g) Development of full-automation algorithms should continue, since improved automation will lead to even greater efficiency and cost-effectiveness.

(h) Research is needed into supply and demand models so that assumptions (e.g., regarding the elasticity of demand with respect to uncertainty), which had to be made to produce meaningful results in this study, can be validated or modified.

9.7 CONVERSION PROCEDURE

The first step in conversion from ERT to SRT should be to install the CCS, train personnel, and build the address data base. When the CCS operates smoothly in ERT service, the percentage of SRT trips should be gradually increased, making any necessary adjustments to fleet size and other operating parameters in order to maintain profitability. (A too-rapid conversion may easily create operating conditions which are unprofitable or service perturbations which cause loss of public confidence.)

9.8 DEVELOPMENTAL AND EXEMPLARY EXPERIMENTS

A developmental experiment is needed to verify the technical feasibility of a SRT-CCS and to provide preliminary indications of its economic viability and public acceptance. Subsequently, several exemplary experiments should be conducted in a variety of different scenarios to resolve economic and social issues. These will also serve as sites where taxi companies and other interested observers can obtain the information needed to help them make decisions.

9.9 CAPITAL INTENSITY AND EMPLOYMENT

Application of CCS's in the taxi industry will increase capital intensity and efficiency. Because of ridership growth, by 1990-1995 employment in the taxi industry will be more than twice the 1975 employment level. (Moreover, these employment openings will be primarily for the low-skill segment of the labor force where unemployment is greatest and most difficult to solve.) Thus, the SRT concept provides both capital intensity and expanding employment opportunities.

9.10 LEGISLATION

Taxi legislation is enacted at a city level or, in some states, at a state level. In most cases, old laws prohibit SRT despite national energy policy, which makes SRT a desirable service. Legislation may be needed to encourage cities and states to permit SRT. Such legislation should not eliminate the privacy of exclusive-ride service which should always be offered at a premium fare.

9.11 RECOMMENDED NEAR-TERM ACTION

The next steps to be taken in developing the concept are:

(a) Initiate work to resolve areas of technical risk

(b) Start the CCS design in preparation for the developmental and exemplary experiments.

(c) Start developmental-experiment planning and site selection.

(d) Encourage direct and indirect legislation to permit SRT operation in cities throughout the U. S.

(e) Prepare and disseminate SRT information to government officials, transportation planners, taxi companies, and concerned citizens.

APPENDIX A

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APPENDIX B

REPORT OF INVENTIONS

The work performed under this contract has identified a number of innovations and improvements listed below. No patentable features were found.

1. <u>Graphics Terminals, paragraph 5.3.4</u>

This constitutes an innovative approach to monitor and control shared-ride taxi operations with potential future application for micro-computer control of smaller shared-ride taxi systems.

2. <u>Hail Signs, paragraph 8.1.2</u>

These are roof or window signs that have been used in other applications, but their introduction into the taxi industry and their control from a central computer are innovations.

3. <u>Zonal Matrix, paragraph 8.1.1.5</u>

The use of additive distance, multiplicative speed, and zone fares in an integrated zonal matrix is an improvement over existing technology and solves several fare collection and operational problems.

4. <u>Automatic Callback, paragraph 7.1.6</u>

An innovative means has been identified whereby automatic recorded messages would be telephoned to customers who are waiting for their taxi. These messages would accurately advise the waiting customer when the taxi will arrive, thus reducing passenger anxiety and frustration and also reducing taxi waits when picking up passengers.

5. <u>Increased Profitability of Taxi Operations, paragraph 4.3.2</u>

Procedures for accomplishing a profitable conversion from exclusive-ride taxi to shared-ride taxi operations are identified for taxi companies in medium and large cities.

6. Importance of Uncertainty, paragraph 4.3.4

The importance of uncertainty (i.e., the difference between the pickup time given to the customer when the request is booked, and the actual arrival time of the taxi) is demonstrated in the cost-effectiveness analysis. Control of uncertainty will be a key factor in the success of shared-ride taxi operations.

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