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SHARED-RIDE TAXI COMPUTER CONTROL SYSTEM REQUIREMENTS STUDY

G.J. Fielding
P. Freeman
B.E. Potter
A.U. Simpson

DAVE SYSTEMS, INC., TRANSMAX DIVISION
2121 West Crescent Avenue
Anaheim CA 92801

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16. Abstract

The technical problem of scheduling and routing shared-ride taxi service is so great that only computers can handle it efficiently. This study is concerned with defining the requirements of such a computer system.

This interim report describes progress on the study and indicates major findings to date. It is an executive-level summary, and it does not attempt to include all information or justify all statements. Rather, it is an overview of accomplishments leading to a concluding section which outlines preliminary system design requirements. These requirements are subject to change since the work in many areas is not yet complete.

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PREFACE

Shared-ride taxi (SRT) service refers to the sharing of the same taxi by two or more passengers with different origins and/or destinations. The taxi makes small detours from the most direct route to pick up or deliver passengers (or parcels) going in the same general direction. By these means, SRT is potentially more efficient than the normal exclusive-ride taxi (ERT). SRT offers potentially improved profitability, lower fuel consumption, feeder service to other mass transit services, and options for community-level and special-needs door-to-door transit.

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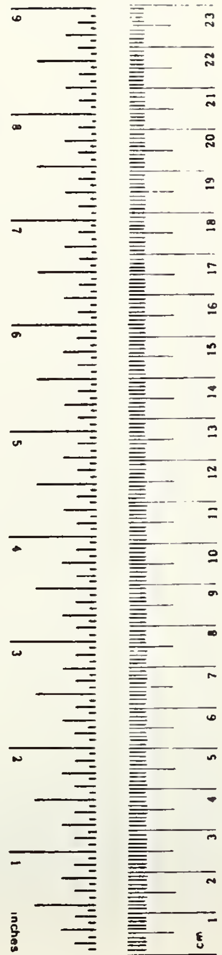
METRIC CONVERSION FACTORS

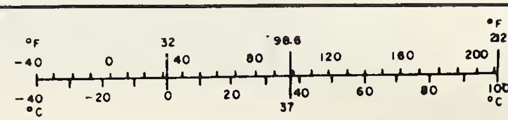
Approximate Conversions to Metric Measures

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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1. INTRODUCTION

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 (SRT) system. A SRT operation using a CCS offers a potential for increased taxi dispatching efficiency, improved driver productivity and profitability, improved quality of service, integration of taxis into area-wide transit, and improved mobility for the transportation disadvantaged.

2. ROLE OF SHARED-RIDE TAXIS

The SRT concept offers a meaningful extra dimension to conventional exclusive-ride taxi (ERT) service; it enables two or more passengers going in the same general direction to share transportation even though they are picked up from and delivered to separate places. SRT accomplishes this by making small detours from the general direction of the taxi in order to pick up and deliver passengers (or parcels), thereby transporting many more passengers per mile and per hour than can be transported by ERT. In El Cajon, California, for example, an increase in passengers carried per taxi-hour from 2.6 in ERT service to 6.5 in SRT service was reported (private communication, W. Hilton, President, San Diego Yellow Cab, May 1977). (Subsidized fares partly caused the increase in demand, but El Cajon illustrates the increased productivity of SRT.) Detailed surveys of SRT operations have shown productivities of 4.1 passengers per taxi-hour (Davenport, Iowa, Davis, F.W., October 1974) and productivities of up to eight passengers per taxi-hour have been reported (Little Rock, Arkansas, Hall, J., April 1977). By comparison, the national average for ERT productivity is about three passengers per taxi-hour [according to the International Taxicab Association (ITA)]. The efficiency of SRT also has been demonstrated in a number of other cities such as Hicksville, New York; Pensacola, Florida; Washington, D.C.; and Jacksonville, Florida, where SRT is an ongoing viable form of public transportation.

Shared riding in taxis is permitted by local 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; i.e., a company operating mostly SRT can still provide exclusive use of the taxi if the customer is willing to pay a premium fare. Therefore, SRT does not eliminate ERT service but augments it by adding the advantages of ride-sharing whenever appropriate. A sampling of services provided by taxi companies is shown in Table 2-1, along with the areas where SRT should prove to be beneficial.

Where taxi companies have initiated SRT, manual dispatching has been used, but service has been restricted because of the inability of dispatchers to handle multiple requests and to schedule vehicle tours. The task is extremely difficult for human dispatchers because of the complexity of shared-ride scheduling. Operating experience shows that an ERT dispatcher can provide full control for between 30 and 40 vehicles in systems where telephone requests predominate (where hail and stand passengers predominate, the dispatcher can, of course, cover many more vehicles), and in peak periods can handle 150 to 200 requests per hour, but for manually controlled SRT, 20 vehicles or 100 requests per hour is considered an upper limit (Heathington, 1974). Observation of operating Dial-A-Ride (DAR) systems suggests that the efficiency of human dispatchers starts to decline beyond 50 requests per hour -- even when the dispatchers are very efficient and use visual aids, such as maps and colored magnetic markers (Fielding, 1976, p. 49). Because most taxi companies have demand levels above these limits, automatic dispatching systems will be required before efficient SRT can be implemented in most communities.

2.1 AREA-WIDE DEMAND-RESPONSIVE TRANSIT (AWDRT)

AWDRT is concerned with the following:

a. Developing conventional transit and paratransit (which includes SRT) systems into integrated area-wide systems.

TABLE 2-1

SERVICES PRESENTLY PROVIDED BY TAXICAB OPERATORS AND CORRESPONDING SHARED-RIDE TAXI POTENTIAL (SIZE OF SAMPLE = 667 OPERATORS)[1]

ERT Service Presently Provided	Percent Providing Service	Corresponding SRT Potential
REGULAR DEMAND SERVICES		
Conventional Taxicab	96.1	Mostly SRT Service - Premium Fare for ERT
Dial-A-Ride	3.6	Subsidized Operation - Transit Feeder
Conventional Bus or Jitney	3.9	Route Deviation - Nonscheduled Feeder
Package Delivery	71.4	Improved Efficiency - Deferred Rates
Special Handicapped	25.0	Improved Efficiency - Vans with Lifts
SPECIAL (CONTRACT) SERVICES		
Company Employees	43.3	Pool Service - Preplanned Tours
School Children	44.4	Improved Efficiency of Scheduling
Hospital Patients	30.9	Improved Efficiency of Scheduling
Government Employees	10.5	Pool Service - Preplanned Tours
Haul Senior Citizens, Handicapped and Public Aid Recipients	10.0	Improved Service - Transit Feeder
Deliver Blood and Hospital Supplies	5.3	Improved Efficiency - ERT for Rush Items
EMERGENCY SERVICES		
Ambulance	3.6	Same as ERT
Emergency Taxicab	49.6	Premium ERT, Possibly Some SRT
Towing	5.5	Same as ERT
PRIVATE AUTO RENTAL OR LEASING		
Auto Rental	6.7	Same as ERT
Auto Leasing	3.4	Same as ERT

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

[1]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.

b. Attracting new riders, while being responsive to existing needs.

c. Maximizing the productivity of all transit elements.

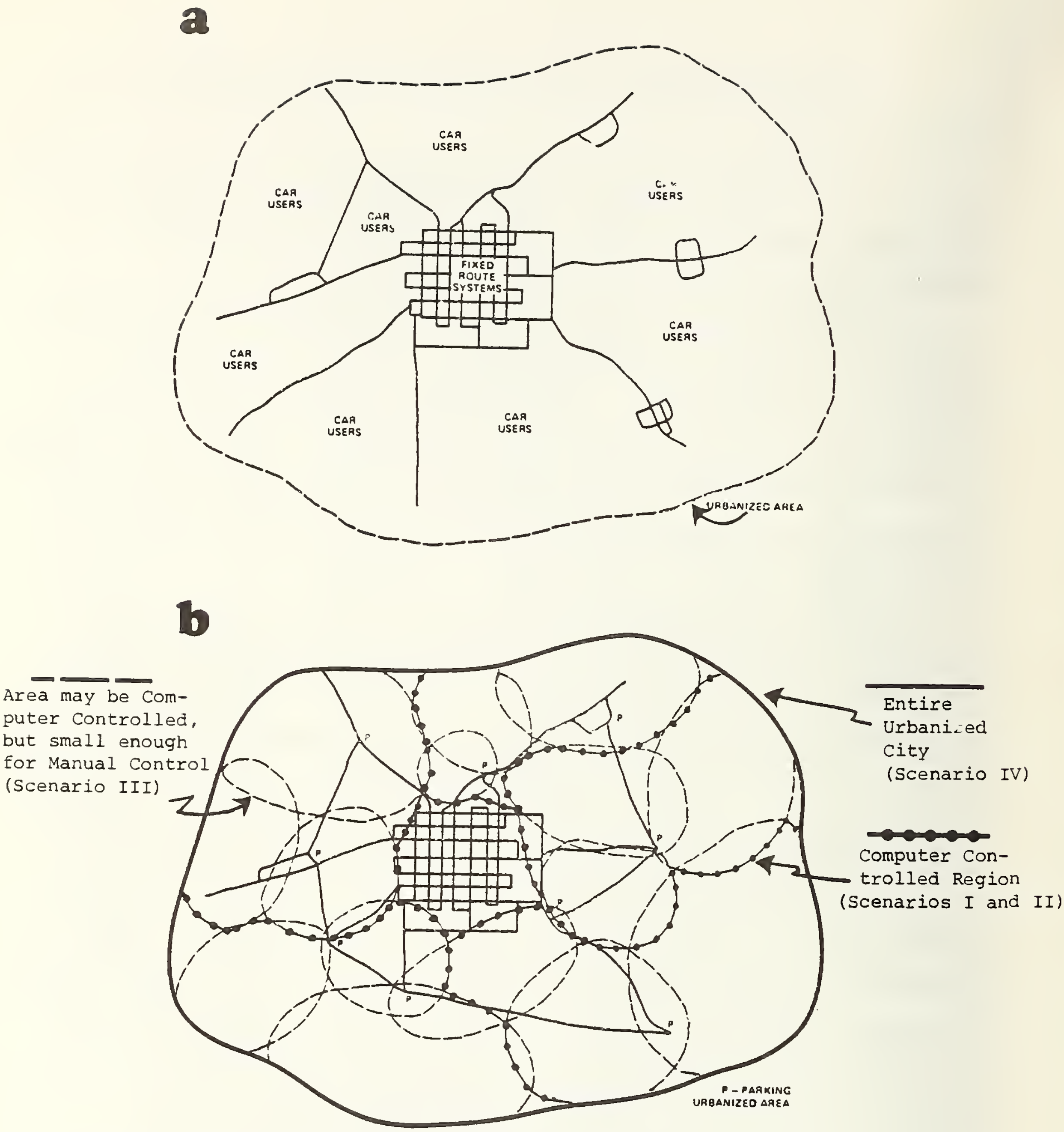
d. Providing transit availability to all segments of the urban population and especially the transportation disadvantaged.

To achieve these objectives, innovations are needed to integrate the best of conventional transit with demand-responsive paratransit. For example, AWDRT might consist of bus transit reconfigured to improve service along arterial corridors, with SRT service expanded to provide effective coverage in the suburbs and to feed into the bus system (Figure 2-1).

Several region-wide systems have been planned for California and elsewhere, but none of these systems are more than partially implemented. However, optimism exists that there is now within the taxi and transit industries a climate of opinion which will allow them to act cooperatively. In most cases, transit properties cannot afford to operate the community-level demand-responsive service desired by suburban residents other than, possibly, service for the special needs of the elderly and the handicapped. Taxi companies provide demand-responsive service at a lower cost but cannot fulfill all the community-level needs without Governmental assistance to keep fares within reach of target populations. Moreover, Governmental agencies -- local, State, and Federal -- are starting to indicate a willingness to change regulations and ordinances which will allow taxis to provide shared-ride mass transportation.

2.2 DEVELOPMENT OF CONCEPT

SRT can be used innovatively to provide a range of public transportation services designed to meet the specific



AFTER: Ward, 1974, p. 184.

FIGURE 2-1. EVOLUTION OF AREA-WIDE DEMAND-RESPONSIVE TRANSIT. 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.

needs of various segments of the population. For example, SRT can be developed to:

a. Provide the sole means of public transportation in small urban areas.

b. Meet the special needs of the elderly, the handicapped, and those who cannot drive or have no access to a private car.

c. Supplement mass transit along major transit corridors in the peak hours and provide a substitute for buses during low-demand hours.

d. Increase ridership of mass transit systems by providing feeder service in low-density residential areas and convenient circulation within the central business district (CBD).

Development of these SRT concepts presents significant challenges to the taxi industry, which has not generally kept up with technology. As discussed above, computers will be needed to control and dispatch SRT fleets in all but the smallest operations. Since existing vehicles used by taxi operators are designed primarily for private use, there also will be a need to develop more suitable paratransit vehicles.

2.3 DEMAND FOR SHARED-RIDE TAXI SERVICE

There is considerable demand for the service that can be provided by SRT. Table 2-2 shows that, based on such factors as moderate (i.e., one percent compound annual rate) population increases; extrapolation of geographic, age, and other changing demographic characteristics of the population; and some non-extreme readjustments in our future "automobilized" society, particularly where fuel consumption, air pollution, or vehicular congestion are most acute; it is estimated that 10 billion person-trips

TABLE 2-2

ESTIMATED ANNUAL PERSON TRIPS AT DIFFERENT TIME PERIODS BY MAJOR MODE OF TRANSPORTATION[1]

Type of Vehicle	1970 - 1975[2] Annual Person Trips	1970 - 1975[2] Percent of Total Trips	1980 - 1985 Annual Person Trips	1980 - 1985 Percent of Total Trips	1990 - 1995 Annual Person Trips	1990 - 1995 Percent of Total Trips
	(millions)		(millions)		(millions)	
PRIVATE TRANSPORTATION	131,937	88.7	180,191	87.5	199,961[12]	84.7
Auto[3]	123,519	83.0				
Truck[4]	8,128	5.5				
Motorcycle	290	0.2				
PUBLIC TRANSPORTATION	16,387	11.0	22,518	10.9	31,211	13.2
Taxicab (ERT)	3,375[9]	2.3	3,295	1.6	1,889[13]	0.8
(SRT)	34		3,501[11]	1.7	9,915[14]	4.2
School Bus[5]	7,112	4.8	6,043	2.9	6,424	2.7
Transit (bus and rail)	5,866[10]	3.9	9,679	4.7	12,985[15]	5.5
OTHER	436	0.3	3,224	1.6	4,907	2.1
TOTAL ANNUAL TRIPS[6]	148,760	100.0	205,933	100.0	236,081	100.0
Population (over 5 years)[7]	188		217		231	
Annual Trips Per Person[8]	791		949		1,022	

[1] Estimates for 1980-85 and 1990-95 are tentative (±20 percent) and based upon estimated changes in personal consumption, per capita income and transportation. A policy of moderate auto disincentives is assumed: current increases in fuel prices will continue, parking charges will increase, and auto travel along congested corridors and in central cities will be "managed," leading to a 10-15 percent reduction in auto use and increased viability for higher-occupancy vehicles.

[2] U.S. DOT/FHWA, Nationwide Personal Transportation Study, 1973, p.31 is the source for 1970-75 and the future projections adjusted by more reliable information as noted.

[3] Car-pool and van-pool trips included. Anticipated to be 5 percent in 1980-90 (Voorhees, 1976b, p. 103).

[4] Trips in commercial goods-delivery vehicles excluded.

[5] Estimate based upon 135 annual school trips per child 5-17 years (N.P.T. Study, 1973, p. 31 and Statistical Abstract of the U.S., 1975, p. 6, Series II projections.) School age population is declining.

[6] Totals are considerably less than forecast in 1972 National Transportation Report,(1972). Scenario includes moderate auto restraints and fewer daily person trips: 2.2 (1970), 2.3 (1975), 2.6 (1985), 2.9 (1995) (Voorhees, 1976b, pp. 22-30). National Transportation Report, 1972 (before the petroleum embargo) forecast 3.3 (1971) and 4.2 (1989) daily person trips.

[7] Statistical Abstract of the U.S., 1975, p.6. Series II projections.

[8] Increased female labor force participation, higher per capita incomes, more leisure time all induce more trip making (U. S. DOT, National Transportation Trends and Choices, 1977, p.46.

[9] Considerable variation between sources: N.P.T. Study (1970) 436 million underestimated total because one-half to two-thirds are non-home based in larger citites. ITA (1970) 2,378 million (Taxicab Management, Aug. 1973, p.5); ITA (1973) 3,409 million (Wells, 1975, p. 2-1) which is the most reliable and is divided between ERT and SRT.

[10] Total passenger trips: APTA, Transit Factbook: 1975-76, p.32, reports: (1970) 7,332 million; (1975) 6,950 million. These include transfer passengers -- normally about 20 percent of total.

[11] Expansion of SRT under contract to local agencies anticipated as federal and state subsidies become available.

[12] Paraprivate transportation including electric vehicles for neighborhood travel. Bicycle travel also increases.

[13] Lower productivity and increasing cost for ERT causes decline when SRT is available. Evidence varies depending on SRT fare, but adverse impact anticipated.

[14] Voorhees, 1976b, p. 101, estimates 25 billion trips by transit and paratransit using paid drivers by 1995. Sum of ERT, SRT, and transit is 24.8 billion.

[15] Doubling parking charges and halving transit fares would increase the transit trips in 1990 by 24 percent in the peak hour and 19 percent daily (U.S. DOT, National Transportation Report, 1974, p. 209).

will be made annually by SRT in the 1990's -- i.e., three times the number of ERT passenger trips presently being carried. The estimated increase in SRT ridership is made up partly at the expense of diversion from ERT (declining at a compound annual rate of 2.9 percent) and partly from a growth in overall taxi ridership (increasing at a compound annual rate of 6.4 percent). This 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.

2.4 SCENARIOS

Four scenarios have been developed to provide representative contexts from which CCS requirements can be defined. Over forty factors, such as population density, quality of service, terrain, regulations, fare structure, etc., were analyzed to define scenario features relevant to CCS requirements.

Seven factors were identified as being of key importance. They are shown in Table 2-3 in two groups. Group I identifies the characteristics which generally hold true for all scenarios. Group II identifies three major distinguishing criteria which define the four scenarios. The way in which the three criteria classify the four separate scenarios and correspond to three prototypical service areas is shown schematically in Figure 2-2.

2.4.1 Scenario I

The CCS accommodates up to 250 requests per hour corresponding to a fleet of about 50 shared-ride taxis. [Note that

TABLE 2-3

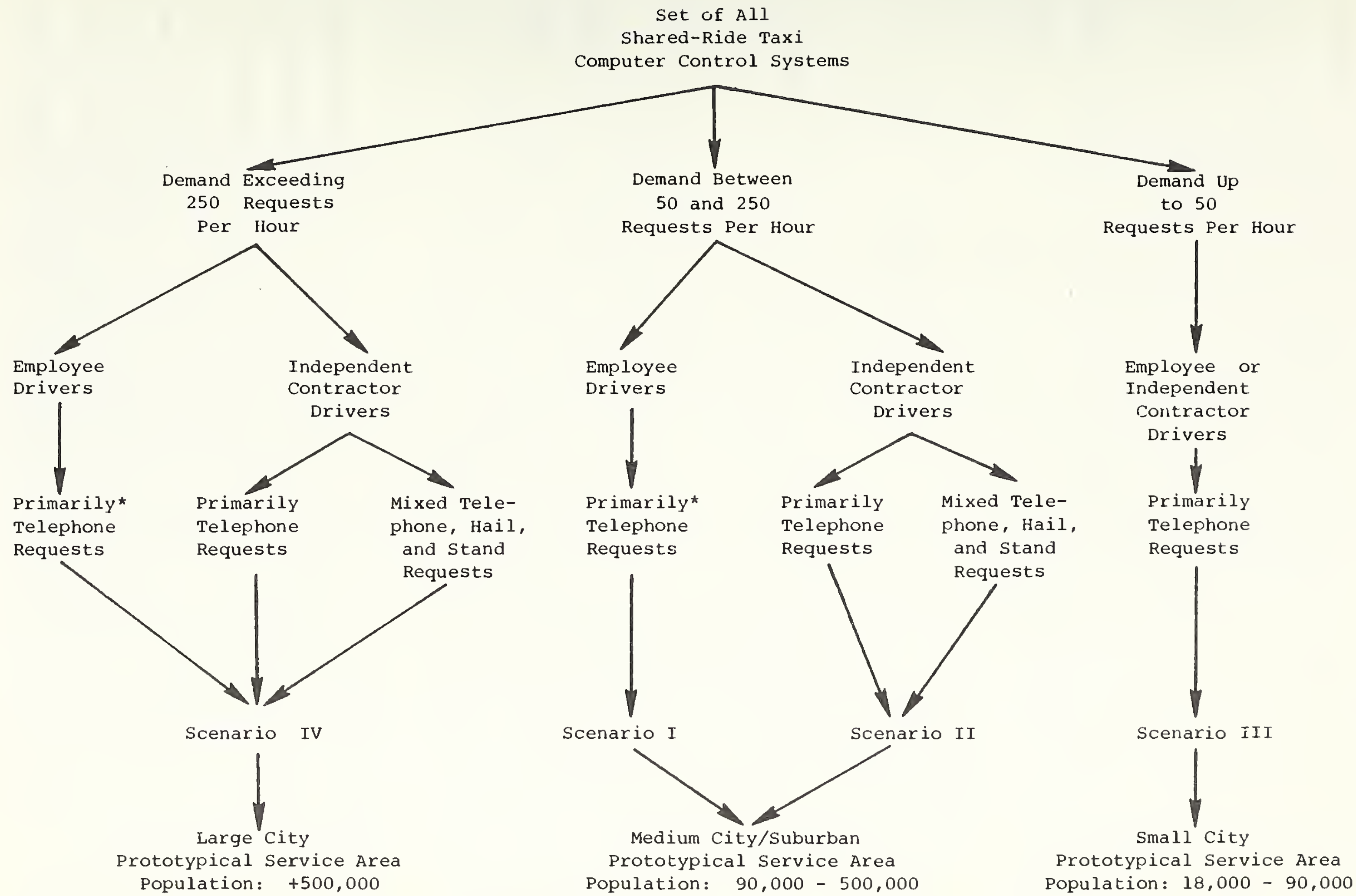
KEY FACTORS DEFINING SCENARIOS
RELEVANT TO COMPUTER CONTROL SYSTEM REQUIREMENTS

Group I: Generic CCS Requirements

I-1 COST	It is assumed that the taxi company will purchase or lease the CCS without subsidy; low cost is, therefore, an important requirement. Moreover, modules should be optional to the degree possible so that a bare-bones CCS can be implemented initially, followed by more expensive options if required.
I-2 REVENUES	Taxi companies generally do not have a large financial reserve; therefore, all existing services (i.e., sources of revenue) of significance must be preserved by the CCS for at least the period immediately following CCS implementation.
I-3 SERVICE RELIABILITY	Service reliability (e.g., close correspondence between expected and actual pickup times) in demand-responsive operations is crucial for development of customer patronage. This dictates utilization of reliability control functions and options for feedback to update passenger expectations.
I-4 TYPES OF SERVICE	Most SRT operations will have some unique combination of emphasis on the types of services to be offered. The generic CCS must incorporate all commonly-used service features and permit the taxi company to select the combination required to meet local conditions.

Group II: Major Distinguishing CCS Requirements

II-1 PEAK HOURLY RIDERSHIP	The size (and hence the cost) of a CCS must be tailored to the throughput required of it. Scenarios can be divided on the basis of the approximate ridership levels at which the CCS configuration undergoes radical change.
II-2 ORGANIZATION	CCS requirements vary significantly between companies which employ taxi drivers and those which lease taxis to the drivers or provide dispatch services to drivers who own their own taxis (e.g., in both latter cases, drivers are independent contractors and may refuse any dispatch assignment. They also may determine their own start and quit times).
II-3 HAIL & STAND POLICIES	Control technique requirements also vary significantly depending on whether the computer knows about a passenger well in advance of boarding (e.g., via a telephone request) or only at the time of boarding. No advance notice, of course, is possible with hail or stand passengers. To permit hail and stand passengers to board without prior acceptance by control creates a different and more difficult problem for automated scheduling algorithms.



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

FIGURE 2-2. SCHEMATIC OF FACTORS DISTINGUISHING SCENARIOS AND CORRESPONDING PROTOTYPICAL SERVICE AREAS analysis shows a fleet of 50 SRTs has equivalent passenger-carrying capability to a fleet of about 100 ERTs (McLeod, M. G., 1972, p. 110).] Drivers are employees of the company and subject to normal employee discipline. All normal requests are made 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 (Figure 2-1b) are medium-sized cities and suburban areas with populations between 90,000 and 500,000.

2.4.2. 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. As independent contractors, they are not subject to the same degree of control as employees, and can accept hail and stand passengers without prior authorization from control. (This presents complexities for automated scheduling which appear to dictate the use of a computer-aided graphics technique until suitable automatic algorithms are available.) Zonal fare methods can be used without risk of theft (since drivers keep all revenues) and also permit normal fare collection in the event of computer malfunction.

2.4.3 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.

2.4.4. 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 2-2b). Prototypical service areas for Scenario IV are cities with populations exceeding 500,000.

2.4.5 Scenario Selection

Analysis has shown no serious reason why a generic CCS cannot accommodate Scenarios I, II and III. Each scenario would require a different set of options, all of which must be incorporated in the generic system. The requirements for functions, configurations, and operations defined in the next section encompass such a generic system.

It is recommended that a target scenario should be selected for a demonstration. Scenario III is too small for a significant demonstration (though a system at the upper end of the Scenario III range might be adequate for a test of a prototype CCS), while Scenario I does not properly demonstrate the features that make SRT different from DAR. Thus, an initial CCS should be oriented toward Scenario II with provisions incorporated for extension to Scenario I and downward compatibility to Scenario III.

3. PRELIMINARY STATEMENT OF SYSTEM REQUIREMENTS

The preliminary system requirements presented in this section are the results of analyses conducted to date. They include functional, hardware, and operational requirements. Analyses of personnel requirements have not yet reached the point where they can be reported.

3.1 FUNCTIONAL REQUIREMENTS

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.

The hierarchy of functions required for a comprehensive SRT-CCS is shown in Figure 3-1; the functions are described in Table 3-1. 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.

Some of the functions required for a comprehensive CCS are not required for an initial demonstration; their incorporation would make the system more complex and thereby

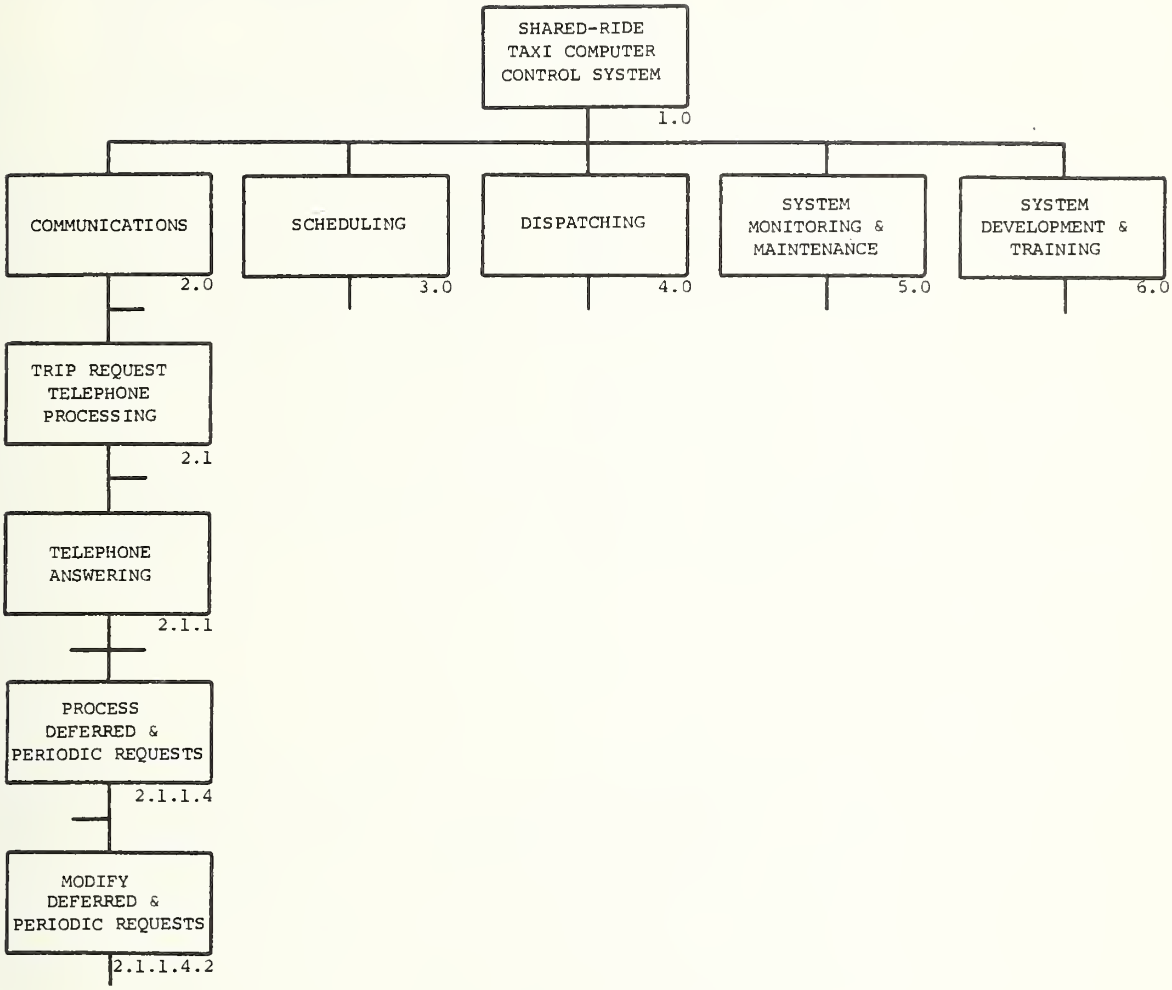


FIGURE 3-1. TOP-LEVEL FUNCTIONAL BREAKDOWN AND EXAMPLE OF FUNCTIONAL HIERARCHY TO FIFTH LEVEL

TABLE 3-1

DESCRIPTIONS OF MAJOR FUNCTIONS

1.0 Shared-Ride Taxi Computer Control System. At this top level the CCS is a "black box" with input and output (I/O) to the external world. All other functions are broken down from this function. Some of the I/O elements involve: customers, drivers, training, computer-aided scheduling, supervision, management information, billing, data bases, and fault diagnosis.

2.0 Communications. These take place between the control center and the customers and drivers. Most requests for service are received by phone, and the telephone-answering and trip-booking functions are similar to those used in the Rochester* and Ann Arbor (Potter, March 1976) DAR systems and the Los Angeles Taxi dispatch systems (Davidson, 1974 and 1976). An automatic telephone answering and recording device may be used to store surges of requests, queuing them for subsequent entry into the CCS. Driver communications are by digital communications and/or voice radio with functions similar to those used in the Rochester and Ann Arbor systems. Prerecorded voice messages are activated by the CCS or by staff and relayed to waiting customers via an autodial telephone link to advise them of an updated time that the taxi can be expected to arrive or to advise imminent arrival of their taxi.

3.0 Scheduling. This incorporates a number of algorithms necessary to control the SRT system. The MIT-developed algorithms include a capability for current request scheduling (Wilson, July 1975). A variation of the MIT algorithms has also been proposed for preplanned tours (Rebibo, October 1976), but it is uncertain whether or not advanced versions presently being developed will be able to accommodate all SRT situations or will have the speed needed for SRT. Consequently, a graphic assignment capability which enhances and speeds proven manual scheduling methods must be incorporated. This will show trips, vehicles, timing, assigned tours, and objective functions on a CRT so that, by the use of a light pen or joy stick, the scheduler can make intelligent assignment decisions. As automatic algorithms are incorporated, the graphics terminal can be relegated progressively to a monitoring and override capability, though in smaller systems it could be kept as a primary means of scheduling. Vehicle locations used in scheduling will be estimated by an interpolation method similar to Rochester*, but with the capability to add more accurate locations from an automatic vehicle location (AVL) system. Transfer capability between SRT and other modes of transit is incorporated.

4.0 Dispatching. If the CCS has a digital communications link, dispatching primarily covers fleet monitoring, tour development, and emergency voice communication. If there is no digital communication link, voice dispatching assumes all of the digital communication functions.

5.0 System Monitoring and Maintenance. This includes monitoring, maintenance and control-parameter functions needed to supervise the system and tune it for best performance. File generation includes the use of census data and dual independent map encoding techniques for street addresses. The street address files can be shared with other users, while vehicle and customer files will normally be protected. Supporting programs include conventional business packages. Management-oriented reports are produced daily. Reliability-enhancing features are incorporated to permit degraded operation despite various types and level of failures. On-line and off-line integrity tests and diagnosis will exercise all major elements according to a standard simulation to compare performance against a reference.

6.0 Training. Training of new personnel will include comprehensive simulations using a ghost system in parallel with regular operations. A full set of prompt messages will be available to help in training but which can be suppressed for fully experienced staff.

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*The Rochester and Haddonfield DAR functional descriptions are presented in Brandon, July 1976; Luckard, November 1974; MITRE NTIS PB 245 569, November 1974; Rebibo, March 1974; First Data Corporation, Operator's Handbook, September 1975; U. S. Department of Transportation, Haddonfield DAR Operator's Handbook, October 1974.

increase the cost and reduce the probability of meeting objectives. Stubs to return messages from unimplemented functions should be introduced in the software so that omitted features can be added later.

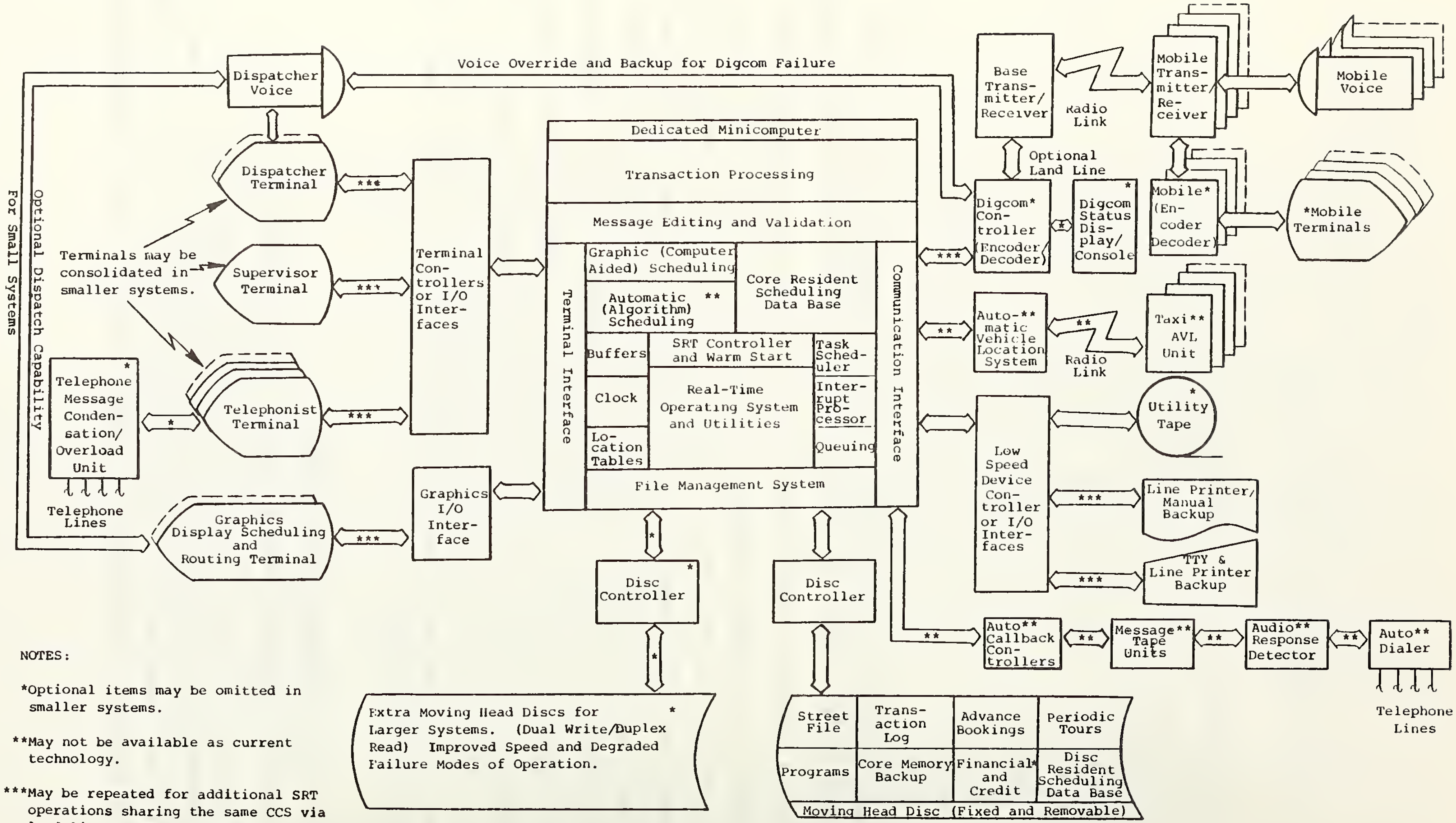
3.2 CONFIGURATION REQUIREMENTS

A schematic of a comprehensive CCS configuration is shown in Figure 3-2. This would be suitable for larger 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.

The "basic" configuration is typical of current on-line/real-time interactive systems engineering practice, 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. A preliminary cost analysis shows, for example, that a production CCS capable of accommodating over 1,000 passengers per day and over 25 taxis should cost under $150,000 (1977 dollars) for all hardware including digital communications (but assuming the radio system already exists) which, assuming a five-year life and current interest rates, corresponds to between 10¢ and 15¢ per passenger. For larger systems, economies of scale should result in even lower CCS costs per passenger.

3.2.1 Minicomputer Main Frame

A minicomputer-based system is appropriate for low cost, availability, and multiplicity of suppliers while still adequate for computing speed and power. It is expected that detail design will show that it must be a multiprogrammable machine with powerful operating and disc file-management



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 land lines and multiplexer.

FIGURE 3-2. SCHEMATIC OF CONFIGURATION FOR COMPREHENSIVE SHARED-RIDE TAXI COMPUTER CONTROL SYSTEM systems in order to handle the throughput and keep terminal response time to a few seconds.

The computer system (hardware and software) should be oriented toward both on-line and real-time capabilities. For example, it should be expandable to 16 terminals; have multilevel hardware interrupt with operating system (OS) support; hardware and software priority task assignments; a real-time clock with OS support; I/O queuing; file security, terminal security, and record lockout; memory parity check; auto-restart; and hardware bootstrap. The OS should support multiple terminal operation, communication devices, spooling, task-swapping, and use of the interrupt structure; the file management system (FMS) must support data structures which are consistent with SRT performance. Error logging and system exercisers are desirable features. To take advantage of existing DAR programs written in FORTRAN, a multi-pass optimizing FORTRAN compiler should be available. It should have a re-entrant library, load and execute, object programs as real-time tasks, and have multiprogramming/multitasking capability.

Main memory should be expandable to at least 128,000 bytes to accommodate the resident OS, active tasks, tours, vehicle data, etc., with multiple partitions. Extended memory to 256,000 bytes is a desirable feature, since each incremental taxi will require additional main memory to accommodate core-resident tour lists and vehicle data.

3.2.2 Terminals

Terminals for smaller systems (e.g., Scenario III) should, at a minimum, be buffered, while in larger systems (e.g., Scenarios I and II), some degree of intelligence will be desirable to the degree permitted by reusability constraints. Intelligent terminals will permit a substantial portion of the I/O processing to be done cost-effectively outside the CPU. The rapidly declining cost and increasing power of microcomputers in the intelligent terminals makes them attractive now, and these trends will make them even more attractive in the future.

Data input format should be designed for rapid data entry without excessive CPU processing of the input. A free-form entry should be applied, such as a Primary Action Code (PAC), which is used in the Rochester and Haddonfield DAR systems, the Los Angeles Yellow Cab system, and by all of the airlines via IBM's Programmed Airlines Reservation System (PARS). A form entry such as the one 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.

3.2.3 Graphics Terminal

It appears that no set of automatic algorithms will be available in the near future to accommodate all SRT requirements. The MIT algorithms are the only ones currently available which have been proven effective for automatic scheduling. Based on preliminary cost effectivity analyses, the required processing capacity and time associated with these algorithms may exceed that which can be afforded for the SRT application. Further, these algorithms do not as yet encompass all types of SRT requirements (for example, they do not automatically handle preplanned periodic tours, taxi fleet management, or starter tours for new taxis entering service without prior notification). Consequently, to insure that the SRT-CCS will operate properly, an alternative human scheduling capability should be incorporated which will perform all of the required decisions for smaller SRT systems, and which can be replaced by automatic algorithms as they become available. This approach effectively "decouples" the success of a SRT-CCS from being contingent on the success of development of a full range of automated scheduling algorithms.

Manual scheduling systems work well but have limited capacity; they currently handle demand levels of 80 many-to-many requests per hour, and have reached peaks of around 150 to 200 requests per hour in mixed-mode (i.e., combined many-to-many and many-to-one) of operation. This manual process could be duplicated and improved by the use of a computer-aided graphics terminal. The computer would keep track of the bookkeeping, which is done in manual systems by the scheduler moving pieces on and off a map. Graphics terminals will have significantly greater throughput than a manual control system not only because of the increased time available for decision-making and the greater potential for concentration (since the computer takes care of overhead actions), but also because several terminals can be operated concurrently. The graphics terminal operator would select a section of the total service area or only those trips which pass a simple screening test. This will avoid excessive clutter on the graphics display.

Manual control systems have been found to produce efficient routing, but the scheduling (i.e., timing of pickups and deliveries) tends to be poor. The graphics terminal is required to display timing data at each stop to permit more accurate consideration of the timing than is currently possible with manual control.

3.2.4 Disc

A moving-head disc should be selected because it is an order of magnitude lower in per-bit cost than a fixed-head disc for the same amount of memory. For satisfactory terminal response time, the moving-head disc's access time of about 50 milliseconds is only satisfactory if the number of disc accesses is carefully controlled -- otherwise, a fixed-head disc with access time under 15 milliseconds will be needed. Preliminary calculations indicate that a moving-head disc will be able to handle a throughput of up to 250 peak-hour requests and 50 taxicabs.

It is estimated that 1.5 to 2 million bytes of disc memory is adequate for an area of about 20 square miles. For larger or smaller areas a factor of up to 50,000 bytes per square mile should be allowed.

The disc file-management system should be able to build and maintain the street address file in real-time, though a periodic reordering of the street address file to incorporate appended items will be acceptable. The search for an address should involve no more than three disc accesses.

3.2.5 Digital Communications

Digital communications will be desirable and cost-effective in all but the smallest operations. Voice communications in shared-ride operations are limited to about 150 requests per hour (i.e., about 30 taxis in operation) per channel. Digital communications have a capacity of about twice that of voice communications for the older radio equipment used in many taxi operations, and up to four times the voice capacity using the latest radio equipment designed for digital communications.

Mobile digital communications units are required to be compact in order to fit into existing taxis without major modification of the vehicle -- 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 CCS hardware is roughly equivalent to the cost of the voice radio system, while the incremental additional cost of digital communications is greater than the cost of the CCS. Thus, from a cost viewpoint, the design of the digital communications system is of paramount importance.

3.2.6 Bottlenecks

The upper limits of the configuration shown in Figure 3-2 are determined by both compute and disc bounds. Using the results of tests by TSC on an earlier version of the Rochester/MIT algorithms, average terminal response time for trip bookings would be on the order of five seconds -- 1.5 seconds for disc access and 3 seconds for compute time. This is beyond the upper limit of acceptability for an order-taking system based on current on-line system technology (Martin, 1973, p. 327) where normal designs consistently achieve response times under two seconds. However, it is understood (Colven and Harper, March 1977) that significant improvements (on the order of a factor of four) have already been made by MIT to the CPU time needed in the Rochester system. This was accomplished by improving the terminal polling procedure and by pruning delivery insertion searches whenever the pickup insertion caused a worse objective function value than some preceding trial. A similar reduction in CPU time was also found in a simulation at the University of California at Irvine using the improved Rochester DAR programs.

Based on these improvements, terminal response time for a booking at a throughput of 250 requests per hour should average no longer than 2.5 seconds; no more than 5 percent of new transactions should require longer than 5 seconds, and no more than 5 percent of ongoing transactions should require longer than 5 seconds.

3.2.7 CCS Reliability

Reliability targets of 99.5 percent availability from 5 a.m. through 2 a.m. every day and no more than two failures exceeding four hours each year appear to be realistic expectations, based on experience with dedicated dispatch and control systems -- specifically Santa Clara (Siersema, March 1977), Ann Arbor (Potter, March 1977) and Los Angeles Yellow Cab (Davidson, March 1977).

The system should have a semiautomatic warm-start capability requiring less than one minute to implement -- this was found to be especially valuable in the Santa Clara system. Any loss of records must be identified.

In the event of a computer failure, the reversion to manual control should be smooth and not apparent to the customers. All current, deferred, and periodic bookings previously accepted by the CCS must be dispatched without loss of quality of service. Experience in 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 two-minute maximum reversion time (following the decision to revert to manual) is required for SRT.

3.2.8 Backup

The CCS configuration identified here should prove to be highly reliable except for the electromechanical items -- the printer and, to a lesser degree, the moving-head disc. Where the SRT company is confident that the staff can revert to manual control, no backup is needed -- this is expected to be for systems with under 25 taxis. Some taxi companies have expressed confidence (ITA Orlando Conference, January 1977) that more than 25 shared-ride taxis can be controlled manually, but even if this is feasible, there will be a more significant decline in productivity and reliability of service.

For larger systems, backup for the disc and line printer will be necessary. The disc backup should contain duplicate files (i.e., all writes from the computer should be dual and a higher-speed I/O bus will be needed). Advantage can then be taken of the spare disc for duplex read capacity, thus extending the throughput limit for the whole system because the increase in write time is more than offset by the reduction in read time. In the event of a failure of one of the two discs, the throughput limit would degrade gracefully due to disc access queue delays resulting from the availability of only one disc.

Line printer backup should be a fast teletypewriter (TTY) terminal, which also serves for supervisory input. The limited speed of the TTY will also cause a graceful degradation of system throughput limit because of queuing delays when transactions are being written to the TTY.

3.3 OPERATIONAL REQUIREMENTS

Certain facets of SRT operations place important requirements on the CCS which must be incorporated so that the CCS system generally can be usable by the taxi industry. Also, the CCS places certain requirements on the method of operation. Key aspects of both types of operational requirements are discussed below.

3.3.1 Fare Calculation Requirements

The three alternative fare-calculation methods for SRT are taximeter, computer-calculated formula, and zonal.

Presently available taximeters are not suitable for SRT. 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, the same trip taken on different occasions will cost different amounts. Most rate-setting bodies and most passengers would find such fare variations to be incomprehensible and unacceptable -- some limited operating experience confirms this opinion even when the service was partly subsidized (RRC, September 1975, p. 154).

The computer can calculate each passenger's fare using a formula based on the shortest road-distance (i.e., excluding all detours for other passengers). This depends on the computer being fully informed about all passengers which, 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 probably cannot be forced to comply without losing independent-contractor status with the IRS and Workers' Compensation regulations. Further, when the computer is down, formula fares cannot be calculated. This is unacceptable for a demonstration where computer reliability has not been proven. However, it may be satisfactory later if very high reliability can be assured.

A zonal-fare system 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 Washington, D. C., and in Pensacola, Florida. For large operations, a small book can be printed. 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 owners or lease the taxis, there is no problem since the fares belong to them anyway.

It is concluded that the SRT-CCS should incorporate both fare options. A zonal-fare system will be needed in leased-taxi and driver-owner 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.

The fare considerations have several implications for an interzonal factors (IZF) file (i.e., a 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 so that the formula-fare calculation is accurate. Then, to get the travel-time estimate, a multiplicative speed factor is needed. (Note: DAR systems include only a time-correction factor which is not adequate for SRT purposes.) 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.

3.3.2 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 transit interfaces (the so-called "scatter" mode of DAR operation) such as the Long Island Railroad's Hicksville station and Washington's Union Station.

Taxi companies currently operating in a shared-ride mode find hail stops difficult to accommodate with manual dispatching and feel that it is important that the CCS incorporate this capability (ITA Orlando Conference, January 1977).

The computer has no prior knowledge of hail-stop passengers and cannot make vehicle assignments. The taxi driver must, therefore, be informed by the computer of the desirable direction and/or destination of potential passengers so that the driver (rather than the computer) can select passengers going in the correct direction. Where legally permitted, the driver can display the 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 the use of a keyboard, and a full keyboard will not necessarily be installed in the taxi; therefore, a simple zone reference is most appropriate.

3.3.3 Organizational Requirements

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 are the property of 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, January 1977). Clearly, the CCS must take into account the prerequisites necessary for drivers to qualify as independent contractors.

There are no uniform rulings by the Internal Revenue Service (IRS) and various Worker's Compensation (WC) boards which clearly define the specific circumstances under which a driver is an independent contractor. The key issue is the character of the control over the driver's work. In general (and oversimplifying a complex issue which is beyond the scope of this work), 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 the key officers of the company are personally liable for the full amount. To qualify as independent contractors, for example, 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 board.

3.3.4 Service Reliability Requirements

Reliability of service is a critical issue for SRT. 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 new requests. Consequently, the reliability of service to a specific customer is potentially lower in SRT than in ERT, and consideration must be given to minimizing this effect.

To the passenger, the key perception of reliability is how close the taxi comes to meeting the service that was promised. This perceived reliability can be greatly improved by incorporating an automatic telephone message subsystem that revises the service promises as required by the operational situation.

In this subsystem, the CCS initiates a telephone message (prerecorded on a set of tapes) to a passenger whenever there is a significant change to the promised service and also whenever the taxi is, for example, two minutes away. The CCS must also accommodate situations where the passenger does not want to be called back, where the passenger's phone is busy or not answered, and where the passenger wants to speak to a human.

3.3.5 Problem Passenger Requirements

When a public regulatory body considers a requested change from ERT to SRT, one of the principal and most vocal issues is how SRT will control or avoid problem passengers. Because SRT is a public transit service and because of civil rights, a reasonable policy (Smart, private communication, May 1977) is that if service is denied to anyone, legally-adequate documentation should be put on file. In existing SRT operations the normal procedure is to place problem passengers in the front seat or to handle them with ERT service. This may solve the legal and civil rights problems 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 work, 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 (without mentioning a specific name or making any accusation).

3.3.6 Effectiveness Monitoring Requirements

The key effectiveness measure used in DAR is passengers per vehicle-hour, while in ERT it is revenues per mile. Neither of these is suitable for SRT, and a new criterion must be used: passenger-miles per driver-hour where the miles are the shortest-route 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 monitored and show information based on time intervals not exceeding one hour.

3.3.7 Credit Requirements

In fulfilling its AWDRT role, SRT should accommodate user-side subsidies 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 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 signed receipt identified by the invoice number. A tabulation of invoices for billing purposes must be generated periodically by the CCS, and traceability to the signed receipt must be auditable.

APPENDIX A

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APPENDIX B

REPORT OF INVENTIONS

The work performed to date under this contract indicates that a number of innovations and improvements are being developed. The following list describes them, but further work may cause additions or deletions.

1. Graphics Computer-Aided Control, paragraph 3.2.3

This constitutes an innovative approach to control of shared-ride vehicles with potential application in smaller shared-ride taxi systems.

2. Hail Signs, paragraph 3.3.2

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. Zonal Matrix, paragraph 3.3.1

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. Automatic Callback, paragraph 3.2.7

An innovative means has been identified whereby automatic tape-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 anxiety and frustration.

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