THE OPERATION AND PERFORMANCE OF A TAXI FLEET

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ABSTRACT

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This work looks at an important but much-neglected form of transportation - taxis. It tries to gain a better understanding of the capabilities of unshared ride taxi fleets. The operation and the service patterns of existing taxi fleets are examined. Particular emphasis is given to the strategies of taxi dispatching and the dispatching systems in use today. Performance models of taxi fleet operations are developed to show how fleets respond to many-to-many, many-to-one, and one-to-one patterns of taxi demand. These models, based on queuing theory, show the important tradeoffs between fleet size, vehicle productivity and passenger wait time. They also show the effects of scale on fleet efficiency and passenger service times. Productivity and cost comparisons are then made between unshared taxis and Dial-a-Ride. Finally, the potential for the application of new technology to the taxi industry is examined, with particular emphasis on computerized dispatching and digital communications.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 INTRODUCTION

Taxis are a very important element of urban public transportation. The need for personal transportation on demand is in fact so universal that taxis are found in almost every major city of the world. The key features of taxi service which have made it so popular are availability and flexibility. Unlike the traditional forms of public transportation, taxis are unconstrained by fixed routes and schedules and are therefore very adaptable to personal and group transportation needs.

This thesis looks at taxi operations in an effort to come to a better understanding of the role of taxis in urban transportation and the unique operating capabilities which taxi fleets have. It does the following:

(1) looks at the current operating environment of taxi fleets

(2) examines the taxi dispatching process

(3) presents some performance models for a taxi fleet, and

(4) looks at how taxi fleets might take greater advantage of today's computer and communications technology.

It is the author's conviction that taxis represent a vital form of public transportation that has been little-understood by urban transportation planners. One justifiable excuse for this oversight in the past is that very little information has been available about the taxi industry itself - its size and composition,and about the operating behavior of taxi fleets.

1.1 The Size of the Taxi Industry in the United States

It has always been difficult to ascertain the number of taxicabs in operation in the United States. Today there are probably about 140,000 taxis in the U.S.[1] In 1955 a figure of 135,000 cabs was reported.[2] Taxi registration data must be carefully interpreted if used to estimate the number of taxicabs. Many taxis change hands several times a year so that double counting in vehicle registration data is a major problem.[3]

Taxicabs are found in cities of all sizes as Table 1.1 shows. But most of the taxis are found in cities having half a million people or more. Notice that the total number of taxis recorded in Table 1.1 is only 76,036 (in 1967) instead of the earlier 140,000 (in 1971) figure suggested. This is because the ITA records of Taxi registrations are incomplete in each of the city size categories. Also,these records do not include taxis in cities having 2,500 people or less. Many cities have "gypsy" cabs which do not have the same legal status as a regular taxicab and therefore have not been included in the ITA records.

Few people are aware of the large ridership and particularly the economic importance of the taxi industry. It is estimated that in 1971 taxis accounted for 20 to 25 percent of all passenger rides by public transportation.[4] Even more significant, however, is the impact of the taxi industry on the economy. More money is spent in the taxicab industry than on all other forms of public transportation combined. In 1970, the total value of expenditures in the taxicab industry was an estimated 1.59 billion dollars (see Table 1.2). The total value of expenditures in the transit industry on the other hand, was estimated at 1.45 billion dollars (the term transit includes local bus, rail rapid transit and commuter rail). The taxi industry has a larger economic share than ridership share of the public transportation market because taxi fares are higher than transit fares.

TABLE 1.1 : 1967 TAXI REGISTRATIONS IN THE UNITED STATES CLASSIFIED BY CITY SIZE

CITY POPULATION (1960 Census)	NUMBER OF CITIES	AVERAGE POPULATION (1960)	NUMBER OF TAXIS (1967)	TAXIS PER 1000 PEOPLE
over 500,000	21	1,361,000	39,648	1.39
250,000 to 500,000	30	359,000	9,577	0.89
100,000 to 250,000	79	144,000	8,282	0.73
50,000 to 100,000	182	69,500	9,162	0.725
25,000 to 50,000	366	34,800	8,537	0.67
10,000 to 25,000	47	16,300	657	0.86
2,500 to 10,000	24	6,670	173	1.08
TOTAL	749	103,000*	76,036	0.99

*average population per city

SOURCE: Calculated from taxi registration and population data given in _1967 Taxicab Licenses and Rates_, published by the International Taxicab Association

TABLE 1.2 : CONTRIBUTION OF THE TAXI INDUSTRY TO THE 1970 U.S. GROSS NATIONAL PRODUCT

VALUE OF EXPENDITURES IN THE PUBLIC TRANSPORTATION SECTOR OF THE ECONOMY, 1970

TAXICABS	$1,593.0 million
TRANSIT	
Local Bus Transit	$966.3 million
Rail Transit	$329.7 million
Commuter Rail	$151.7 million
TRANSIT TOTAL	$1,447.7 million

SOURCE: U.S. Department of Transportation News, Office of the Secretary, "Breakdown of the Nation's Estimated Total Transportation Bill", September 17, 1971.

Given the relative importance of taxis as a form of public transportation it is unreasonable to be spending large sums of Federal money on transit research and development while spending little or nothing in the taxi sector. No comprehensive government-sponsored studies of the taxi trade have been carried out in the United States - such research is greatly needed.

1.2 Previous Research on Taxis

Although the taxi industry does have an association, The International Taxicab Association, this organization does not have the funding to carry out extensive studies of the industry. ITA research is limited primarily to surveys of rate structures, taxi registrations by city and taxi operating costs (see, for example, refs. 17, 26). Because of the dispersed and fragmented nature of the industry and constant turnover in the ownership of small fleets and independent operators, the task of monitoring the national taxicab scene is both difficult and expensive.

The most comprehensive analysis of the taxi industry in the United States is a thesis written by Robert Bivens in 1960.[5] The British Government just recently completed a major study of the London Taxicab Trade.[6]

Most of the taxi research to date has been done in three areas - regulation, taxi demand and taxi operation. More has been written about taxi regulation (particularly about controlling the number of taxicabs and the setting of fares) than about any other aspect of taxi transportation. (References 5, 18, 23, 27, 30, 32, 33 and 39.) This is not surprising since taxi regulation is a constantly-recurring municipal issue. Relatively little work has been done on taxi demand (References 35, 38, and 46) and taxi operation (Reference 24), however. This is unfortunate because transportation planners continue to be kept in the dark about how taxis fit into the entire urban transportation picture.

Specifically in the area of taxi operation, Meyer and Wolfe[7] use probability theory to develop a number of models for the operation of a taxi fleet. Unfortunately these models do not take into account the queuing behavior of taxi fleets. It is here that this thesis presents a new approach to the modelling of taxi fleet operations.

1.3 Contents of the Thesis

The primary motivation behind this thesis is to develop an understanding of taxi operations and fleet performance, so that transportation planners can make more intelligent decisions whenever taxis are, or may be a viable transportation alternative. Answers to a number of important questions are sought:

1) What is the current role of taxis in providing transportation for the urban areas?

2) How do taxi fleets operate in different parts of the city?

3) How is dispatching carried out, and what effects does it have on operating efficiency?

4) How is the performance of a taxi fleet measured and what factors influence this performance?

5) What are the effects of scale in the performance of a taxi fleet?

and 6) Are there any new methods that might be employed within the taxi industry to make taxi operations more effective?

These questions and a number of other important issues in taxi transportation are addressed in the thesis.

Chapter 2 studies the nature of taxi operations and the many factors which must be considered in establishing and running a taxicab fleet. Fleet operating objectives and measures of performance in common use today are discussed. Chapter 3 investigates a very important function in fleet operations - taxi dispatching. The dispatcher controls the fleet and assigns phone orders to the appropriate vehicles. An analysis of alternative vehicle selection criteria is presented, criteria which could form the basis of taxi dispatching algorithms for use by a computer. Different types of taxi dispatching systems in use at the present time are examined and compared.

Several taxi fleet performance models are presented in Chapter 4 that indicate how taxi systems are able to respond to different demand patterns. The purpose of these models is to establish some of the major tradeoffs involved in operating a taxi fleet. A number of interesting scale effects are discovered which demonstrate the advantage of monopolistic taxi service and of shared dispatching services.

Chapter 5 addresses the potential for greater use of computers in the taxi industry, particularly for dispatching purposes.

Finally, Chapter 6 summarizes the major findings of the thesis and lists a number of important recommendations.

Notes on Chapter 1

1. Discussion with Ted Kline, editor of Taxi News Digest, a New England area Taxi Publication. In a telephone conversation with the author, Mr. Wyckoff of Rockwell Manufacturing felt that the 140,000 figure was probably a good estimate. Rockwell manufactures taximeters and a number of market surveys of the taxi industry have been done by the company.

2. Taken from "Traffic in Taxis--Some Investors are Seeking a Profitable Ride in Cabs", an article by J. Richard Elliott, Jr., in Barron's National Business and Financial Weekly, Volume 37, March 4, 1957 p. 3

3. For example, in the March 15, 1971 statistical issue of Automotive Industries, taxi registrations are recorded for 16 states in 1971, a total of 118,235 registered taxicabs. The number of taxis listed for New York alone is 83,720.
To further add to the confusion, the Automobile Manufacturers Association records a figure of 169,000 fleet taxis in 1969 in their 1970 edition of Automobile Facts and Figures.

4. According to the '71-'72 Transit Fact Book transit ridership in 1971 was estimated at 5.5 billion (Table 4, p. 7). Taxis, on the other hand, are estimated to have carried about 1.7 billion passengers in 1971 (discussion with Ted Kline, editor of Taxi News Digest). In 1955, taxis are reported to have carried 1.3 billion passengers (in the article by J. Richard Elliott, Jr. op.cit.)

5. Bivens, R.W., "The Taxicab in Modern Urban Transportation in the United States" Master's Thesis, Georgia Institute of Technology, 1960

6. The Hon. A. Maxwell Stamp, chairman, Report of the Departmental Committee on the London Taxicab Trade, Home Department, Her Majesty's Stationery Office, Cmnd 4483, London, England, October 1970

7. Meyer, R.F., and H.B. Wolfe, "The Organization and Operation of a Taxi Fleet" Naval Research and Logistics Quarterly, June 1961, pp.137-150

CHAPTER 2 THE OPERATION OF A TAXI FLEET

Today's taxi operations are so varied that an objective analysis of them is difficult. But this chapter attempts to explain some of the more important features of taxi operations.

A taxi company normally obtains its operating rights at the municipal government level. Operating authority must be secured from each municipality served by the fleet.[1] Ordinances and laws relating to the setting of fares, control of the number of cabs, enforcement of service standards and the issuance of cab stands are entirely a local matter and vary greatly from one municipality to another. Taxi regulation matters are not specifically addressed further in this thesis, but research is presented in later chapters which will hopefully shed new light on the regulation of the taxi industry.

This chapter is written in two parts. The first part briefly points out some features of taxi demand which shape the operating environment of taxi fleets - how taxi use varies from one part of the city to another, and how taxi use changes from hour to hour during the day. The second part describes a number of aspects of taxi operation in more detail:

(a) the magnitude of fleet operations in the taxi industry

(b) the incidence of ride sharing

(c) differences between downtown and suburban taxi operations

(d) maintaining control of the taxi fleet in real time

(e) cab stands and their use

and (f) the determination of taxi fares.

With this as background in taxi operations, the objectives of a taxi company are presented along with an outline of some measures of performance for a taxi fleet. Finally an analysis is given of the factors which interact to determine the operating efficiency of a taxi fleet.

2.1 Some Features of Taxi Demand

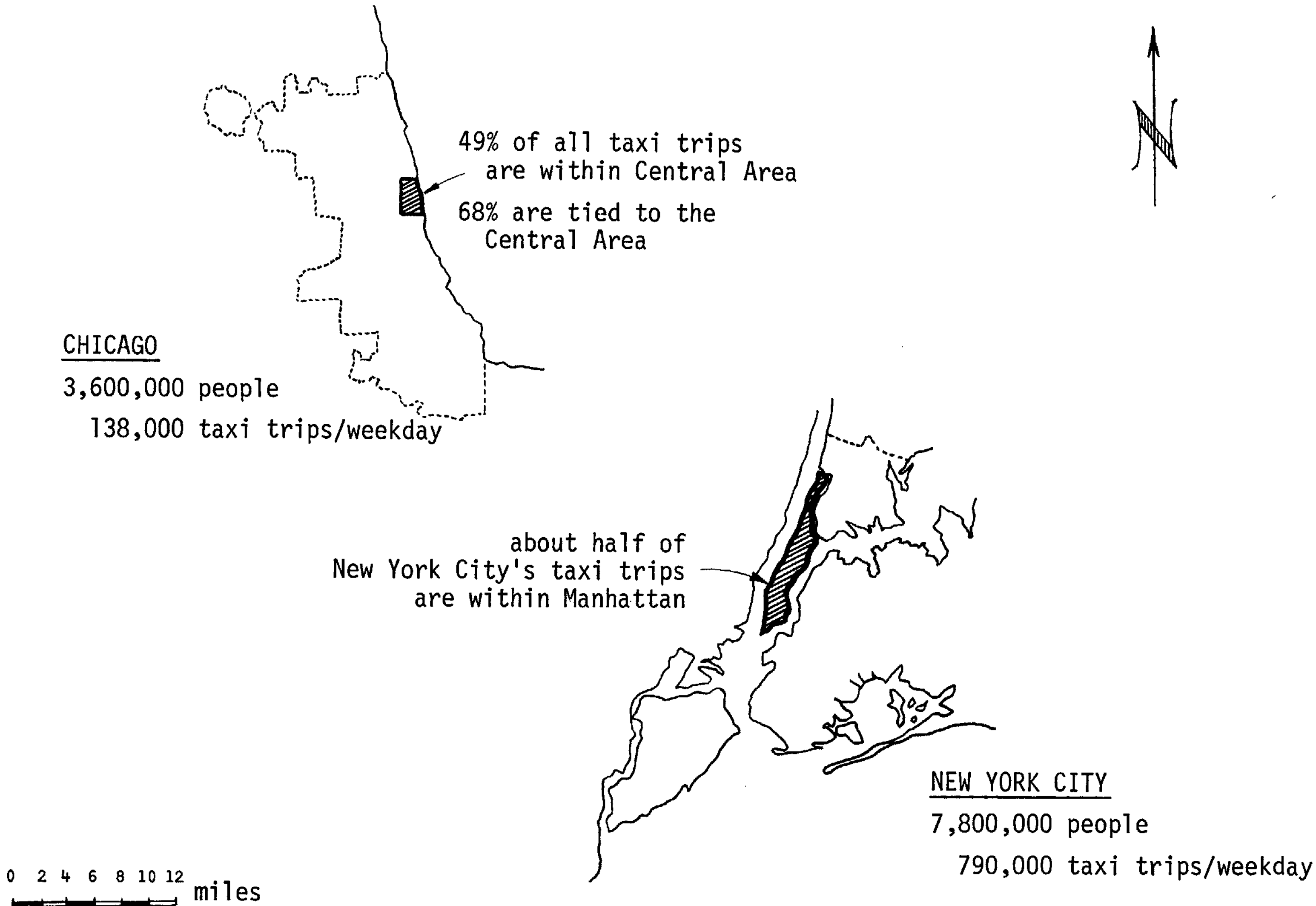
2.1.1 Spatial Patterns of Taxi Demand

Taxis are a remarkably flexible form of transportation, adapting to demand patterns which occur anywhere in the urban spectrum from downtown to the rural fringe. Taxi operations seem to thrive as well in the small town as they do in the metropolis.

Activity centers such as hotels, transportation terminals, hospitals, and stores are strong generators of taxi traffic. In a survey of taxi trips made to and from cab stands in the City of Boston, hotels accounted for 32 percent of trips, transportation terminals 11 percent, and the Massachusetts General Hospital 8 percent of the taxi trips. Much of the remaining 49 percent of the taxi travel was to or from other focal points of activity.[2]

Taxi trip-making in metropolitan areas tends to focus very strongly on the downtown sectors. The density of taxi trip ends is extremely high within the Central Business District and falls off very rapidly as you move radially outward through the suburbs. A study of taxi trip patterns in Metropolitan Chicago showed that 68 percent of all taxi trips originated or terminated in the 4-1/2 square mile central area.[3] (See Figure 2.1.) Contained in this area are a large proportion of Chicago's hotels, railway terminals, office buildings, department stores, restaurants and theatres. Although this central area represents only 2 percent of the surface area of Metropolitan Chicago it totally dominates the pattern of taxi trips.

Results of research done by the Tri-State Commission in New York[4]



SOURCES: see Figure 2.2

FIGURE 2.1 : DOMINATION OF TAXI TRIP PATTERNS
BY CENTRAL BUSINESS AREAS

shows that the nucleation of taxi traffic by the Central Business District is even stronger in New York than in Chicago (also illustrated in Figure 2.1). Manhattan is surely the Mecca of the U.S. taxicab industry. It alone accounts for about half of the taxi travel within New York City. In one part of Manhattan, the density of taxi trip destinations exceeds 40,000 per square mile per day.

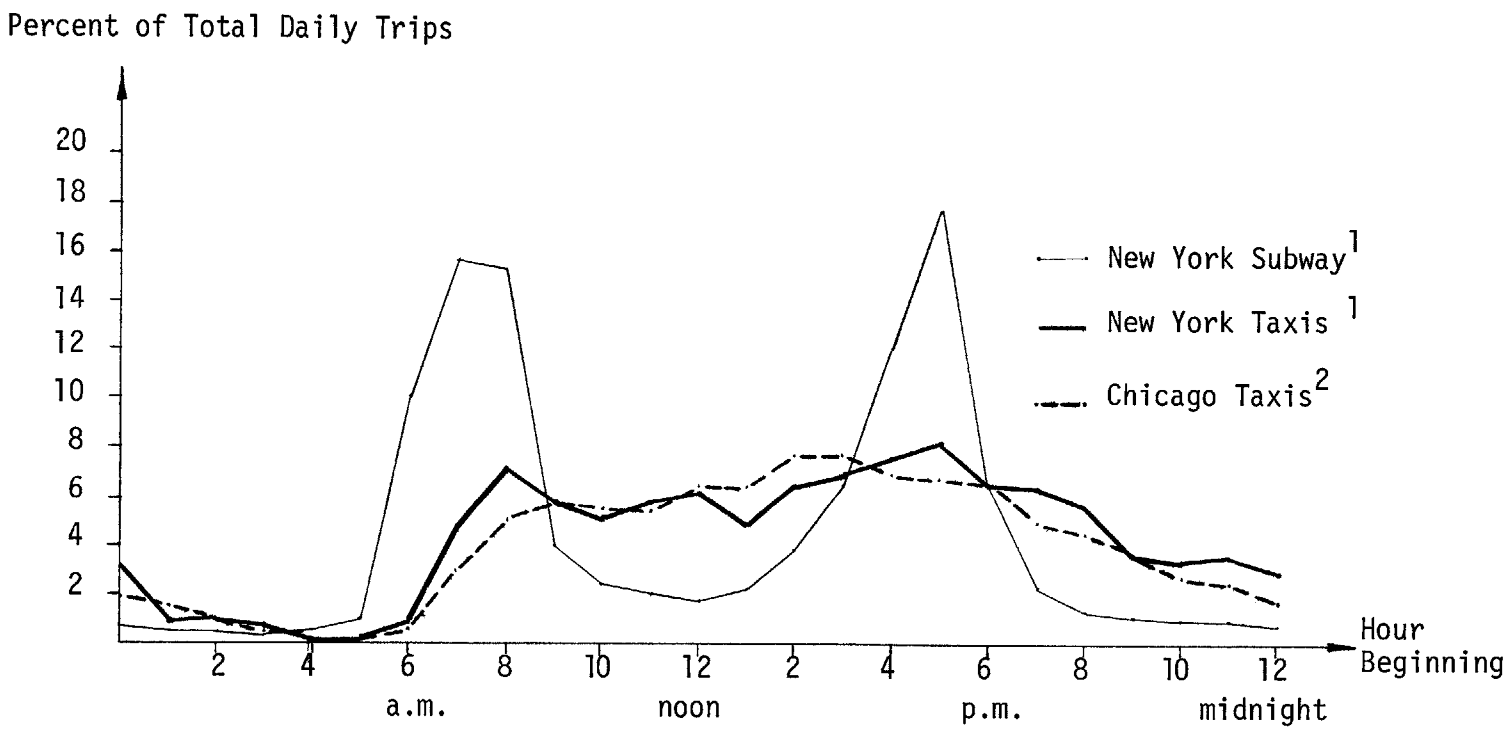
But this trip destination density falls off very rapidly with distance - few centers situated more than 5 miles from Manhattan have a trip-end density exceeding 5000 per square mile per day.

Even suburban taxi operators find that most of their taxi trips are governed by commercial and other activity centers. A study of Belmont Cab taxi trips is made in Appendix A and Figures A9 through A19 show the importance of poles of activity to the suburban taxi operator.

2.1.2 Taxi Use by Time of Day

Taxis are one form of public transportation that do not have serious peaking problems. Figure 2.2 shows how taxi travel is distributed over the day in Chicago and in New York. Notice in particular that taxi travel is relatively steady from early morning to early evening. During no hour is the taxi system called upon to carry more than 8 percent of the entire day's traffic. This is in sharp contrast to transit systems as can be appreciated by looking at the peaking curve for the New York subway. Commuter trains usually carry 25 percent of their total daily load during one of the 24 hours, rail transit from 14 to 20 percent and transit bus only slightly less.[5]

Taxi operators on the other hand are assured of a relatively constant



SOURCES: 1. "Who Rides Taxis?" Tri-State Transportation Commission Regional Profile, p.2, February 1969

2. "The Operation and Regulation of Taxicabs in the City of Chicago" chart 2, p. 47. Research report prepared by the Transportation Center, Northwestern University, March, 1958. Based on a sample of 3,681 taxi trips in the CATS study area.

FIGURE 2.2 : TAXI TRIPS BY HOUR OF THE DAY

flow of revenue over the entire day. It is therefore unnecessary to use peak hour revenues to subsidize off-peak operations. Taxi companies can schedule drivers in a near-optimal fashion. There is no necessity for split-shift operations (often an expensive procedure for transit authorities).

There are a number of reasons for the relatively flat taxi ridership curve during the day. It was seen earlier that taxicabs are used heavily in downtown areas, the very areas of the city that become congested during rush hours. Consequently, taxi productivity falls off during peak hours. Peak clipping, involving the rejection of some people desiring taxi service often occurs with downtown fleets because there are not enough cabs during rush hours to satisfy the demand.

A second reason for the peak smoothing that occurs for taxi systems is that taxis are a very attractive mode for travel in off-peak hours. The door-to-door aspect of taxi service is an important attribute for shoppers and older folk who are more likely to travel during off-peak hours than during the peak hours. Taxis provide their patrons with safe transportation direct to the destination, a characteristic which is particularly appreciated at night. Taxis usually offer better service during the off-peak period than they do during the peaks - cabs are readily available and street travel is faster. Public transit systems on the other hand usually cut back service during off-peak periods and increase operating headways. Evening and weekend transit service is often eliminated altogether. Thus, taxis enjoy a competitive advantage during off-peak periods over other forms of public transportation, an important factor in the steadiness of taxi ridership.

2.2 Taxi Fleet Operations

2.2.1 Types of Taxi Operations

There are 3 types of taxi operations: fleets, associations and independents. Fleets consist of groups of cabs under common ownership such as Checker Taxi of Boston with 275 licenses.

Some larger fleets are publicly owned with stock being offered for sale through various stock exchanges. Fleet drivers are hired by the company and paid a commission based on the day's earnings. (Drivers usually earn between 45 percent and 50 percent of the revenue recorded on the waybill.[6])

Associations are composed of individually-owned cabs. Each association cab is usually driven by its owner although some individuals may own several association cabs. The Independent Taxi Owners Association of Boston with about 615 cabs is an example. Associations offer many advantages to the independent - a common name and cab color scheme (having big-company status), a dispatching service which gives the driver a constant source of phone orders to supplement his street work, a maintenance facility for servicing his vehicle, lobbying power for rate increases, and a source of support in time of difficulty.

The independent is an individual operating on his own. Many independents do not have the option of belonging to an association - either there is no association available or the independent is located so far away from the area served by the association that he cannot take advantage of the services that it offers.

Taxi fleets account for a large proportion of all taxis in service. In 1955 out of an estimated total of 135,000 cabs in the United States, 76,600 were fleet taxis.[7] Probably a similar number of fleet taxis are in operation today. Most of these fleets are concentrated in the center of metropolitan areas.

At the present time the City of Boston has 1525 licensed taxicabs. About half of these cabs belong to fleets while most of the remaining cabs are registered with associations. Only about 50 of the taxis are operated strictly as independents.[8]

Most of this thesis is concerned with the operation of a taxi fleet where the term "fleet" is taken in a very general sense and applies to any group of taxis that is centrally dispatched. (Many associations belong to this category and will henceforth be included whenever the term "fleet" is used.) Fleet operations have the greatest potential for providing coordinated taxi service. Centralized control permits rapid response to customer service requests in a way that utilizes resources most efficiently and economically.

2.2.2 Ride Sharing

A very small proportion of all taxi companies offer shared-ride taxi service at reduced fares. Under the shared-ride system two or more parties travelling independently may share the same cab for all of, or portions of their trips. More passengers can be carried per vehicle hour under ride sharing because rides are pooled. Consequently, ride-sharing taxi patrons are entitled to lower fares. Ride sharing is not without penalty however, travel time is increased if deviations from the most direct route are made to pick up and drop off other passengers.

In Washington, D.C. ride sharing is authorized at all hours for specified activity centers (railway, bus and air terminals, D.C. stadium, the Armory, and government buildings on days of early dismissal) and during peak hours and snow emergencies. At all other times group riding is permissible only with the consent of cab occupants. Fare reductions for a passenger participating in group riding range from 15 percent to 40 percent depending upon distance travelled.

In the greater Boston area, less than 5 percent of all cabs are operated on a shared ride basis. Taxis in the cities of Lynn and Lowell are exceptions to the rule with their ride-sharing operations.

Taxi operators not currently offering lower-priced ride-sharing services are opposed to this system on two accounts. First, they feel it detracts from the prestige nature of the taxi business - one of offering the passenger exclusive door-to-door service. They feel that most of the existing passengers would object to sharing the vehicle and having to deviate from the most direct route in order to pick up and drop off other passengers. Secondly, they feel that ride-sharing reduces the size of the taxi market - fewer cabs are used to transport the same number of people at lower fares. Hence, total revenue will be reduced. (It should be realized, however, that the sharing of rides may reduce operating costs more than revenues with a possible increase in profit potential.)

Although the author agrees that it would be unwise and undesirable for taxi fleets to entirely abandon exclusive service in favor of ride-sharing, particularly in downtown areas, taxi operators should consider offering shared ride transportation in parallel with the more traditional form of taxi service. Ride sharing may also be desirable during rush hours or for serving specific activity centers. Many transportation needs, currently unserved could be met through taxi ride sharing. It will be suggested in Chapter 4 that shared-ride taxis can be a very efficient, low-cost form of urban transportation.

2.2.3 Differences Between Downtown and Suburban Operation

The structure of a taxi operation is greatly determined by the area of the city it serves. Downtown cab companies handle a relatively small proportion of telephone orders and a much larger proportion of street work (the passenger either goes to a cab stand or hails an empty cab on the street). People who live downtown will often step out onto the street to get a cab rather than placing a phone order. Phone orders placed with Checker Taxi of Boston account for only about 25 percent of the taxi trips, the remaining 75 percent being street work.[9]

Suburban companies, on the other hand, depend on the telephone for most of their orders. Brookline Red Cab, for example, experiences about 80 percent phone work[10]. The Belmont Cab company obtains 61 percent of its business through phone orders. 38 percent of the customers secure a cab at a cab stand and less than 1 percent of the ridership obtains the cab by hailing it down on the street. (Cab companies downtown experience a much larger proportion of rides through street hailing.)

Suburban fleets are usually tightly controlled by a central dispatcher, who tries to follow the location of each vehicle so that he can assign phone orders to cabs in the most efficient manner. (Taxi dispatching will be covered in detail in Chapter 3.) Downtown fleet operations, on the other hand, tend to be loosely controlled. The drivers are free to travel where they like, seeking out profitable fares on the street and at cab stands. Downtown dispatchers seldom attempt to monitor the positions and status of all cabs. Consequently the assignment of phone orders is often done very inefficiently.

The density of demands for taxi service varies greatly from one part of the city to another. For example, the suburban community of Belmont, Massachusetts generates a taxi demand density of about 4 demands per square mile per hour (see Appendix A) while downtown areas of the city experience densities exceeding 500 demands per square mile per hour. Because of the dispersion of suburban taxi demand, a high degree of control is required to minimize wasted empty mileage and expedite passenger service.

2.2.4 Controlling the Fleet

At any point in time, the taxis of a fleet are scattered throughout the service area. Yet if phone orders are to be responded to quickly, the dispatcher must be able to contact drivers.

Before the advent of the two way radio, telephone lines were put in to all cab stands. The number one driver on the stand was responsible for staying by the phone to await orders from the dispatcher. Phone orders were dispatched from the nearest stand to the caller.

The two way radio revolutionized taxi operations - no longer are cabs completely bound to their stands for orders. The radio brought communications flexibility that was vastly superior to the stand phone system. Calls can now be answered by the closest available cab (at least in theory) thereby providing the public with a faster-reacting system.

Unfortunately the radio has had a paradoxical effect on large downtown fleet operations - as much as it has brought greater potential for centralized control, the onus is on the driver to make his position known and respond to the dispatcher's announcement of phone requests. Instead of the dispatcher being in control, the driver is in control. In fact, many taxi drivers in fleets such as Checker of Boston simply turn their radio off for the entire day. Taxi companies try to improve the use of the radio by requesting all drivers to log in a minimum number of phone orders during the shift.

Driver compliance in the proper use of the radio is not so much of a problem for small suburban fleets where the dispatcher keeps track of the locations of all cabs, whether they are doing street work or taking phone orders.

2.2.5 The Use of Cab Stands

Cab stands are a necessary element in the taxi system. Their use is required by law in many municipalities. The stands provide a stop-over point where taxis can park and thereby avoid the accumulation of unpaid mileage. Stands should be widely distributed in the service area so that taxis do not have to waste miles just in driving back to the stands.

Taxi stands should be put in conspicuous locations near activity centers. It is to the benefit of both the taxi user and the taxi company that stands be placed where they are most needed. Some downtown taxi trips result from impulse buying[12]. It is therefore important that taxi stands be situated so as to maximize exposure of available taxis to people who would use a cab if an empty one were to appear at just the right time.

For a given city, there is an optimal locational pattern of cab stands. It is the economic responsibility of authorities which approve the location of cab stands to attempt to achieve an optimal allocation of cab stands within the city. (In the city of Boston, cab stands occupy 1/200th of the total curb space.[13]) Curb space is a valuable urban resource for which many interests compete -- a market exists for curb space like other commodities. A thirty foot cab stand may have alternative value as a commercial loading area (generating revenue for the municipality), as parking space (generating parking revenue) or has the potential for being converted to a curb lane to expedite traffic flow in the city. Cab stands that are seldom used should be converted if there exists some other use of higher value. On the other hand, more curb space should be allotted to taxi stand use where a need for that stand can be demonstrated and there is a strong willingness-to-pay on the part of taxi operators for the use of that space as a cab stand.

There are two types of cab stands -- those which can be used by any licensed taxi company on the first come, first served basis, i.e. the "public" taxi stands, or those which are assigned to a particular taxi company -- the private taxi stands. The latter type of stand has the advantage that under improper use of that stand, stand privileges may be immediately revoked by the city. Responsibility for the stand is well-defined and an annual fee is often paid by the cab company to which the stand has been assigned. These fees sometimes exceed $100 per cab space annually, but in 1958 one-third of the cities with a cab stand fee charged less than $20 annually per space.[14] Of the two types of stands, a "public" stand has the potential for higher, more consistent utilization since any taxi can use a public stand.

2.2.6 Methods of Determining Taxi Fares

A knowledge of methods of fare assessment is essential to an understanding of taxi operations. There are three systems for determining taxicab fares: meter, zone and flat rate. In some cities a combination of two systems is used such as "meter and flat", "zone and flat" or "meter and zone".

The most widely used fare system is based on the taximeter. In fact about four fifths of all licensed taxis used meters in 1965 (see Table 2.1). Taximeters are very common in large cities but are used less in small cities where zone and flat rate systems are popular.

The Taximeter

The taximeter is a mechanical-electrical device that calculates fares as a function of distance and time. Distance information is fed into the meter by means of an odometer cable, and a clock mechanism within the meter advances the fare readout at a predetermined rate whenever the taxi is travelling below a certain speed.

There are usually three components to the metered taxi fare - the "drop", the mileage charge and the time charge. The drop is the minimum charge which is assessed after the passenger enters the cab. It gets its name because it appears on the meter as soon as the cabbie swings down or "drops" the lever which puts the meter into operation. (In Boston, for example, the first one-fifth mile is 50 cents.[15]) Additional distances are covered by the mileage charge in proportion to distance travelled, but paid in advance (10 cents for each additional one-fifth mile). The time charge is automatically assessed by the meter whenever the taxi is travelling below a certain speed, the speed at which the time charge and the mileage

TABLE 2.1 : TAXI FARE SYSTEMS IN USE IN THE UNITED STATES IN 1965

1960 POPULATION	NO. OF CITIES	% USING METERS	% USING ZONES	% USING FLAT RATES	% USING TWO RATES
Over 500,000	21	95.2%	4.8%	-	-
250,000 to 500,000	30	100.0%	-	-	-
100,000 to 250,000	79	86.0%	10.1%	1.2%	2.5%
50,000 to 100,000	180	78.8%	15.5%	4.4%	1.1%
25,000 to 50,000	364	53.8%	33.3%	10.1%	0.5%

In cities where ....

Taximeters are used, there are	57,215 licenses	or 78% of total
Zone system is used, there are	13,999 licenses	or 19% of total
Flat rates are used, there are	1,550 licenses	or 2% of total
Two different rates are used, there are	592 licenses	or 1% of total
TOTAL	73,356 licences	100%

SOURCE: "Taxicab Licenses and Rates, 1965" National Association of Taxicab Owners affiliated with Cab Research Bureau Inc.

charge are equal. (In Boston, the time charge is 10 cents per 1.2 minutes whenever the taxi is travelling below 10 mph.)

The odometer drive and clock drive are never engaged at the same time, however. The fare readout is advanced by either one or the other, but not both.

The taximeter frees the cab drivers of tedious fare calculations. But it is even more valuable to the cab company owner for keeping a running record of miles travelled and revenues collected by each cab. The taximeter also deters theft on the part of the drivers because drivers are held accountable for all trips recorded on the meter.

Zoned Fares

Under the zoned fare system taximeters are not used. Fares are not calculated on the basis of distance travelled but change when zonal boundaries are crossed. Such a system has built-in inequities. In Washington, D.C. for example, an unshared ride of one third of a mile can cost anywhere from 60¢ to $1.45 and an unshared ride of one tenth of a mile costs $1.10 whenever it involves crossing an interzone boundary.

Large, privately-owned fleets are seldom operated in cities having a zone system except on a rental basis, because companies have no way to monitor the revenue collected by the driver. Drivers rent the cabs from the company for a weekly fee which in 1967 ranged from $30 to $60 depending upon the condition of the vehicle and whether or not radio and air conditioning were included.[16]

In spite of the problems associated with administering a zoned fare system, many cities, particularly those having a population of less than 50,000 have found the zone fare system to be best-suited to their local needs (refer again to Table 2.1).

Cities which offer shared-ride taxi service normally operate a zoned fare or flat fare system, since meters cannot be used to determine an equitable assessment of fare.

Flat Fare System

The flat fare system is popular in many small cities and towns. For example in Lakewood, Ohio (1960 population was 66,154) the flat rate of 75 cents will take a passenger anywhere in the city.[17] In Wyandotte, Michigan (1960 population 43,519) a basic fare of one dollar is used. Flat fares are very often used in parallel with the taximeter system for specifying the fixed cost of travel between popular origin-destination pairs.

Extras

It should also be mentioned that some cities permit the taxi companies to make extra charges for additional passengers, extra stops, and the carrying of parcels, for example.

2.2.7 Objectives and Measures of Performance in the Operation of a Taxi Fleet

The operation of a taxi fleet affects the fleet owner/operator, dispatcher, cab drivers and taxi patrons. Each has a different interest in the way the fleet is operated. The fleet owner is primarily motivated by profit but realizes that he can maximize net revenues only by providing patrons with a high level of service. (This is particularly true of fleets operating in a competitive environment and having a high percentage of phone orders.) The dispatcher is most concerned about efficiency in handling phone orders - that they are responded to quickly and reliably. (Sometimes the dispatcher is held responsible for the overall performance of the fleet since it is his job to assign each incoming phone order to the closest available cab.) Cab drivers working on a commission basis are driven to bring home as large a waybill as possible. Consequently they try to maximize the proportion of time that they are busy with fares. Taxi patrons are most concerned about quick and reliable response to their phone orders. Since the company owner determines operating policy it is he who must strike a balance between the conflicting interests involved.

Maximizing Company Profits

The average taxi fleets change very little in size from year to year. Similarly the ridership and consequently revenues are relatively steady from one year to the next. The objective of maximizing profits therefore becomes primarily one of minimizing total fleet mileage. A large fraction of taxi operating costs (aside from the driver's commission) is directly proportional to miles travelled (gas, oil, maintenance, accident costs and tires together amount to about 5 cents per mile).

Many taxi operators believe that the statistic which best indicates the daily performance of their fleet from a profit standpoint is the cents per mile figure.

Cents Per Mile

The cents per mile statistic is determined by dividing the total day's revenue for the fleet or an individual cab by the total mileage travelled. By looking at the cents per mile figure for each cab, and the fleet as a whole, the experienced operator can determine how well the dispatcher and each driver has performed. The cents per mile ratio is also extremely useful as a predictor of company profit since it measures revenue relative to operating cost.

Cents per mile is primarily a function of fare structure, the trip length distribution and a statistic called the percentage of paid miles (or percent paid miles) which will be discussed momentarily.

$$\frac{\text{cents}}{\text{mile}} = \frac{\text{average fare}}{\text{average trip length}} \times \text{percent paid miles} \qquad (2.1)$$

Notice that for metered fares, cents per mile can be increased by increasing any one of the fare components - the drop, the mileage charge or the time charge. It will also be increased if the average trip length becomes shorter, since the drop is incurred more frequently per revenue mile travelled. It is for this reason that many operators prefer many short trips to a few long ones. Given an established taxi operation the operator is most likely to be able to improve his cents per mile performance by bringing about an increase in the percent paid mile performance of the fleet.

Percentage of Paid Miles

This statistic is a measure of the proportion of total miles travelled during which fares are being carried. 50 percent paid miles means that for every mile the cab travels with a fare-paying passenger it travels another mile empty. Empty or "deadhead" miles are inevitable - almost every phone order results in deadhead miles to make the pickup. Additional deadheading occurs after the passenger is dropped off and the empty cab heads for a stand.

Taxi fleets are rarely able to exceed 50 percent paid miles. Downtown fleets usually achieve a higher proportion of paid miles than do suburban fleets for two reasons:

1. The demand densities per taxi are much higher in the downtown areas

and consequently cab drivers have a better chance of finding a new fare close to the last drop-off point.

2. Downtown companies handle a predominance of street work. Regardless of their location cabbies do not have to travel far to get to one of the closely-spaced cab stands and therefore minimize wasted mileage. Each time they drop off a fare in a busy commercial area, there is a good chance that they will be hailed before they have driven far. Suburban companies, however, deal mostly with phone orders which require extra empty travel to make the pickup.

Suburban fleets rarely achieve greater than 40 or 45 percent paid miles.

Apart from demand pattern considerations, the dispatcher and drivers are instrumental in achieving a high percent paid mile score - the dispatcher through an ability to select the appropriate cab to handle each phone order and the driver through refraining from putting needless mileage on the odometer. Both these points will be examined later at greater length.

Percent Utilization

Another important measure of fleet performance is the percent utilization - the percent of time that a vehicle is occupied with a fare. Since the operator must pay insurance, depreciation and license fees for each vehicle in use, it would seem to be in his best interest to maximize the utilization of each vehicle. As we shall see later, however, increases in percent utilization may result in decreases in percent paid miles and the operator must strike a balance between the two.

The concepts of percent paid miles and percent utilization are probably best illustrated by showing the passage of time and the accumulation of mileage over a taxi trip cycle. Figure 2.3 shows a complete trip cycle

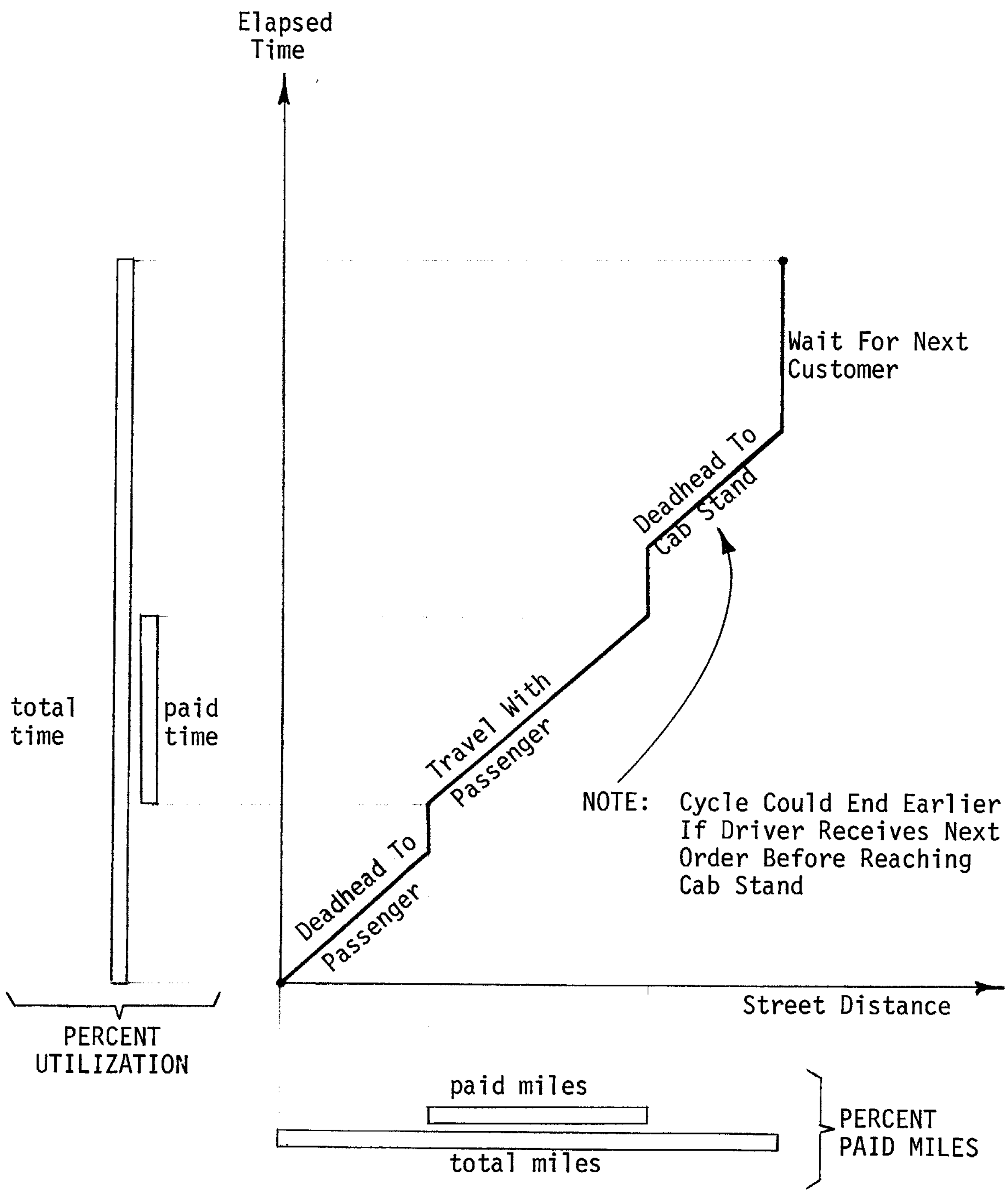


FIGURE 2.3 : TRIP CYCLE FOR A TAXI SERVING A PHONE ORDER

for a telephone order from the time the dispatcher receives the order to the time when the taxi is ready for the next order. Notice that the percent utilization is less than the percent paid miles because there are periods when the taxi is standing still. Figure 2.4 illustrates a similar trip taken from a cab stand. Both the percent paid miles and percent utilization are higher than they were for the phone-ordered trip because the initial deadheading pickup trip has been eliminated.

Vehicle Productivity

Vehicle productivity is a measure of the rate of turnover of fares and has units of fares per hour (not to be confused with passengers per hour). Most unshared ride taxi systems have productivities in the range of 2 to 3 fares per vehicle hour.[19] But because taxis carry an average of 1.2 to 2.0 passengers per fare[20], taxis actually carry between 3 and 6 passengers per vehicle hour.

Productivity is related to the speed at which taxi trips are handled, average trip length and percent utilization:

$$\text{Productivity} = \text{Percent Utilization} \times \frac{\text{average trip speed}}{\text{average trip length}} \qquad (2.2)$$

Productivity is directly proportional to the average speed of the paid part of the taxi trip cycle (and therefore very congestion-sensitive) and inversely proportional to the average trip length.

Productivity figures are also useful in computing the revenue-producing capability of a fleet since

$$\frac{\text{revenue}}{\text{cab hour}} = \text{productivity} \times \text{average fare} \qquad (2.3)$$

Level of Service

The most important element of taxi operation to the taxi user is the

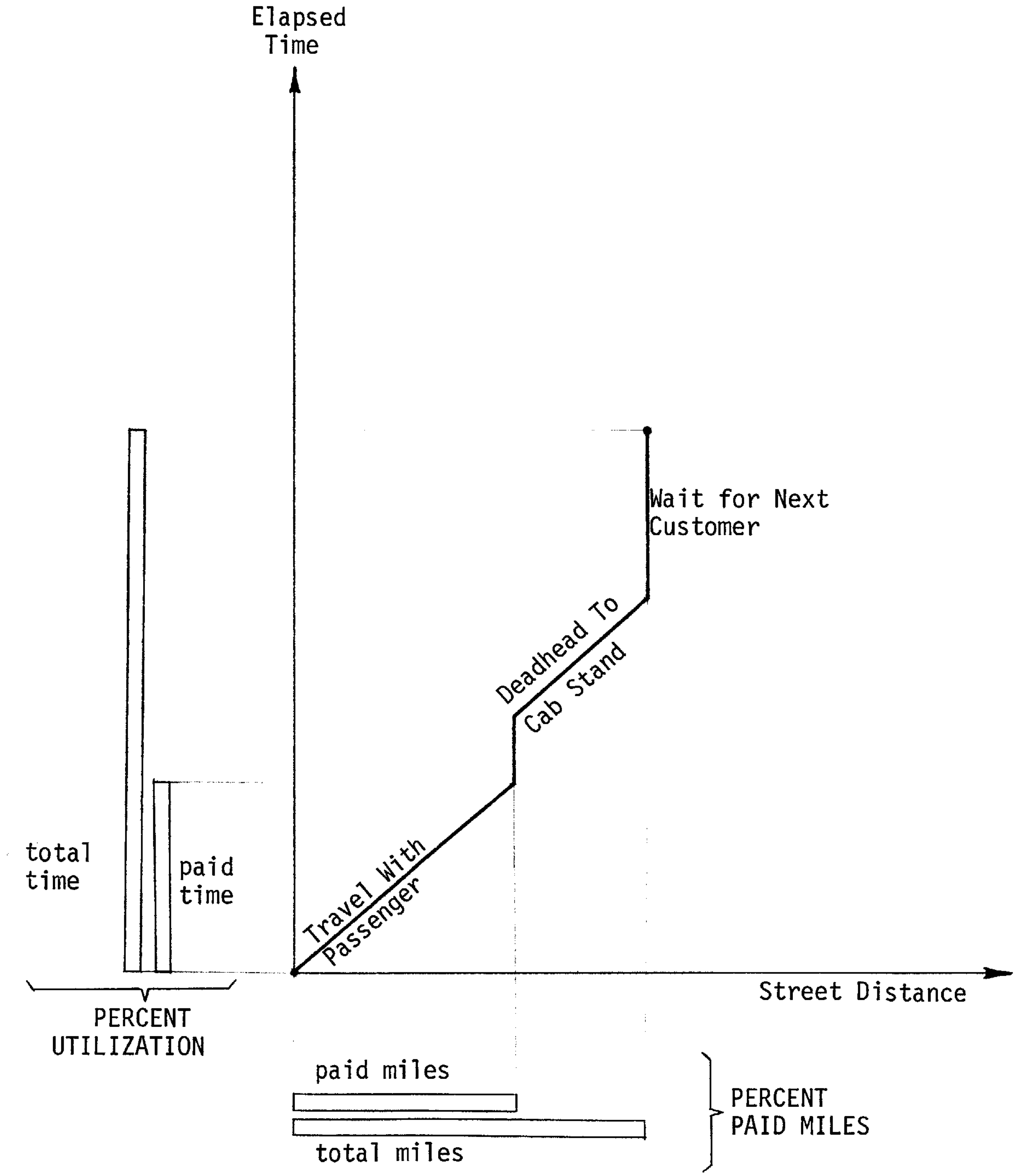


FIGURE 2.4 : TRIP CYCLE FOR A TAXI SERVING A STAND OR STREET ORDER

the pickup and travel time level of service provided. Level of service measures apply primarily to phone orders where a pickup time is involved. It is advantageous from the taxi patron's point-of-view to minimize both the mean pickup time and its standard deviation, the latter representing a measure of pickup reliability.

2.2.8 Factors Influencing Fleet Efficiency

As pointed out in the last section, the most important measure of fleet efficiency is the percent paid miles. This efficiency is related to many factors, some of which involve demand density and configuration, driver performance and dispatching performance. The effects of these factors are now summarized:

(1) Demand Density

As demand density increases, dead mileage becomes a smaller and smaller proportion of total mileage. Consequently the percent paid miles increases.

(2) Demand Pattern

A high proportion of many-to-one trips (such as to and from a business center) tends to increase the percent paid miles. A large number of one-to-one trips may boost fleet efficiency even further. A detailed analysis of these effects is given in Chapter 4

(3) Percent Phone Orders

Phone orders impose tighter constraints on taxi operations than does street work. When a company accepts a phone order it also accepts the responsibility to travel extra dead mileage to pick up the passenger and furthermore to get a cab to the customer as quickly as possible

A street order is different, however. With it there is no commitment to the extra pickup mileage nor is there any commitment to service the passenger immediately. A customer trying to get a cab on the street must take his chances.

This is not to say that phone work is undesirable - it just results in lower operating efficiency.

(4) Shape of Service Area

Taxi demand patterns typically have a dense region of trip production in the center of the service area where high productivities can be achieved. Moving outwards across the periphery of the service area, trip generation density falls off rapidly, accompanied by a decline in efficiency.[18] It is therefore desirable to have a service area with the smallest possible circumference per unit area. A compact service area (circular or square) is therefore preferred to an elongated service area.

(5) Location of Cab Stands

As mentioned in section 2.2.5, good cab stand locations are critical to an efficient taxi operation. In order to minimize dead mileage, stands should be positioned so that their pattern and density is similar to the pattern of taxi trip origins. Furthermore they should be located so as to maximize exposure to potential taxi users by putting them in areas of concentrated activity such business centers.

(6) Type of Dispatching System

The three types of dispatching systems - vehicle call, location call and area call (to be discussed at length in Chapter 3) are arranged in order of decreasing efficiency.

(7) Dispatcher's Abilities

The skill of the dispatcher can have a pronounced effect on fleet performance. Good dispatchers have an ability to remember where cabs are, where they are going and when they will become free. They can select the closest available cab, and anticipate future demands. The dispatcher's primary function, aside from providing phone customers with prompt service, is to eliminate wasted mileage. Chapter 3 is devoted entirely to dispatching performance.

(8) Ability to Provide Reliable Pickup

The dispatcher's ability to reliably predict phone customer's pickup time affects both productivity and efficiency:

(1) Customers will be ready when their cab arrives. The driver will not have to wait a long time for the customer to appear.

(2) The probability of a no-show is significantly reduced. No-shows are a serious problem for downtown Boston fleets. Because of unpredictable pickups, some taxi users call several cab companies and take the first taxi to appear.

(9) Aggressiveness of Drivers

Drivers who seek fares aggressively can effect noticeable improvements in productivity, particularly where the majority of taxi business is street work.

(10) Theft by Drivers

When drivers steal from the company by not reporting trips the apparent productivity and efficiency of the fleet falls.

(11) Location of Garage

Taxi trips to and from the garage represent dead mileage. Such trips occur at the beginning and end of the shift and during the shift for gas, oil, maintenance and washing. A central location for the garage is most desirable.

(12) Exposure of the Fleet to Potential Customers

Good exposure of the fleet is imperative for downtown taxi operations. Some customers take a cab just because it is available. A larger share of this latent demand (which is conducive to higher fleet efficiency) might be realized by a more systematic coverage of the demand-intensive areas of the city and by communications from the drivers indicating which stands and streets have surplus of cabs and which have a deficiency. Dispatchers could act on this information to re-distribute the fleet.

(13) Choice of Fleet Size

By increasing the fleet size, a suburban operator may be able to improve his percent paid miles. With more vehicles covering the same service area, phone orders can be served faster and with shorter pickup distances than before. The resulting efficiency improvements are, however, offset by lower daily waybills which the drivers will not like and by additional financial outlay for more vehicles and insurance.

The relative importance of each of the above factors in the operating efficiency of a particular taxi company depends entirely upon the operating environment of that fleet.

2.3 Summary

This chapter has attempted to give the reader a basic understanding of taxi fleet operation. Emphasis has been placed on fleet operations because it is the large fleets which have the greatest potential for providing a coordinated operation which leads to efficient, reliable and responsive transportation service.

At least half of the taxis in the United States belong to fleets while a large proportion of the remaining taxis belong to associations which have very similar operating characteristics to those of fleets.

Taxi transportation is very heavily oriented towards the central business areas of large cities. Hotels, transportation terminals, office buildings all have a magnetic effect on taxis. Even suburban taxi travel is strongly polarized by commercial centers.

Taxis do not experience the peaks in traffic which are so much of a problem for other modes of public transportation. Taxi use is quite steady throughout the day. Because taxi service does not deteriorate during off-peak periods like other modes of public transportation, the use of taxis increases relative to the other modes during off-peak hours.

Very few cities in the United States offer shared ride taxi service. This is unfortunate because taxi companies have the potential for providing a lower cost transportation service (in addition to the service they now provide), thereby meeting transportation needs which are not currently being fulfilled.

Suburban taxi fleets handle a much larger proportion of phone orders (60 to 80 percent) than do the downtown fleets (20 to 30 percent). Consequently the dispatchers of suburban fleets have a more critical role than do the dispatchers of the downtown operations.

Since taxis are oriented towards activity centers, taxi stands are an important part of taxi operations. Many municipalities do not allow taxis to park at will or cruise and consequently they must return to the stands. But if taxi stands are incorrectly located or incorrectly used, they can be responsible for causing serious inefficiencies of operation.

A number of operating objectives for a taxi fleet have been identified. Most taxi companies are private enterprise in nature and consequently they must make a reasonable rate of return on investment to survive. Profit maximization is therefore of great importance. But profits are also dependent upon good service. In particular, suburban operators under pressure from competition are very reputation-dependent and must provide reliable pickup service.

Two important economic measures of fleet performance are the percent paid miles and the revenue per mile. Vehicle productivity (as measured in passengers per vehicle hour) is not considered by fleet operators as an important measure of effectiveness. Most drivers are paid by the revenue mile and a large proportion of the remaining vehicle operating costs are mileage-dependent rather than time-dependent.

Many factors work together to determine the operating efficiency of a taxi fleet- demand pattern and density, percentage of phone orders and location of cab stands for example. But one of the most important factors is dispatching - particularly the dispatcher's skill and the mechanics of the dispatching system. For this reason the next chapter is devoted entirely to a discussion of taxi dispatching.

Notes on Chapter 2

1. See, for example, Rules and Regulations for Hackney Carriages, 1970 City of Boston Police Department

2. Barbera, Kevin, "Introduction to the City of Boston Taxicab Industry", Traffic Quarterly, April 1972, p. 282

3. Transportation Center, Northwestern University, The Operation and Regulation of Taxicabs in the City of Chicago, Unpublished research report, 1958, chapter 3 section A

4. Tri-State Transportation Commission, Who Rides Taxis? Regional Profile, 1969

5. Meyer, J.R., Kain, J.F., Wohl, M., "The Urban Transportation Problem" Harvard University Press, Cambridge, Mass. 1965 p.67

6. The waybill is a daily record kept by the driver, often required by municipal law, which lists each trip with an indication of the origin, the destination and the fare. Some companies require additional information such as the time the trip was taken and the number of passengers in the party.

7. Elliot, J. Richard, Jr., "Traffic in Taxis--Some Investors are Seeking a Profitable Ride in Cabs", Barron's National Business and Financial Weekly, Volume 37, March 4, 1957, p.3

8. Discussion with Mr. Ted Kline, editor of Taxi News Digest, Boston, June 1972

9. Discussion with Mr. Ned McCarty, manager of Checker Taxi, Boston, March 1972

10. Discussion with Mr. Ned McCarty, operator of Brookline Red Cab, Brookline, March 1972 (Mr. McCarty is affiliated with both Brookline Red Cab and Checker Taxi of Boston.)

11. See Appendix A

12. Discussion with Mr. Ned McCarty, manager of Checker Taxi, Boston March 1972

13. Barbera, Kevin, op. cit. p. 283

14. ATA Data Book, 1958-1959, The American Taxicab Association, Inc., Chicago, Ill., 1958

15. City of Boston Police Department, Rules and Regulations for Hackney Carriages, 1970 p. 7

16. Washington, D.C. Public Service Commission, February-March Survey of Taxicab Fleets and Associations, 1969

17. International Taxicab Association, 1967 Taxicab Licenses and Rates, 1967 p. 7

18. Most municipalities grant taxi licenses which authorize the holder to do street work in that city. Once a licensed cab is outside its own municipality it can no longer do street work. Consequently most external trips involve deadheading one way.

19. In Appendix A, it is shown that vehicle productivities for Belmont Cab vary from an average of 2.2 fares per vehicle hour to a peak of 3 fares per vehicle hour. Brookline Red Cab reports productivities of about 2.5 fares per vehicle hour.

20. In New York (Tri-State Transportation Commission op. cit. p.3) there is an average of 1.4 passengers per trip (some of the fleets experience higher occupancies than this, however). Brookline Red Cab records the number of passengers carried during each taxi trip and reports about 1.2 passengers per fare. Mr. Ted Kline of Taxi News Digest suggests that the occupancy of some downtown Boston fleets is close to 2.0 passengers per taxi trip.

CHAPTER 3 TAXI DISPATCHING

Because taxi dispatching is such an important facet of taxi operations, it is treated separately in this chapter. Many taxi operators are unaware of the potential for improving the dispatching of their fleets. Two reasons for the existence of this improvement potential are:

(1) Limitations of the Human Mind

The human mind is capable of high levels of performance only for dispatching small fleets. As fleet size increases, the dispatcher's decision-making becomes more complex and his efficiency declines.

(2) Inefficiency Built Into the Dispatching System (Applies primarily to large fleets)

Most taxi dispatching systems in use today were designed around the capabilities of the human dispatcher. (For example, a large fleet operation will be broken down into smaller operations each of which can be managed by a single dispatcher.) However, in the process of initially setting up the dispatching system, efficiency has been sacrificed for the sake of keeping the system simple. Significant efficiency improvements are now possible by re-designing the dispatching systems and taking full advantage of today's communications and electronics technology.

The dispatcher has the responsibility of making a multitude of small decisions which collectively determine fleet performance, In this chapter, the strategies for these decisions are examined - how vehicles are selected to service the phone orders and how vehicles are redistributed when they become empty. Taxi companies have developed a curious array of dispatching systems, but these systems can be categorized and are compared in section 3.3. Taxi dispatching costs are then examined and finally a sensitivity analysis of dispatching improvements is made.

3.1 The Dispatching Function

The dispatcher acts as the interface between the demand for taxi service and its supply as shown in Figure 3.1. Phone orders are recorded by one of the operators and handed to the dispatcher. The dispatcher then tries to determine the closest available cab and assigns the order to that cab by radio. The dispatcher does not have the same assignment responsibility for taxi trips that are initiated on the street, either at a cab stand or through hailing. Some of the smaller fleets and associations do, however, require the cab drivers to radio in whenever they accept assignments from the street and report when they are free once more.

The majority of taxi companies whether located downtown or in the suburbs give priority to their phone orders. If a particular cab is the most convenient one of the fleet to handle a phone request, he is expected to take that phone order even if he is about to be hailed on the street. (Most drivers, however, prefer taking a passenger-at-hand rather than servicing a phone order. Telephone orders sometimes result in a "no-show".) The rationale behind this company policy is that many of the phone customers are repeat business which represents steady income for the company.

The phone operators and dispatchers work in close proximity because interaction is required between the two functions. There must be minimum delay in handing the written phone order to the dispatcher so that it may be assigned to a cab as quickly as possible. Furthermore, dispatchers must frequently inform operators of the current system wait time for pick-up - this wait time varies considerably according to the availability of

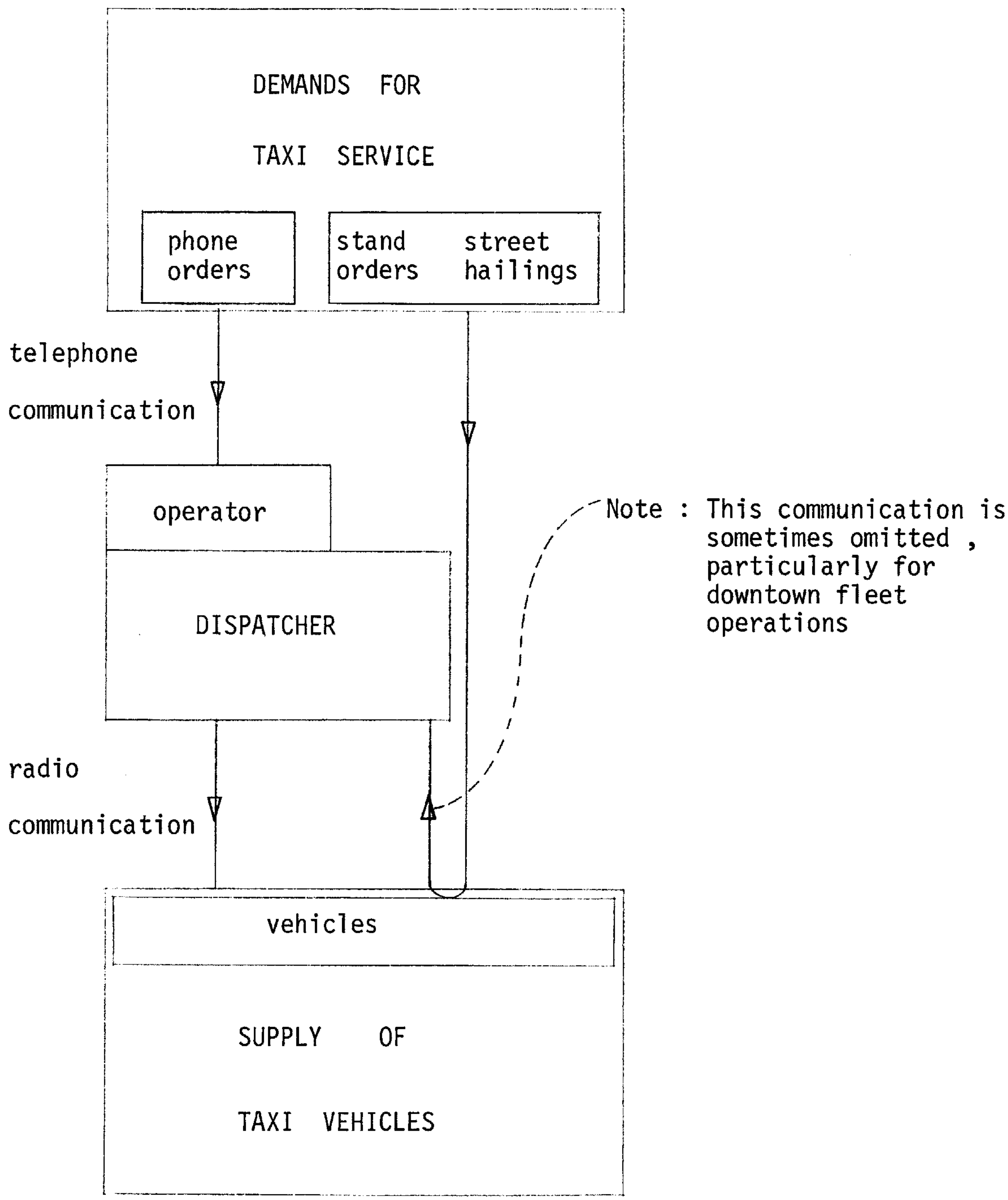


FIGURE 3.1 : THE DISPATCHING FUNCTION AS AN INTERFACE BETWEEN TAXI DEMAND AND SUPPLY

cabs and congestion conditions. Dispatchers sometimes ask operators for more details about a particular phone order if it appears an error was made or the cab driver cannot locate the party he is to pick up.

One particularly successful technique for the small taxi company is to have one person simultaneously handle the jobs of the operator and the dispatcher. A single dispatcher-operator can handle fleets of up to 25 vehicles with a high standard of efficiency. The dispatcher-operator at Belmont Cab, Belmont Massachusetts handles as many as 60 taxi trips/hr (about 35 phone orders/hr) with a fleet of up to 25 cabs.

Large fleets and associations having more than about 25 cabs will use 1 or more dispatchers and 2 or more operators. The ratio of operators to dispatchers usually ranges from 2 to 3 operators per dispatcher.

Turning now to the dispatcher's task of making the best possible use of the fleet to service incoming orders, the next section looks at alternative strategies for the dispatcher.

3.2 Taxi Dispatching Strategies

The dispatching strategies are the rules which form the basis for all decisions made by the dispatcher. Dispatching strategies consist of the following:

(1) Vehicle Selection Criteria

How should a vehicle be selected to handle a particular service request?

and (2) Idle Time Strategy

Where do taxis proceed as soon as they drop off a passenger?

Vehicle Selection Criteria

Three criteria can be identified for choosing the "best" vehicle to service a particular demand. These criteria are arranged in order of increasing complexity from the point of view of data requirements. But each successive criterion promises the fleet operator a higher percent paid mile performance than the previous one.

SELECTION CRITERION #1: Select the Closest of the Currently Available Cabs

By "closest" is meant the cab with the least travel time to the caller. This criterion is a very simple one to implement because most cab drivers are required to report their location as soon as they become free. Pickup times can be predicted quite reliably. But this criterion is not the most efficient one for either minimizing passenger pickup times or for minimizing fleet dead miles.

SELECTION CRITERION #2: Select the Cab that will be Able to Pick Up the Caller Sooner than Any Other Cab

This criterion is more efficient than the first because there may be occupied cabs close to the caller that will become free in time and be able to make the pickup sooner than the cab selected by Criterion #1. The second criterion not only results in better pickup times but also reduces dead mileage. But in order to apply Criterion #2 it is necessary to know the locations and the occupancy status of all cabs and be able to predict when occupied cabs will become free. Note that no criterion can improve on Criterion #2 for providing the taxi user with the best possible pickup service.

SELECTION CRITERION #3: Select the Cab that will Meet an Acceptable Standard for Pickup Time but Minimize the Expected Dead Mileage, by Taking into Account the Probable Future Demand Distribution

This criterion puts the interest of the fleet operator foremost but ensures that the customer will be given an adequate level of service. It improves on Criterion #2 whenever there are several cabs, all meeting a specified level of service standard for picking up a passenger. Application of the criterion will select the cab which results in the minimization of expected dead mileage for the system. The expected future demand distribution is used to determine the expected dead mileage. Criterion #3 makes the best use of the information available to the dispatcher, but may be difficult to apply.

Note that the use of each of these criteria will always result in a choice among several of the closest cabs to the caller. In a large number of cases, criteria 1 through 3 will select exactly the same cab. In other cases, a different cab will be selected but the advantage will be slight. In the few remaining cases, a significant reduction in dead mileage will result.

The economic improvement to be gained in passing from one criterion to the next must be weighed against the extra cost of data acquisition and manipulation which the more complex criteria entail. In many situations the very simplest criteria will be the most cost-effective.

But the best selection criterion for use by the dispatcher of a particular taxi fleet will depend upon the operating environment of that fleet - the pattern of demand being served and the abilities of the dispatcher. The determination of the best criterion to be used by a cab company can be carried out by performing a computer simulation to see how often one criterion is better than the previous one. The preferred vehicle selection criterion will depend primarily on the taxi company's demand pattern and its trip-end densities.

Illustration of the 3 Selection Criteria

Two examples are sufficient to demonstrate the hierarchy of the 3 criteria. In Figure 3.2, taxis A and C are idle when the request for taxi service comes in. Taxi B is one minute from dropping off its fare. The application of Criterion #1 chooses Taxi A to service the request and the passenger will be picked up in 6 minutes. Criterion #2, however, suggests that the dispatcher should assign Taxi B with pickup occurring in 3 minutes instead of 6 minutes. This decision gets a cab to the customer 3 minutes faster and also eliminates about 1 mile of wasted travel.

In Figure 3.3, Taxi A is located at a cab stand in a busy commercial center and Taxi B is deadheading back to the center after a long trip outside the service area. According to Criterion #2, Taxi A should be selected since it can make the pickup in 4 minutes. But if 5 minutes is a permissible pickup time, then by Criterion #3, the choice of Taxi B will result in a savings of 8 minutes of empty travel or about 2-2/3 dead miles. (With Criterion #2, Taxi A travels empty for 4 minutes and Taxi B travels empty for 9 minutes. But by Criterion #3, Taxi A remains at the commercial area while Taxi B deadheads for 5 minutes.

Criterion #1 Selects Taxi A
Criterion #2 Selects Taxi B

Criterion #2 is Better Than Criterion #1

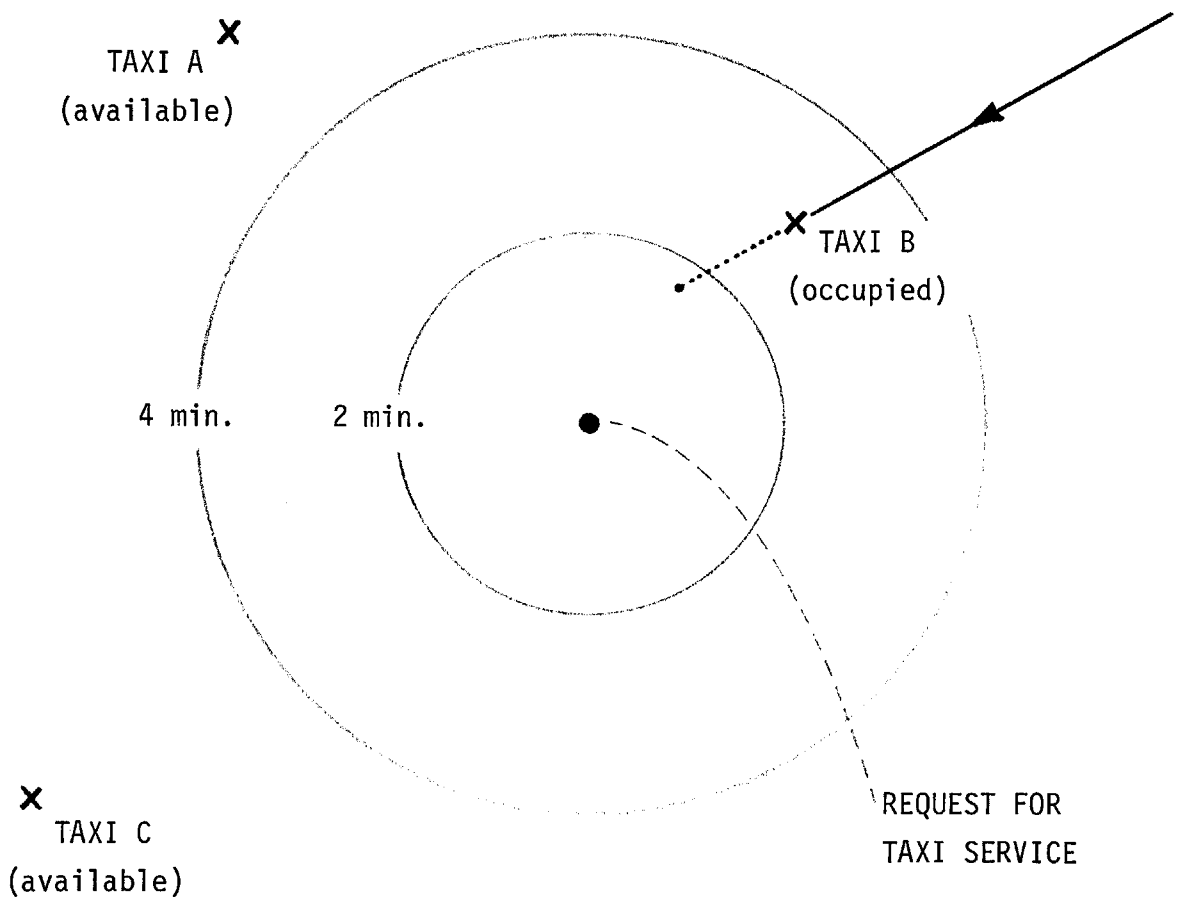


FIGURE 3.2 : SUPERIORITY OF SELECTION CRITERION #2 TO SELECTION CRITERION #1

Criterion #2 Selects Taxi A

Criterion #3 Selects Taxi B

Criterion #3 is Preferred to Criterion #2

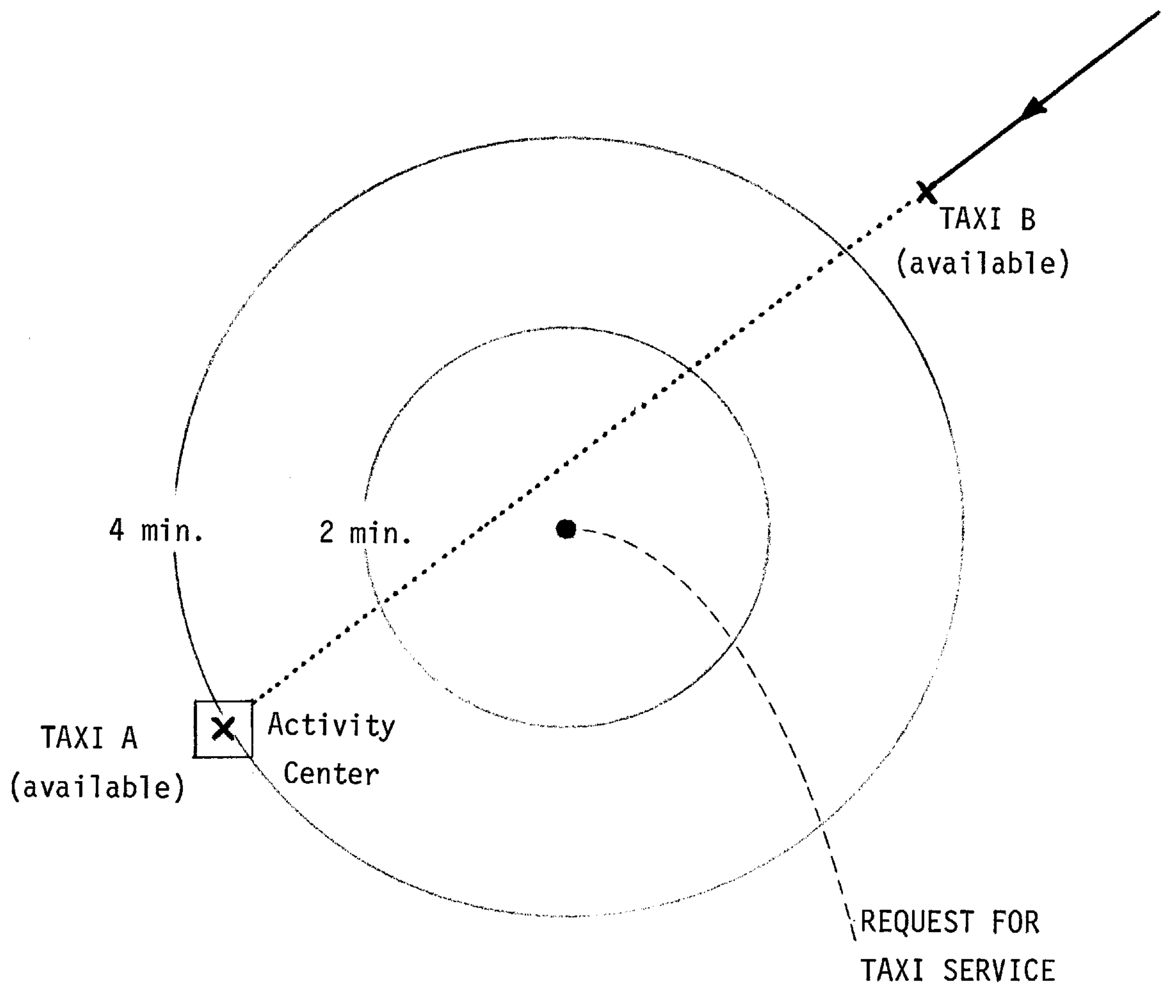


FIGURE 3.3 : SUPERIORITY OF SELECTION CRITERION #3
TO SELECTION CRITERION #2

Criterion #3 therefore saves 8 minutes of empty travel.)

Idle Time Strategy

The idle time strategy is concerned with how idle taxis should be continually redistributed so as to be in the most advantageous position to handle future demands, Many taxi companies have a net outward flow of taxis from the service area. Returning taxis must be directed in real time by the dispatcher and told where they are to proceed, Or the taxis may be given a set of operating procedures which are to be followed unless the dispatcher intervenes.

Most municipalities have regulations stipulating that the only place an idle taxi may park and wait for customers is at a cab stand. Because cruising for passengers tends to waste mileage, taxi drivers are usually required by their company to proceed to a cab stand as soon as they become free. Operating rules are established that specify which stand the cabbie is to drive to when he becomes free.

The two most common strategies which taxi fleets have adopted for choosing the cab stand are:

1) drive to the closest stand

2) drive to the cab stand which has been assigned for the day.

The first strategy minimizes dead mileage but does not automatically redistribute cabs to a configuration that will be most responsive and efficient for handling future demands. The dispatcher must be continually aware of this need for redistribution. (See, for example, the ever-changing demand pattern of the Belmont Cab Company, illustrated in Figures A10 through A19.) The second strategy constantly repositions the fleet into a basic pattern and relieves the dispatcher of the responsibility for redistribution. However, the second strategy results in excessive, needless, deadheading right across the service area. The first strategy is therefore preferred to the second provided the dispatcher is ever-sensitive to vehicle locations and makes the necessary adjustments.

3.3 Taxi Dispatching Systems

The comparison of the dispatching operations of many different taxi companies results in a bewildering array of dispatching systems. Each company seems to have its own adaptation. But on closer examination, however, it will be realized that all taxi dispatching systems fall into one of the following 3 categories: vehicle call, location call or area call.

Vehicle Call System

The vehicle call system is one in which the dispatcher attempts to continuously monitor the positions of all vehicles. Sometimes the dispatcher uses a visual aid to assist him in keeping track of vehicle locations and status. The dispatcher is in complete control of the fleet - whenever the dispatcher loses awareness of a particular cab, he will ask that cab to radio in its location. The vehicle call system is particularly suited to small suburban taxi fleets handling a high proportion of phone orders and having good driver cooperation. The fleet must be small enough so as not to exceed the dispatcher's ability to keep track of the vehicles. A high proportion of phone orders is desireable so that the taxi drivers will be dependent upon the radio for customers and the dispatcher will not always be thwarted, trying to handle phone orders but finding most of the fleet tied up with street work.

Location Call System

The location call system differs from the vehicle call system in that the dispatcher makes no attempt to keep track of every taxi. Taxis radio in their locations whenever they are free. The distinguishing feature of the location call system is that the dispatcher keeps a list in front of him of available cabs and their locations. As phone orders come in, the dispatcher selects the closest available cab from his list (or waits until a cab logs in near the location), gives the pickup instructions to the driver and then crosses that cab's number off the location list. Many variants of this system are used. One common variant is the zone system such as the one employed by Metro Cab of Toronto. The service area is divided into zones, each zone having a number. Whenever a taxi becomes free the driver radios in, giving his cab number and zone number. The dispatchers record the locations of available cabs on a columned pad, each column corresponding to a zone. When a telephone request is received for a cab in zone 5, for example, the dispatcher looks for the top cab on the zone 5 list, and radios pickup instructions to the driver. If no cabs are available in zone 5, the dispatcher looks for an available cab in one of the adjacent zones.

The advantage of the zone system is that it will handle a fleet of any size. If more than one dispatcher is required, responsibility can be divided by having each dispatcher control a group of zones. There is no limit to the size of service area that can be handled by the zone system. The zone system does, however, have one major disadvantage - there is no guarantee that the closest cab will be chosen to service a call. Within any zone there may be other cabs closer to the call than the top man on dispatcher's zone list. Furthermore, there is a very good chance that a cab in an adjacent zone is actually closer to the caller.

All location call dispatching systems have a common weakness - they operate on the basis of available cabs (Selection Criterion #1, instead of Selection Criterion #2 or #3 as previously discussed in section 3.1.)

Area Call System

The area call system is commonly used by large downtown fleets for which phone orders represent a small proportion of the total orders handled. Dispatchers have no idea of the location of individual cabs. When the dispatcher is given a phone order, he calls on the radio for an available cab in the immediate area of the order. If he calls a cab stand, the top cab on the stand automatically gets the order. If no cab is at the stand or if no stand is in the area, the dispatcher will "free call", and any cab driver who feels he is sufficiently close to the area (and wants the order) calls in to the dispatcher, giving his current location. Once he has found a cab for the order, the dispatcher then reads the pickup details over the radio.

Sometimes the dispatcher has difficulty finding available cabs to take the orders (particularly during rush hours, brief rainshowers or snowstorms). Under such conditions the order slips begin to accumulate in front of him and his performance comes to resemble that of an auctioneer. If the dispatcher is unable to find cabs to take the phone orders he will inform the operators who will in turn tell callers that all taxis are currently busy and they will have to call back later. In spite of these measures some phone orders are accepted by large fleets but never serviced.

Comparison of the 3 Dispatching Systems

One of the most significant differences between the 3 systems is the degree of centralized control inherent in each. The vehicle call system is highly centralized. The dispatcher has knowledge of the locations of all cabs. He decides which cab will handle each assignment - he is in complete control (power which many cab drivers resent). The location call and area call systems are more decentralized. Drivers are not obligated to take phone orders from the dispatcher. Under location call, the dispatcher still chooses the driver that each phone order is given to. But under area call the dispatcher has no control over which cab gets a particular assignment. The onus is completely on the driver. One might suspect that many area call drivers frequently ignore the dispatcher's call for cabs even when they are in the best position to handle the phone order. This lack of driver cooperation detracts greatly from fleet efficiency.

According to many company owners, their number one problem is theft. Cab drivers receive a relatively low wage to begin with and if a driver feels he needs more money he will sometimes steal fares from the company. This can be done in at least two ways:

1) picking up a fare without turning on the meter and charging the customer a flat rate for the trip.
2) illegally picking up two or more people going to the same area, charging them each full fare, while declaring only one fare on the waybill.

The theft problem is reduced considerably by tight, centralized control over the drivers. The theft problem is likely to be much less severe with a vehicle call system than with either a location or area call system. A reduction in theft will appear immediately as an apparent increase in productivity.

The particular dispatching method selected for a taxi operation depends very much upon fleet size, percent phone orders and degree of driver cooperation. As the fleet size increases it becomes operationally difficult for the dispatcher to make all the decisions involved in managing the fleet. Decentralized systems are more amenable to large fleet operation and require much less mental gymnastics on the part of the dispatcher. As the percent of street work increases, it becomes less efficient for each cab to radio in all changes in location and status. From the viewpoint of information management the location or area call systems are more tractable for downtown taxi operations. It is very difficult to assess the efficiency penalty involved in operating either a location or area call system rather than a vehicle call system.

3.4 Dispatching Costs

Dispatching accounts for a small proportion of the total cost of operating a taxi fleet. Referring to Appendix B which lists a breakdown of the 1970 taxi operating costs for the nation, it can be seen that the average dispatching cost is 10.4¢ per phone order. Assuming a taxi trip length of 3 miles, and an average ratio of paid miles to total miles of 0.45, the number of miles travelled per phone order is about $\frac{3}{.45} = 6.7$ miles. Therefore the dispatching cost per total mile travelled by each cab is about $\frac{10.4\text{cents}}{6.7\text{ miles}} = 1.55$ cents per mile[1]. The total per mile operating cost for 1970 is recorded as 28.5 cents per mile. Dispatching therefore represents a mere $\frac{1.55}{28.5}$ = 5.5 percent of the total operating cost (approximately).

The dispatching cost includes the following: wages for the dispatchers and operators, cost of direct telephone lines, and the depreciation and maintencance costs for the radio transmitter, antenna and mobile transceiver units in each cab. Wages make up about 80 percent of the dispatching costs.

Although the cost of dispatching is relatively low (i.e. 5 or 6 percent of the total operating cost) dispatching has a multiplier effect on costs since the dispatcher has a large influence over cab mileage. (Every unnecessary cab mile costs the company owner between 5 and 8 cents per mile. The cost of these wasted miles cuts heavily into company profits.)

3.5 The Value of Dispatching Improvements

Dispatching improvements effect an increase in profit and may simultaneously upgrade the responsiveness of the fleet to phone orders. (Or, dispatching improvements may allow the fleet operator to reduce the size of his fleet while maintaining the same phone order level of service.)

In the last section, it was pointed out that the average taxi trip is about 3 miles in length with an accompanying deadheading trip of about 3.7 miles. Using the operating cost figures from Appendix B, the total cost of the trip cycle is 6.7 miles x 28.5 cents per mile = \$1.91. The revenue collected is 6.7 miles x 31.4 cents per mile = \$2.10.

Suppose, now, that a dispatching improvement results in a 10 percent reduction in dead miles travelled - a saving of 0.4 miles. From Table 3.1, the value of each dead miles saved varies from 4.9 cents per mile to 8.2

TABLE 3.1 : UNIT COST OF DEAD MILEAGE

variable costs	Gasoline	2.34	
	Tires	.30	
	Labor Cost	1.18	
	Parts Cost	1.04	
		4.86	cents per mile
fixed costs	Insurance	1.67	
	Depreciation	1.66	
		3.33	cents per mile
	Total Cost	8.19	cents per mile

Note: Fixed cost savings result only if the fleet is reduced in size. Therefore, dead mile reductions achieve savings of 4.86 cents per mile or more depending upon accompanying reductions in fleet size.

SOURCE: Appendix B

cents per mile. Using the conservative lower estimate, a 10 percent reduction in dead mileage saves about 2 cents per taxi trip or about $12.50 per day for a fleet of 25 taxis, each handling 25 trips per day.

Looking at it another way, a 10 percent reduction in dead mileage results in an increase in profit of about 10 percent. Company owners are therefore strongly motivated to establish and maintain high levels of dispatching efficiency.

3.6 Summary

This chapter has examined the dispatching process in depth. The dispatching function lies at the very heart of taxi operations and provides a centralized control and communications system for the fleet. The actions of the dispatcher determine the service levels experienced by the passenger, the utilization of each vehicle of the fleet and ultimately the profitability of the company.

The dispatcher has two important types of decisions to make:

1) the selection of vehicles to handle the incoming requests
2) the redistribution of idle vehicles to handle future demands in the best possible way.

It is the vehicle selection process which is the more critical of the two.

Three vehicle selection criteria, all variants of selecting the closest taxi to the caller, were presented and compared. It was found that the more exacting of these criteria also require more complex information inputs and are therefore more expensive to apply. For each dispatching application it is necessary to trade off the higher cost of applying a better selection criterion with the economic benefit resulting from less wasted vehicle mileage.

The strategy for redistributing idle taxis is built into the operating rules that tell the taxi driver which cab stand he must proceed to when he becomes idle. But dispatchers often intervene to effect a redistribution of taxis to points of greatest need.

Three categories of taxi dispatching systems have been identified - vehicle call, location call and area call. The vehicle call system has the greatest potential for efficiency because it centralizes knowledge of vehicle locations and status with the dispatcher who then makes the necessary allocations. Under the location call and particularly the area call systems, however, the dispatcher has only partial knowledge of the fleet - individual drivers are free to travel where they want without the dispatcher's knowledge. The drivers can give their location only when they wish to receive a phone order.

In spite of the desireability of the vehicle call dispatching system from an efficiency point-of-view, the vehicle call system is not practical for large (i.e. more than 25 vehicles) manually-dispatched fleets which service a low percentage of phone orders. The less efficient location or area call systems must then be used. Advanced electronic technology, however, can be employed to convert a location or area call system to operate more effectively on a vehicle call basis (more details will be given in Chapter 5.).

The cost of dispatching represents a mere 5 or 6 percent of the total fleet operating costs, but the dispatching system exerts control over a much larger share of the operating costs. It is estimated that a 10 percent reduction in dead mileage brought about through better dispatching may boost profit levels by as much as 10 percent.

In the next chapter, some performance models of taxi fleet operation will be presented. These models suggest that there is a significant margin for improvement over the efficiencies of today's manual dispatching systems.

Notes on Chapter 3

1. Mr. Ned McCarty of Brookline Red Cab (about 100 vehicles) reported that during the month of January 1972 the total cost of dispatching was $4,870. Total mileage travelled was 326,600 miles. The dispatching cost per cab mile travelled was therefore 1.5¢ per mile.

CHAPTER 4 THE PERFORMANCE OF A TAXI FLEET

This chapter examines the variables and relationships involved in the performance of a taxi fleet (assuming no ride-sharing) and a number of analytic models of taxi fleet performance are developed. These models are of value on at least three accounts:

(1) they give us a basis for comparing the performance of taxi fleets with that of other transportation systems such as Dial-a-Ride (or shared taxi) and fixed route transit service. The performance models can be used by transportation planners to determine the cost of a taxi system relative to other modes;

(2) the models demonstrate a number of important tradeoffs between fleet size, vehicle productivity and passenger waiting times. In developing these models emphasis was placed on the search for these tradeoffs rather than on trying to produce a detailed micro-model of taxi operations;

(3) the models suggest performance limits which cannot physically be exceeded by a given fleet. This knowledge is useful particularly in trying to evaluate the relative efficiency of today's manual dispatching operations.

The first section of the chapter suggests that for analysis purposes, all taxi demand patterns may be broken down into a number of elemental patterns. Fleet performance models are then developed in sections 4.3 to 4.5 for each of these basic demand patterns and then they are compared in section 4.6. Some important results regarding the effects of scale on fleet performance are pointed out. Near the end of the chapter comparisons are made between the potential productivities of taxi and Dial-a-Ride fleets and major differences in the hourly operating costs of the two systems are noted. Finally section 4.10 presents a summary of the major findings of the chapter.

4.1 The Basic Taxi Demand Patterns

The elemental patterns which can be combined to simulate the demand pattern for any demand-responsive transportation system are the many-to-many, many-to-one, and one-to-one configurations as shown in Figure 4.1. Each configuration requires a unique type of taxi operation to service that pattern.

An important parameter in the many-to-one and one-to-one patterns is the degree of symmetry in the flow. A pattern can have an asymmetric flow in terms of a net flow along an axis or a net flow radially inwards or radially outwards.

The combinations of these patterns and degrees of symmetry that are encountered in real taxi systems can best be appreciated by looking at Figures A10 through A19 in Appendix A. These figures show the spatial arrangement of all trips served by the Belmont Cab Company during one day of operation.

A series of analytical models will be developed later in the chapter, one for each demand pattern shown in Figure 4.1. Each of these models gives the upper limits of fleet productivity, utilization, percent paid miles, and passenger Level of Service that may be achieved while operating in a particular demand environment.

All of these models draw heavily on queuing theory. A brief summary of the major concepts in queuing theory and some of its relationships are

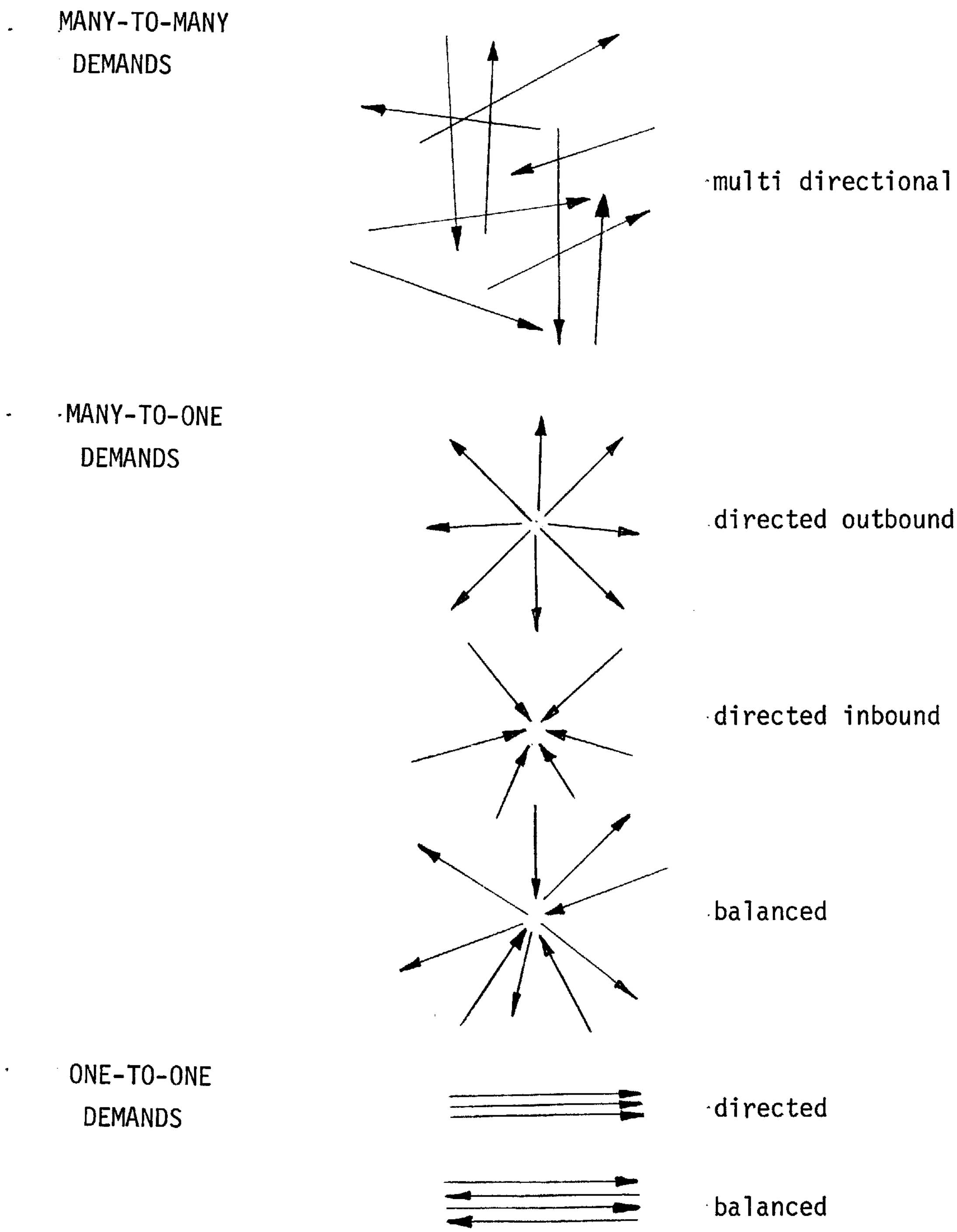


FIGURE 4.1 : THE BASIC TAXI DEMAND PATTERNS

therefore presented in the next section.

4.2 The Estimation of Queuing Delays

Queuing theory is very useful for predicting the delays which will be experienced by users of taxi systems. Figure 4.2 illustrates the single server queuing process which can be used, for example, to simulate the serving of passengers arriving at a terminal and being taken one at a time by a taxi to many different destinations. Passengers arrive at rate λ per hour and are served at rate μ per hour by the taxi. In this model, passengers are transported on a first come, first served basis. (Note that the taxi service rate depends upon the trip length, trip speed, time taken to load or discharge passengers and the amount of deadheading required for the taxi to get to the next customer.)

Figure 4.3 shows the same terminal being servied by S taxis. The total average service rate is now μS passengers per hour. A fleet of many taxis offers superior service to that provided by a single taxi. For example. if $\lambda = 8$ passengers per hour, and service is provided by a single taxi having $\mu = 12$ passengers per hour, then the average queuing delay experienced by passengers is 10 minutes. If the arrival rate doubles ($\lambda = 16$) and two taxis are put into service, each with $\mu = 12$, the average delay is reduced from 10 minutes to 3.9 minutes. (These results follow from the application of equation 4.2 and 4.3 to be presented later.)

In order to calculate queuing delay, one must know not only the values of λ, μ, and S but also the probability distribution function for the length of time between passenger arrivals, and the probability distribution function for the amount of time the taxis take to serve the passengers. If

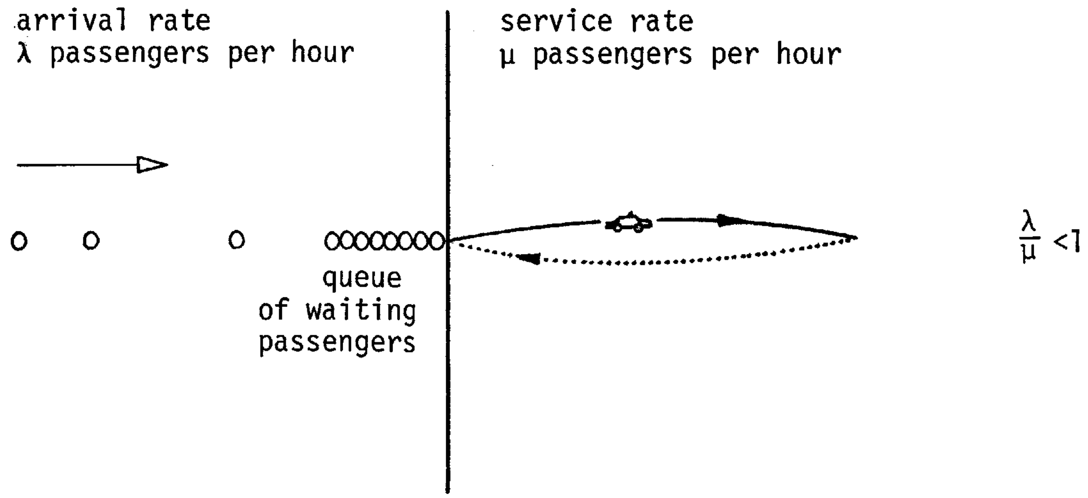


FIGURE 4.2 : REPRESENTATION OF THE SINGLE SERVER QUEUING PROCESS

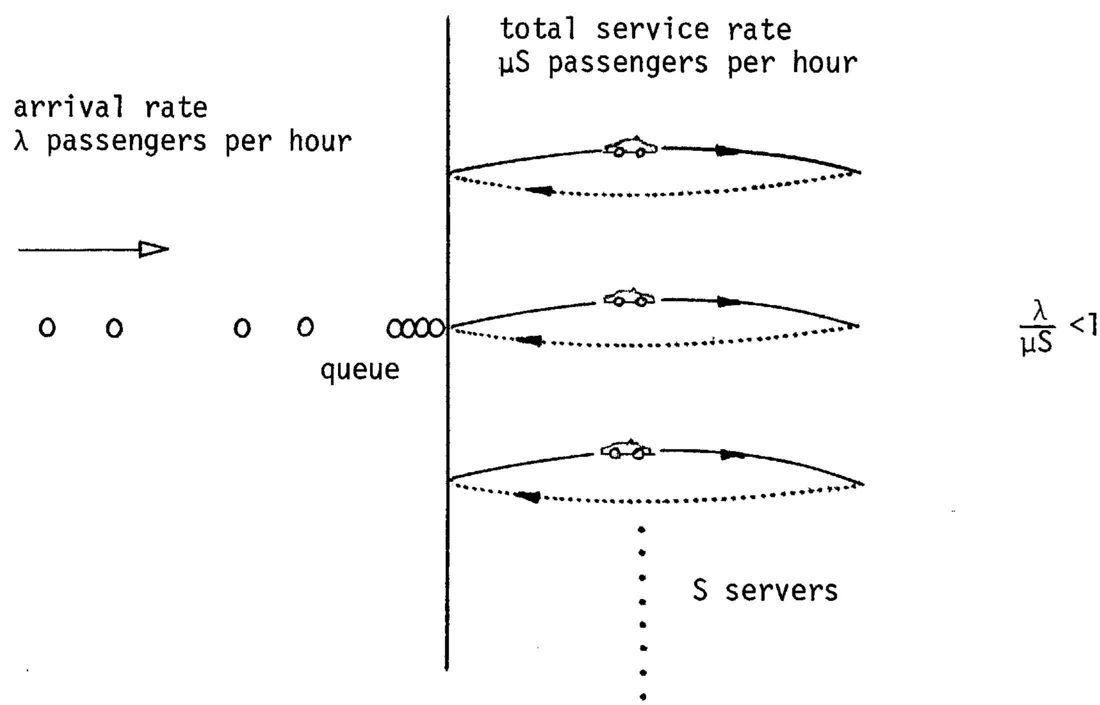


FIGURE 4.3 : REPRESENTATION OF THE MULTIPLE SERVER QUEUING PROCESS

passengers arrive in truly random fashion at an average rate of λ per hour then the probability density function (pdf) for the interarrival times is $\lambda e^{-\lambda t}$. This distribution is illustrated in Figure 4.4.

The exponential nature of this function suggests that short interarrival times are very common while longer times between arrivals are much less frequent. Passengers appear to arrive in bunches rather than spaced out equally in time.

Most of the queuing models developed assume exponential interarrival times in developing the basic queuing formulas but may use either an exponential or a general function for describing the distribution of service times.

Delay for a Single Server Queue

The average amount of time a passenger spends waiting in a queue for service by a single taxi is given by the following formula:[1]

$$\text{Average Time in Queue} = \frac{\lambda}{60\mu^2}\left[\frac{\mu^2 V+1}{2(1-\rho)}\right] \text{ minutes} \quad (4.1)$$

$$= \frac{\lambda M_2}{120\,(1-\rho)} \text{ minutes} \quad (4.2)$$

where λ = average arrival rate (passengers per hour)

μ = average service rate (passengers per hour)

$\rho = \frac{\lambda}{\mu}$

V = variance of the service time distribution (min^2)

M_2 = second moment of the service time distribution (min^2)

($M_2 = V + \text{mean}^2$)

The above formula assumes random arrivals and is known as one of the Pollaczek-Khintchine formulas. Notice that the average waiting time

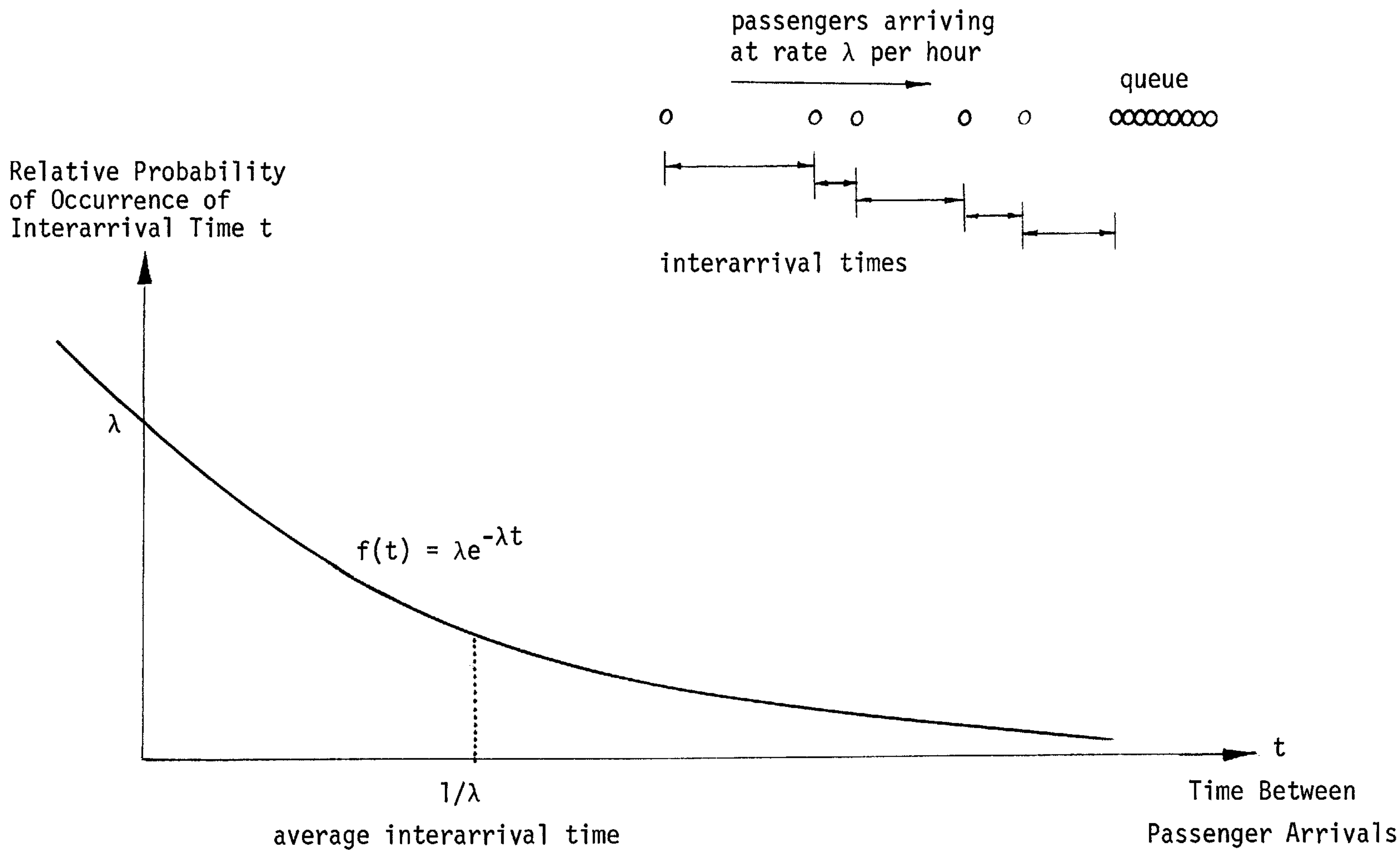


FIGURE 4.4 : PROBABILITY DENSITY FUNCTION FOR RANDOM ARRIVALS AT RATE λ PER HOUR

increases in direct proportion with increases in the arrival rate and with increases in the second moment of the service time distribution. Notice also that as the ratio of arrival rate to service rate (ρ) approaches 1 (indicating that taxis are no longer servicing passengers much faster than they arrive) the denominator of the expression becomes very small and therefore the average waiting times becomes very large.

For any given probability density function describing the service time distribution, the second moment or variance can be readily derived using the techniques shown in Appendix C. For example, the variance of the exponential service time distribution, $\mu e^{-\mu t}$ in the range (o. ∞) is $\frac{1}{\mu^2}$.

Delay for a Multiple Server Queue

The derivation of the delay equation for the multiple server queue is considerably more difficult than for the single server queue. A derivation assuming an exponential interarrival time density $\lambda e^{-\lambda t}$ and an exponential service time density $\mu e^{-\mu t}$ and S servers is given in Wagner[2]:

$$\text{Average Time in Queue} = 60\ \frac{p(\text{all servers busy})}{\mu S-\lambda}\ \text{minutes} \qquad (4.3)$$

where λ = average arrival rate (passengers per hour)

μ = average service rate (passengers per hour)

S = number of taxis

(all servers busy)

p = probability that all servers are busy

$$= \frac{\rho^S}{S!(1-\frac{\rho}{S})} \cdot \frac{1}{\left[\sum_{j=0}^{S-1} \frac{\rho^j}{j!} + \frac{\rho^S}{S!(1-\frac{\rho}{S})}\right]} \qquad (4.4)$$

This latter probability function is tabulated in Wagner[3]. The average delay for a multiple server queue behaves in much the same way as the average delay for a single server queue, but as explained earlier, a multiserver queue has much lower delays than the equivalent single server queue.

4.3 Performance Functions for Many-to-Many Taxi Operations

One of the most common forms of taxi transportation involves travel from a random origin in the service area to a random destination creating a many-to-many trip pattern. Queuing theory can be used to simulate many-to-many fleet performance by assuming that each cab operates independently of the other cabs and serves its share of incoming requests.

The single server queuing model is used rather than the multiple server queuing model because each sub-area of the service area is not served simultaneously by all vehicles of the fleet (since the taxis do not always return to the same point). This assumption that single server queuing behavior predominates over multiple server queuing behavior in the many-to-many performance model is a very major assumption and can only be verified conclusively by performing a number of computer simulations (unfortunately not within the scope of this thesis).

The single server queuing model can be readily applied to estimate the delays experienced by passengers while waiting to be picked up. These delays result from:

1) the time which elapses before a nearby cab becomes free, and
2) the time required for the cab to travel from its last drop point to pick up the new passenger.

Once the average pickup delay and the taxi service cycle characteristics are known, the fleet performance can readily be calculated.

Calculation of Average Pickup Delay

Suppose we are given a service area of A square miles to be served by N taxis. The density of incoming demands is D calls per square mile per hour. Taxis are assumed to travel at an average speed of 20 miles per hour in the service area (3 minutes per mile) and the average time required for a taxi trip is $\bar{t}$.

The effective service area handled by each cab is $\frac{A}{N}$ square miles. When the taxi becomes free it may be at any location in that $\frac{A}{N}$ square miles, while the next passenger awaiting pickup will also be randomly located within the area. Assuming a rectangular street grid, the average length of trip required for a taxi to go from its last dropoff to the new pickup is $\frac{2}{3}\sqrt{\frac{A}{N}}$ miles (Manhattan trip length distribution - see Table C1, Appendix C). The corresponding average travel time for the pickup trip is $2\sqrt{\frac{A}{N}}$ minutes. The average service time per customer is therefore $\bar{t} + 2\sqrt{\frac{A}{N}}$ minutes. Assuming a Manhattan distribution of service times, the second moment M_2 of the service time distribution is $\frac{5}{4}(\bar{t} + 2\sqrt{\frac{A}{N}})^2 \text{ min}^2$. The taxi service rate is simply the reciprocal of the service time, or:

$$\text{service rate per cab} \quad \mu = \frac{1}{\bar{t} + 2\sqrt{\frac{A}{N}}} \quad \frac{\text{passengers}}{\text{minute}} \tag{4.5}$$

The only information yet required to apply the single server queuing delay formula is the arrival rate experienced by each cab. But this is equal to the total arrival rate DA for the service area divided by the number of taxis, N, i.e.

$$\text{arrival rate per cab} = \frac{DA}{N} \ \frac{\text{passengers}}{\text{hour}} \tag{4.6}$$

$$= \frac{DA}{60N} \ \frac{\text{passengers}}{\text{minute}} \tag{4.7}$$

Substituting the above information into equation 4.2 which expresses the queuing delay for a single server queue we obtain:

$$\text{Average Time Spent Waiting for a Taxi to Become Free} = \frac{\lambda M_2}{120(1-\rho)} \text{ minutes}$$

$$= \frac{\frac{DA}{N} \times \frac{5}{4} (\bar{t} + 2\sqrt{\frac{A}{N}})^2}{120[1 - \frac{DA}{N} \times (\bar{t} + 2\sqrt{\frac{A}{N}})]} \text{ minutes}$$

$$= \frac{5}{8} \frac{(\bar{t} + 2\sqrt{\frac{A}{N}})^2}{(\frac{60N}{DA} - \bar{t} - 2\sqrt{\frac{A}{N}})} \quad \text{minutes} \qquad (4.8)$$

<u>Sample Calculation</u>

$$D = 4 \frac{\text{demands}}{\text{sq.mile hour}}$$

$$\frac{N}{A} = 2 \frac{\text{cabs}}{\text{sq. mile}}$$

$$\bar{t} = 7.5 \text{ minutes}$$

From equation 4.8, the average time a passenger spends waiting for a taxi to become free is: $\frac{5}{8} \frac{(7.5 + \sqrt{2})^2}{30 - 7.5 - \sqrt{2}}$ minutes

$$= 2.35 \text{ minutes}$$

To this figure must be added the average time for the taxi to drive to pick up the passenger, namely $2\sqrt{\frac{A}{N}} = 1.41$ minutes. The total average delay experienced by the customers is therefore 2.35 + 1.41 = 3.8 minutes.

Using equation 4.8, the delay curves for demand densities of up to 16 demands per square mile per hour, up to 5 cabs per square mile and an average taxi trip time of 7.5 minutes are plotted in Figure 4.5.

<u>Fleet Performance Measures</u>

Also shown in Figure 4.5 are the mean level of service experienced by

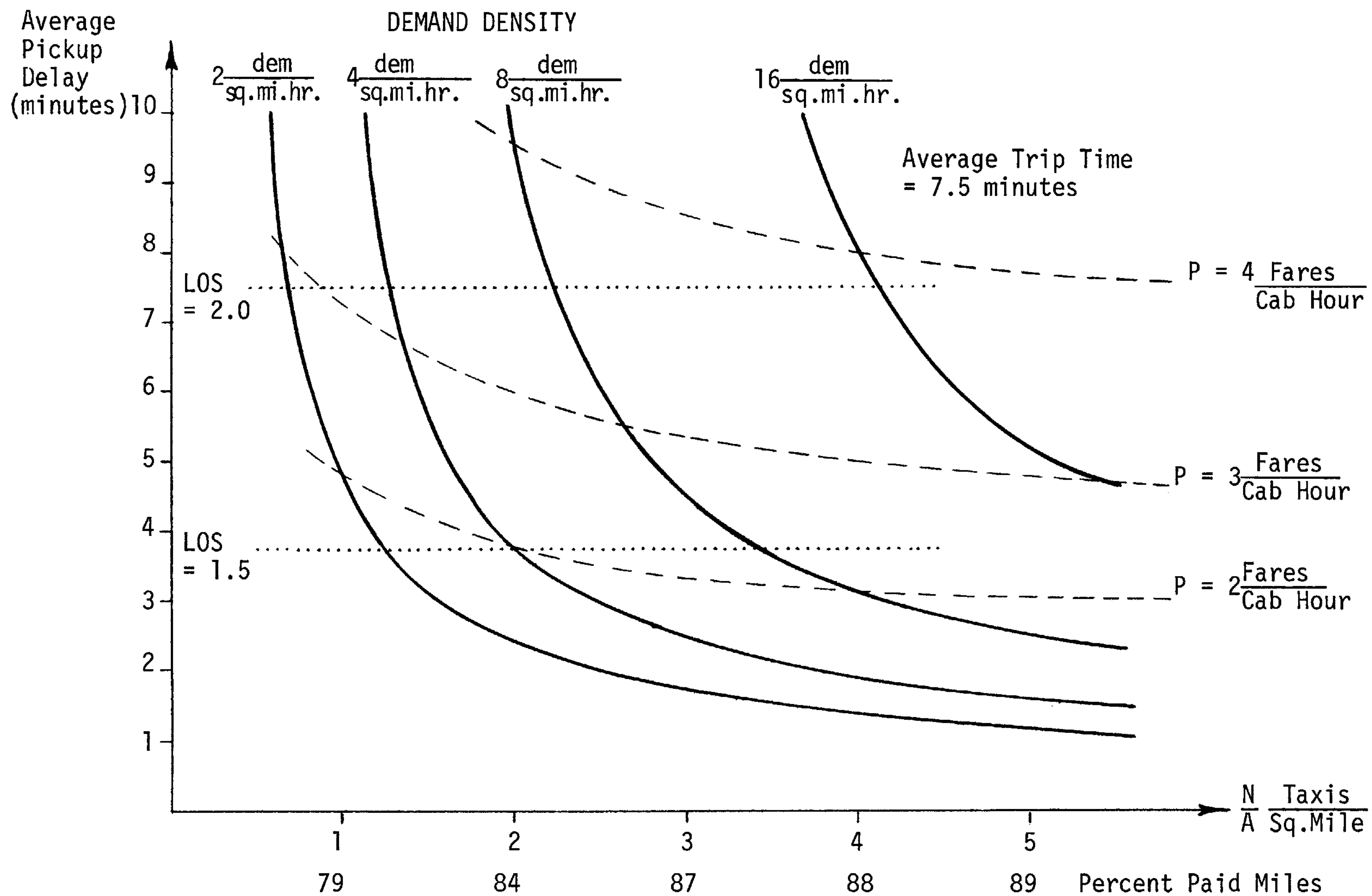


FIGURE 4.5 : QUEUING MODEL OF MANY-TO-MANY TAXI OPERATIONS

the passenger and the productivity of the fleet, both being represented as functions of demand density and of cab density.

The passenger level of service (LOS) is defined as follows[4]:

$$\text{LOS} = \frac{\text{Total Service Time from Request to Arrival at Destination}}{\text{Direct Driving Time (by auto)}}$$

$$= \frac{\text{Wait Time + Travel Time by Taxi}}{\text{Travel Time by Taxi}} \qquad (4.9)$$

The average level of service provided by Belmont Cab (Appendix A) for example, is about $\frac{\text{5.5 mins average wait time + 8.5 mins average travel time}}{\text{8.5 mins average travel time}}$

$= 1.6$

Fleet productivity is identical to the arrival rate per cab and is obtained by dividing the demand density by the cab density:

$$\text{Fleet Productivity} = D \times \left(\frac{A}{N}\right) \frac{\text{fares}}{\text{cab hour}} \qquad (4.10)$$

The production function for a taxi fleet is represented by the lines of constant productivity. Given a service area of size A having a demand density of D these lines show what average productivities may be achieved by a fleet of N vehicles. Like all production function curves, however, they show only the maximum achievable productivities. If, for example, the fleet vehicles accumulate dead mileage excessively, the productivities indicated by the production function may no longer be achieved.

The percent paid miles achieved by the fleet is purely a function of the cab density but is affected indirectly by the demand density. This follows because the model assumes that the only deadheading done by the taxi covers the $\frac{2}{3}\sqrt{\frac{A}{N}}$ miles that are required on the average to go from the dropoff point of one customer to the pickup point of the next customer. Theoretical values of percent paid miles are given along the cab density axis in

Figure 4.5. Notice that the percent paid miles increases with fleet density but at a marginally decreasing rate.

Ability of the Many-to-Many Queuing Model to Predict the Performance of a Real Taxi Fleet

By using the fleet performance data collected during the survey of the Belmont Cab Company (Appendix A) it is possible to get an idea of the predictive accuracy of the queuing model just developed (equation 4.8). From Appendix A we obtain the following average operating characteristics for the Belmont Cab Company:

Effective Service Area $A = 5$ sq. miles (Figure A9)

Average Demand Density $D = 4.1 \frac{\text{demands}}{\text{sq.mile hour}}$ (Figure A9)

Average Vehicle Density $\frac{N}{A} = \frac{9}{5} = 1.8 \frac{\text{cabs}}{\text{sq.mile}}$ (Figures A24, A9)

Average Trip Time $\bar{t} = 8.1$ minutes (Figure A23)

Applying equation 4.8 we obtain:

Average time spent waiting for a taxi to become free

$$= \frac{5}{8} \frac{(8.1 + 1.49)^2}{(26.4 - 8.1 - 1.49)}$$

$$= 3.4 \text{ minutes}$$

Average time for a taxi to drive to pick up a passenger

$$= \frac{2}{\sqrt{1.8}}$$

$$= 1.5 \text{ minutes}$$

Total delay = 3.4 + 1.5 = 4.9 minutes

The average observed delay during the survey was in fact 5.5 minutes. One might have expected that the queuing model would underestimate the observed delay simply because the model assumes a perfectly efficient taxi operation.

Although the model appears to be able to predict pickup delays quite well, a significant discrepancy is observed between the percentage of paid miles predicted by the model (80 to 90 percent) and the percentage of paid miles being achieved by real taxi fleets (40 to 50 percent). This discrepancy arises for at least two reasons:

(1) The queuing model assumes that a cab will always remain at its last dropoff point until a new service request is made, It does not make allowances for empty travel to cab stands and any other travel that is not directly associated with picking up a passenger. This factor contributes greatly to the apparent discrepancy.

(2) The queuing model assumes that the fleet and the service requests are both of uniform distribution. In reality, however, the density of taxis and of demands is non-uniform at any point in time, due to a phenomenon associated with randomness. The model therefore assumes that the taxis are closer to their pickups than they are in reality.

Implications of the Model

The graphs presented in Figure 4.5 are useful for demonstrating a number of important tradeoffs involved in many-to-many taxi operations. Given a fleet operating at a particular demand density (D = 4, for example) the operator can look at figure 4.5 and determine the effect of changing the size of his fleet. The effects of increasing the fleet size include the following:

1) Level of Service is Improved

Passenger wait time is reduced because there are more vehicles serving the same number of passengers. A free cab will be available sooner, and on the average it will not have to deadhead as far to pick up the new passenger.

2) Operating Costs are Reduced

With the increase in percent paid miles which accompanies fleet expansion the operator will encounter fewer dead miles and therefore have lower operating costs.

3) Fixed Costs are Increased

The operator must make a larger capital investment in cabs and larger annual outlays for insurance, depreciation and licenses.

4) Fleet Productivity is Reduced

This will be a sensitive issue with commissioned drivers. If, for example, the productivity is halved a driver's pay for working one shift will similarly be halved.

Additional effects of fleet expansion, not directly related to the queuing model but worthy of note are:

5) Competitive Edge is Improved

If the operator is competing with other taxi companies in the service area it may be to his advantage to use an excess of cabs.

6) Dispatching Complexity Increases

The dispatcher may not be able to handle a larger fleet as efficiently. The theoretical improvement in percent paid miles may therefore not be fully realized.

The model clearly shows the relative advantage of high density taxi operations over low density operations. For a fixed level of service and fixed average trip length, operation in a lower demand density environment results in both a lower percentage of paid miles and lower achievable productivities. (See Figure 4.5.) This result tends to justify the suburban operator in seeking a higher level fare structure than the city operator since the operating cost per fare is higher for the suburban operator than for the city operator.

The Potential for Shared Dispatching Services

The queuing model can also be used to illustrate the advantage of offering a shared dispatching service for a number of independent taxi companies operating within the same service area. Suppose 4 companies each experience a demand density of D = 2 demands per square mile per hour and each have a fleet of $\frac{N}{A} = 1$ cab per square mile of service area. By consolidating their dispatching operations the new fleet of $\frac{N}{A} = 4$ cabs per square mile experiences a net demand density of D = 8 demands per square mile per hour. The resulting changes in passenger wait times, passenger LOS and the percent paid miles are shown in Table 4.1. Passenger wait times are reduced by about 1/3 from an average of 4.8 minutes to an average of 3.1 minutes, LOS is consequently improved from 1.64 to 1.41. Furthermore, the ultimate achievable percent paid miles of each fleet is boosted from 79 percent for independent dispatching to 88 percent for shared dispatching. Vehicle productivity remains unchanged so that drivers need not be concerned about lower waybills. Cooperative dispatching services clearly have great potential for improving the efficiency of taxi operations from the viewpoint of both the passenger and the fleet owner.

4.4 Performance Functions for Many-to-One Taxi Operations

Three configurations of many-to-one taxi operations are examined in

TABLE 4.1 : ILLUSTRATION OF THE ADVANTAGE OF A SHARED DISPATCHING SERVICE FOR FLEETS OPERATING IN THE SAME SERVICE AREA (MANY-TO-MANY DEMANDS)

	Before	After
Number of Independently-Dispatched Fleets	4	1
Total Demand Density	8 demands/sq.mile/hour	8 demands/sq.mile/hour
Demand Density Experienced by each Fleet	2 demands/sq.mile/hour	8 demands/sq.mile/hour
Effective Vehicle Density	1 cab /sq.mile	4 cabs/sq.mile
Time Passenger Waits for Cab to Become Free	2.8 min.	2.1 min.
Time Passenger Waits for Cab to Deadhead to him	2.0 min.	1.0 min.
Total Passenger Wait Time	4.8 min.	3.1 min.
Passenger Travel Time in Taxi	7.5 min.	7.5 min.
LOS	1.6	1.4
PERCENT PAID MILES	79 percent paid miles	88 percent paid miles
Vehicle Productivity	2 fares per cab hour	2 fares per cab hour

SOURCE: Figure 4.5

this section:

Configuration (1): Travel radially outbound from a central terminal to random destinations in a square service area

Configuration (2): Travel radially inbound to a central terminal from random origins throughout the square service area

Configuration (3): Balanced travel radially inbound and outbound between the terminal and randomly-located points in the service area.

Configurations (1) and (2) involve one-way deadheading by the taxi fleet. In configuration (3), however, efficiencies of greater than 50 percent paid miles are easily achieved. In fact, it will be demonstrated that fleets operate more efficiently in a balanced many-to-one environment than they do in a many-to-many environment.

In order to be able to compare the fleet performance for the many-to-one demands with the fleet performance for many-to-many demands, a standard trip time of 7.5 minutes and travel speed of 20 mph were selected to provide a common basis for modelling the systems.

If we assume once again a rectangular street grid, the dimensions of the square must be 5 miles by 5 miles in order to have an average trip time of 7.5 minutes (trip length of 2.5 miles) as measured from the center of the square. The trip time distribution is triangular (see Appendix C) and trips range from 0 minutes to 15 minutes in duration.

<u>Configuration (1): Radially Outbound Travel</u>

Service is provided from the taxi terminal at the center of the square. Passengers are handled on a first come, first served basis so that effectively a queue of waiting passengers forms at the terminal. Each passenger may be served by any one of the fleet taxis. The multiple server queuing model is therefore well-suited to the simulation of fleet performance in handling the demand pattern of configuration (1).

Calculation of Average Pickup Delay

A total of N taxis serve the 25 square mile area A which has demand density D demands per square mile per hour. The total rate of arrival λ of passengers at the terminal is DA. Since the average outbound trip time is 7.5 minutes, the average taxi trip cycle has an average duration of 15 minutes and a service rate μ of 4 fares per hour.

The multi-server queuing delay formula (4.3) assumes random arrivals and exponentially-distributed service times. For configuration (1), however, the arrivals are random but the service times have a triangular distribution. In order to apply formula (4.3) it becomes necessary to assume that multiserver queuing delay is proportional to the second moment of the service time distribution and it can be shown from the formulas that multiserver queuing delay approaches single server queuing delay as S approaches 1. The assumption therefore would seem to be quite justified.)

Using equation (4.3) and applying the second moment correction factor calculated from Table C1:

$$\text{Average Time Spent Waiting for a Taxi} = \frac{M_2(\text{triangular distribution})}{M_2(\text{exponential distribution})} \times 60 \times \frac{p(\text{servers busy})}{(\mu S-\lambda)}$$

$$= \frac{7}{6} M^2 \times \frac{1}{2M^2} \times 60 \times \frac{p(\text{servers busy})}{4N-25D} \text{ minutes} \quad (4.11)$$

where p(servers busy) as given in equation 4.4 is a function of S(=N) and $\rho = \frac{\lambda}{\mu} = \frac{25D}{4}$

Sample Calculation

$$D = 2 \frac{\text{demands}}{\text{sq.mile hour}}$$

N = 15 cabs

p(all servers busy)[for S = 15, ρ=12.5] = .42

From equation 4.11, the average time a passenger waits for a taxi after his arrival at the terminal is:

$$\frac{7}{12} \times 60 \times \frac{.42}{(60-50)} \text{ minutes}$$

$$= 1.47 \text{ minutes}$$

Delay curves were plotted from equation 4.11 and shown in Figure 4.6. With a careful choice of fleet size for a given demand density it is possible to achieve relatively high productivities without sacrificing level of service. The most desirable operation point is within the "knee" of the delay curve. Above this point marginal productivity improvements can be realized only by greatly sacrificing passenger LOS. Below this point productivities decrease very rapidly in return for negligible improvements in LOS. In spite of the high productivities and good LOS achievable with the outward radial demand pattern, the percent paid miles will never exceed 50 percent because deadheading always occurs on the inbound portion of the taxi trip cycle.

Configuration (2): Radially Inbound Travel

In this simulation, passengers travel by taxi from random points throughout the 25 square mile service area to the terminal at the center of this service area. (No travel occurs in the radially outbound direction.) Upon receiving a request for service, the dispatcher sends a taxi to make the pickup. On the average, a taxi will deadhead for 7.5 minutes and

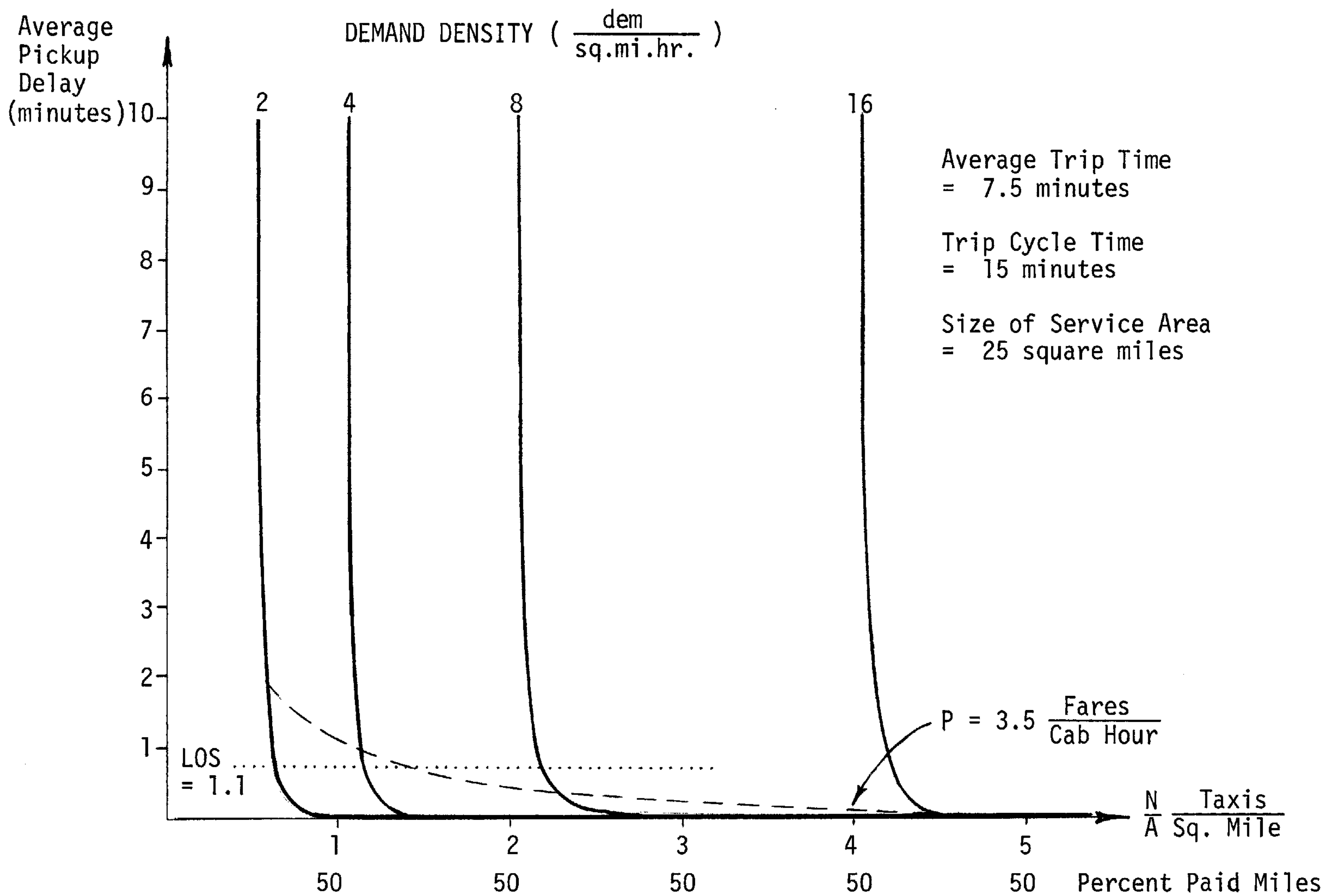


FIGURE 4.6 : QUEUING MODEL OF MANY-TO-ONE TAXI OPERATIONS (TRIPS RADIALLY OUTBOUND ONLY)

cover a distance of 2.5 miles before the pickup is made.

The queuing process for this configuration is identical to that for the model of radially outbound travel. The dispatcher handles the incoming orders on a first come, first served basis and the queue consists of the line-up of written orders in front of the dispatcher. These orders are assigned in turn to the cabs immediately as the cabs become free at the terminal. Since any one of the N cabs may be assigned to a particular phone order, the process is one of multiple server queuing.

As in the previous configuration (outbound trips only) the total rate of arrival of service requests λ is 25D demands per hour and the service rate μ is 4 fares per hour. The average delay curves are similar to those shown in Figure 4.6. They are in fact the same curves but shifted upwards by 7.5 minutes to allow for the outbound deadheading of taxis to make their pickups. This time is experienced by the customer as an additional delay with the result that the achievable LOS will always exceed 2.0 .

However, if the operator wishes to reduce this LOS he can have the dispatcher disperse his cabs as soon as they arrive back at the terminal to put them in a better position to respond to future requests. By dispersing the cabs about 2.5 miles from the terminal, for example, it may be possible to reduce an LOS of 2.1 down to about 1.6. But an increase of unpaid mileage will be caused by this strategy, forcing the percent paid miles from 50 percent to an even lower value.

Configuration (3): Balanced Travel Radially Inbound and Outbound

If the radially inbound travel is balanced by radially outbound travel, then much of the deadheading of configurations (1) and (2) is eliminated. This occurs because cabs with fares inbound to the terminal are each able to pick up a new passenger almost immediately after they arrive at the terminal. The average service cycle, then, consists of a 7.5 minutes inbound trip, a 7.5 minute outbound trip and a deadheading trip of $2\sqrt{\frac{A}{N}}$ minutes. (Once again we take the approach that each cab is responsible for serving $\frac{A}{N}$ square miles of the service area and will require on the average $2\sqrt{\frac{A}{N}}$ minutes to deadhead from his last dropoff point to pick up the new passenger.) The average service time for two fares is therefore $(15+2\sqrt{\frac{A}{N}})$ minutes and the service time distribution is predominantly triangular with second moment $\frac{7}{6}(15 + 2\sqrt{\frac{A}{N}})^2 \text{min}^2$ (From Table C1, Appendix C).

Passengers arriving at the terminal with rate $\lambda = \frac{DA}{2}$ passengers per hour experience multiserver queuing delays, while passengers wishing to be transported inbound to the terminal (arrival rate $= \frac{DA}{2}$) experience single server queuing delays.

Once again we make the very critical assumption of single server queuing rather than multiserver queuing (for the inbound passengers). From equation 4.2, the average delay experience by inbound customers is

$$= \frac{M_2}{2(\frac{1}{\lambda} - \frac{1}{\mu})} \text{ hours}$$

$$= \frac{\frac{7}{6}(15 + 2\sqrt{\frac{A}{N}})^2}{2(\frac{120N}{DA} - 15 - 2\sqrt{\frac{A}{N}})} \text{ minutes}$$

$$= \frac{7}{6} \frac{(7.5 + \sqrt{\frac{A}{N}})^2}{(\frac{60N}{DA} - 7.5 - \sqrt{\frac{A}{N}})} \text{ minutes} \qquad (4.12)$$

Sample Calculation

D = 4 demands per square mile per hour

N = 30 cabs

$$\text{average delay for inbound customers} = \frac{7}{6}\,\frac{\left(7.5 + \sqrt{\frac{25}{30}}\right)^2}{\left(\frac{1800}{100} - 7.5 - \sqrt{\frac{25}{30}}\right)}$$

$$= 8.6 \text{ minutes}$$

For each value of D the average delay experienced by outbound customers was also calculated using the multiserver delay formula 4.3. In all cases the delays experienced by passengers travelling outbound from the terminal were negligible relative to the delays experienced by the inbound passengers. The average passenger delay for the balanced many-to-one system is therefore equal to half the average inbound passenger delay (i.e. half the value indicated by equation 4.12). Figure 4.7 illustrates the average delays, productivities and service levels for a balanced many-to-one fleet operation.

Implications of the Balanced Many-to-One Model

Most of the tradeoffs inherent in the balanced many-to-one model are very similar to those already listed for the many-to-many model. But the efficiencies of balanced many-to-one operation appear to exceed those of many-to-many operation, particularly in terms of percent paid miles. From the example given in Table 4.2, it can be seen that for the same demand density and fleet size, the balanced many-to-one pattern results in both a better service level and a higher percentage of paid miles. In making this comparison it must be realized that the reported service levels for the balanced many-to-many system are an average between the very poor

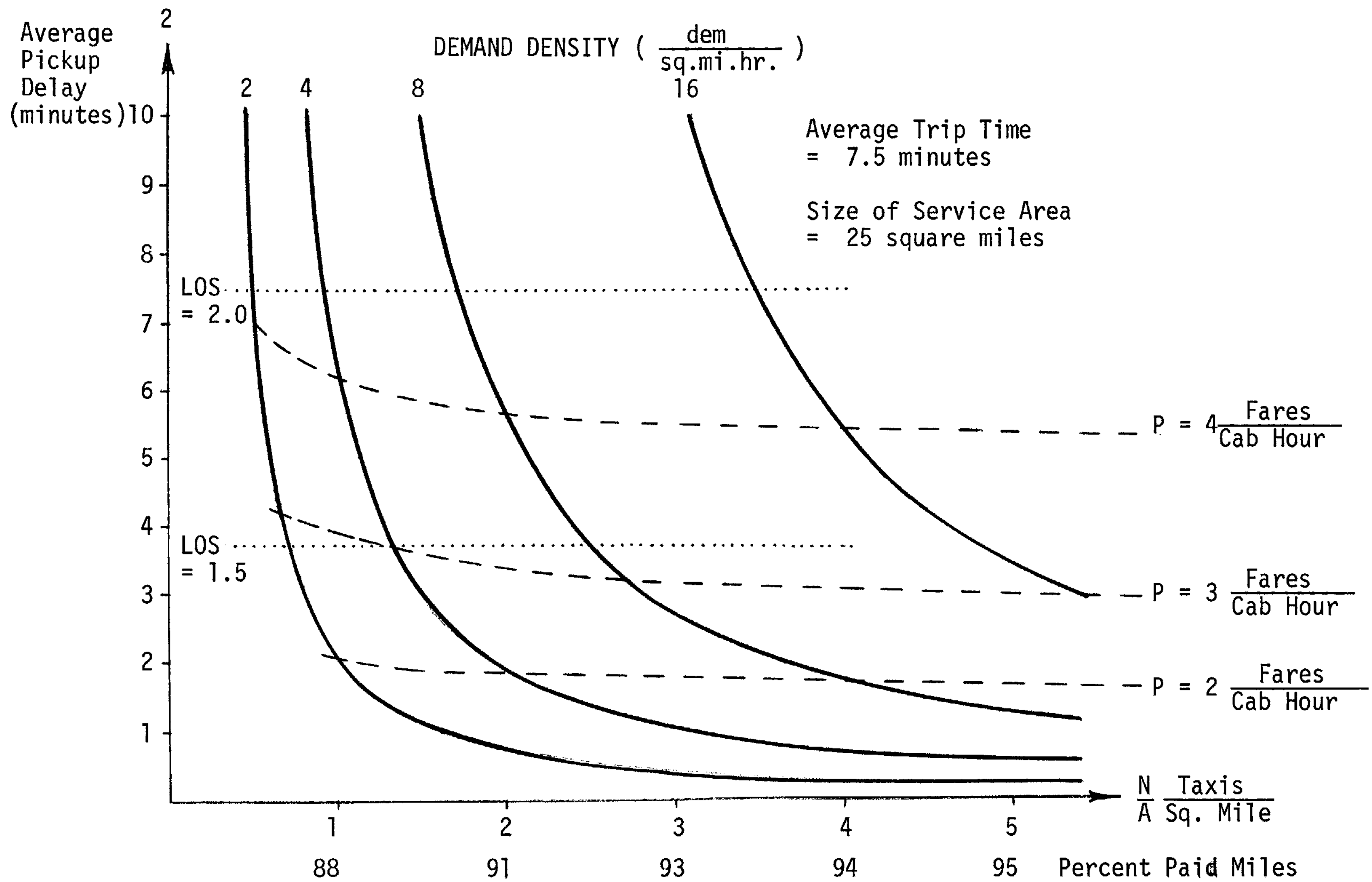


FIGURE 4.7 : QUEUING MODEL OF BALANCED MANY-TO-ONE TAXI OPERATIONS

TABLE 4.2 : COMPARISON OF OPERATING EFFICIENCIES FOR BALANCED MANY-TO-ONE AND MANY-TO-MANY DEMAND PATTERNS

	BALANCED MANY-TO-ONE	MANY-TO-MANY
Demand Density	D = 8 demands/sq.mile/hour	D = 8 demands/sq.mile/hour
Vehicle Density	$\frac{N}{A}$ = 2 cabs/sq.mile	$\frac{N}{A}$ = 2 cabs/sq.mile
Vehicle Productivity	P = 4 fares/cab hour	P = 4 fares/cab hour
Average Pickup Delay	$\bar{d}$ = 5.6 minutes	$\bar{d}$ = 8.1 minutes
Average Travel Time	$\bar{t}$ = 7.5 minutes	$\bar{t}$ = 7.5 minutes
SERVICE LEVEL	LOS = 1.7	LOS = 2.1
PERCENT PAID MILES	91 percent	84 percent

SOURCE: Figures 4.5 and 4.7

service levels for inbound passengers and the excellent service levels for the outbound passengers.

Figure 4.7 also demonstrates the great advantages of operating a shared dispatching service for cab companies experiencing strong, balanced many-to-one demands and operating in the same service area. In this and the other respects pointed out earlier, fleets operating in the many-to-many and balanced many-to-one environments have remarkably similar performance characteristics.

4.5 Performance Functions for One-to-One Taxi Operations

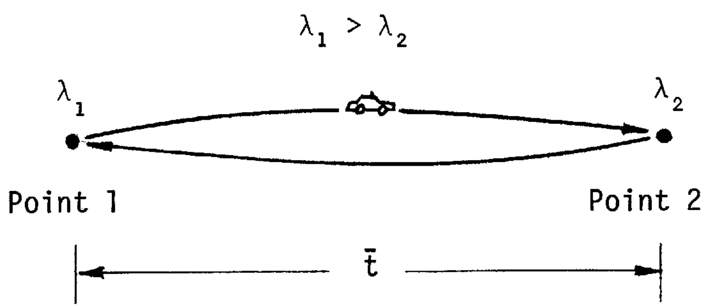
One-to-one operations occur wherever a shuttle service is provided between two activity centers. The most basic type of shuttle service operates with a single taxi. (See Figure 4.8.) Meyer and Wolfe[5] use probability theory to study this system. In particular, they examine the implications of the following three alternative idle time strategies:

STRATEGY 1: A free[6] taxi remains at the point where it became free and deadheads only in response to a service request

STRATEGY 2: A free taxi always deadheads to the busier point (no radio equipment required)

STRATEGY 3: A free taxi always returns to the busier point but may be recalled while deadheading (radio is required)

Meyer and Wolfe[7] show that strategy 3 always produces a lower average passenger wait time than strategy 2. (Note also that strategy 3 always provides better utilization and higher percent paid miles than strategy 2). But the desirability of strategy 3 relative to strategy 1 depends upon the percent utilization[8] of the taxi and r, the relative strength of source



λ_1 = arrival rate at point 1 (passengers per hour)

λ_2 = arrival rate at point 2 (passengers per hour)

λ = total arrival rate for system (passengers per hour)

$= \lambda_1 + \lambda_2$

$\bar{t}$ = average travel time from point 1 to point 2 (hours)

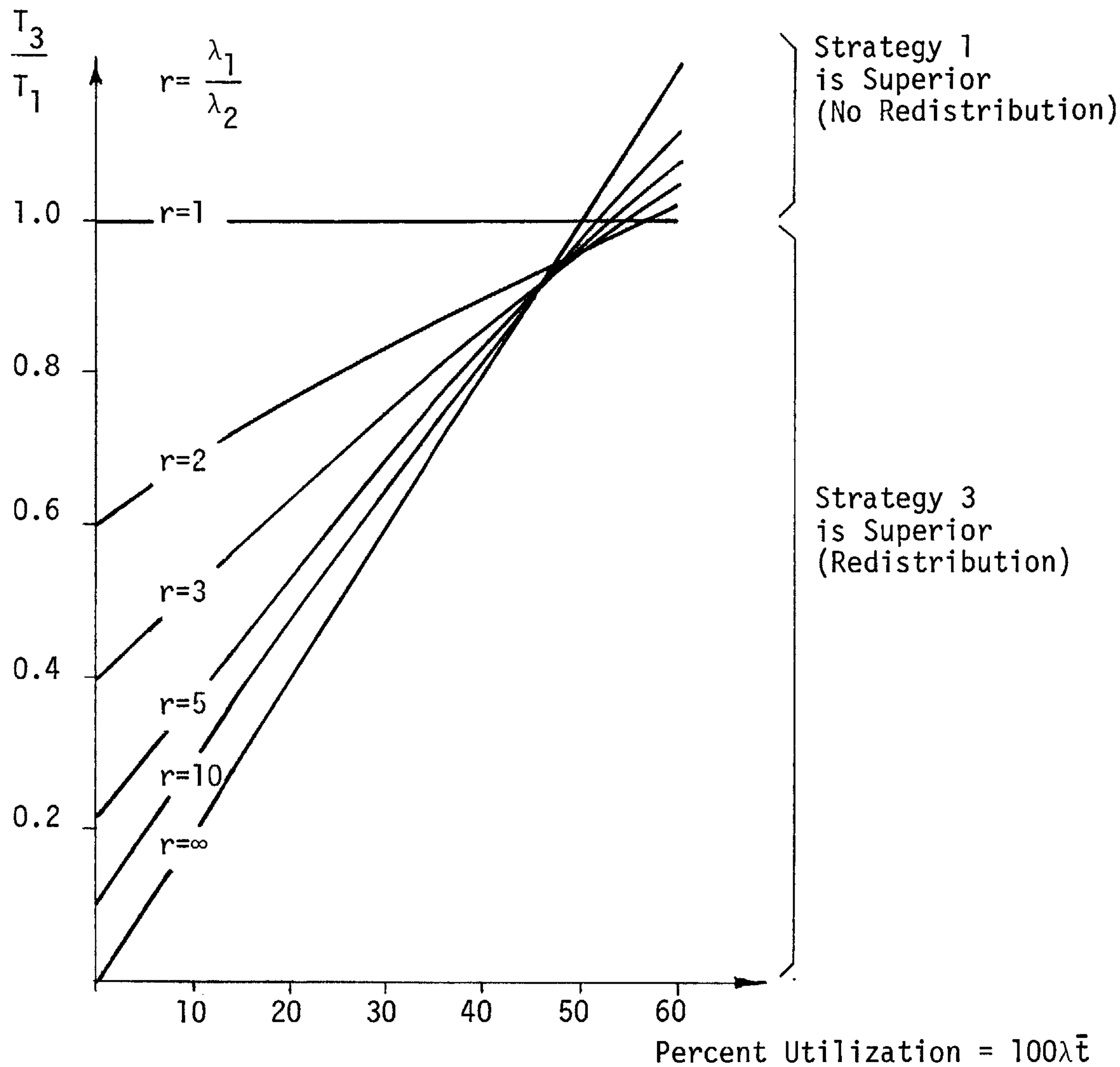
FIGURE 4.8 : ONE-TO-ONE SHUTTLE SERVICE

demands ($r = \frac{\lambda_1}{\lambda_2}$ where $\lambda_1 > \lambda_2$ - see Figure 4.9). For low levels of utilization (up to 50 percent), strategy 3, which automatically redistributes the taxi to the point of highest demand, results in a lower average wait time than strategy 1. Furthermore, as r increases, the relative advantage of strategy 3 increases. But for high levels of utilization (greater than 50 percent) redistribution is no longer desirable since the free taxi will not have to wait long for a fare to make the return trip. Strategy 1 results in lower average wait times than strategy 3. Once again this advantage increases as r increases.

One other interesting result of the Meyer and Wolfe analysis is that under strategy 1 (no redistribution of idle vehicle) the percent paid miles is given by the following[9]:

$$\text{Percent Paid Miles} = \frac{100}{2(1 - (\frac{\lambda_1}{\lambda})(\frac{\lambda_2}{\lambda}))} \qquad (4.13)$$

If either λ_1 or λ_2 is zero, then the percent paid miles becomes 50 percent since every trip is accompanied by a deadheading return trip. The maximum possible value for the percent paid miles is 67 percent which occurs when the arrival pattern is symmetric and $\lambda_1 = \lambda_2$. This result suggests that no matter how heavily the system is being utilized, a significant proportion of deadheading will always occur. This result seems contradictory however. At very high utilization rates a large queue of waiting passengers will form at points 1 and 2. With such large queues to continually feed the taxi one would suspect that a very high percentage of paid miles, considerably in excess of 67 percent would be achieved. One must conclude that because the probability theory used by Meyer and Wolfe does not take queueing effects into account it therefore breaks down at high rates of



T_3 = Total Passenger Wait Time Per Hour By Strategy 3

T_1 = Total Passenger Wait Time Per Hour By Strategy 1

FIGURE 4.9 : COMPARISON OF THE RELATIVE PERFORMANCE OF IDLE TIME STRATEGIES 3 AND 1

utilization. This, however, does not invalidate their valuable work on idle time strategies.

Queuing Model of One-Way Shuttle Service

We now consider a multiserver queuing model (which also covers the case of a single server) in which passengers wish to travel in one direction only. Since taxis are always deadheading in the return direction, the percent paid miles is always 50 percent.

Passengers arrive at the first terminal in random fashion at a rate of λ per hour and all passengers are ferried to the second terminal. Assuming once more a travel time of 7.5 minutes, the entire taxi cycle takes 15 minutes and the service rate μ is 4 per hour. By further assuming that the round trip takes exactly 15 minutes the service time distribution has a variance of 0 and a second moment of (15 minutes)^2.

By applying the multiserver delay formula (4.3) with the correction factor for the second moment, the following is obtained:

$$\text{Average Time spent waiting for a taxi} = \frac{M_2(\text{uniform distribution})}{M_2(\text{exponential distribution})} \times 60 \times \frac{p(\text{all servers busy})}{\mu S-\lambda}$$

$$= \frac{(15 \text{ minutes})^2}{2(15 \text{ minutes})^2} \times 60 \times \frac{p(\text{all servers busy})}{\mu S-\lambda}$$

$$= 30 \times \frac{p(\text{all servers busy})}{4N-\lambda} \text{ minutes} \qquad (4.14)$$

where N = number of taxis in service

λ = average arrival rate (passengers per hour)

and p(all servers busy) is tabulated in Wagner[10]

Sample Calculation

For N = 10

λ = 32 passengers per hour

μ = 4 passengers per hour

$\rho = \frac{\lambda}{\mu} = 8$

p(all servers busy) = .41

From equation 4.14,

$$\text{average time spent waiting for a taxi} = \frac{30 \times .41}{40 - 32} \text{ minutes}$$

$$= 1.54 \text{ minutes}$$

Figure 4.10 illustrates fleet performance for a one way shuttle service using formula 4.14. For a particular demand level λ, fleet operators should choose to operate close to the knee of the delay curve at a point where the average LOS is just starting to become objectionable to the taxi customers. By cutting back the fleet size as far as possible, operators save not only capital costs, depreciation and insurance but they also improve vehicle productivity.

One-way shuttle service leads to the same economies in the sharing of dispatching operations that have been demonstrated for each of the previous demand configurations.

Queuing Model of Two Way Balanced Shuttle Service

In this case the passengers arrive at each terminal at the same rate ($\frac{\lambda}{2}$ passengers per hour) and every passenger is transported one-at-a-time to the opposite terminal. The service process can be viewed from the eyes of a passenger arriving at either one terminal or the other. The service time (for each taxi) is the total travel time involved in a round trip (15 minutes) plus the amount of time that the taxi waits at the opposite

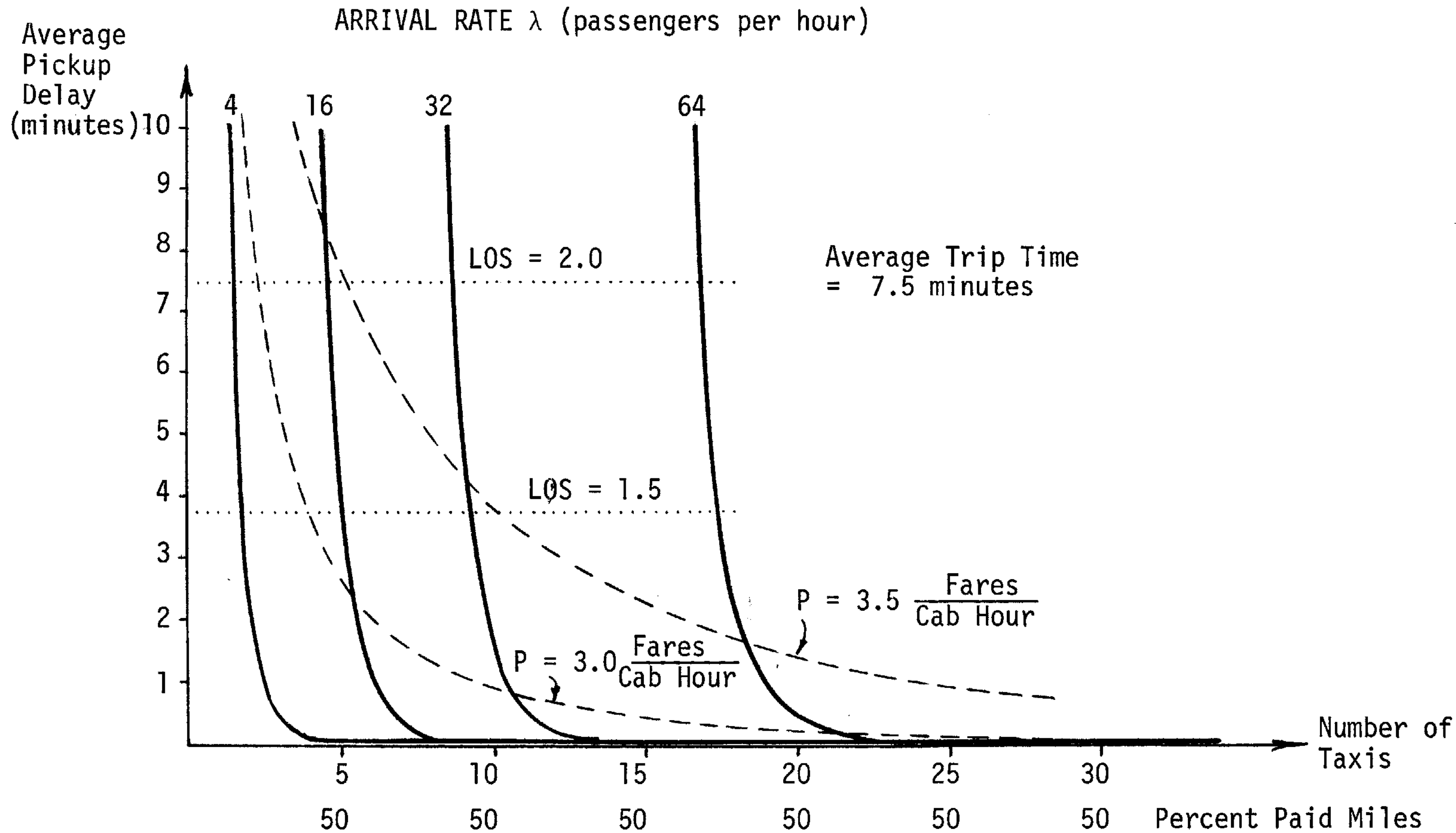


FIGURE 4.10 : QUEUING MODEL OF ONE WAY SHUTTLE SERVICE

terminal to pick up a return fare. (It will be assumed that the taxi never deadheads but always waits for the next passenger for the return trip.)

There are three possible states which will be encountered by a taxi waiting to make the return trip:

(1) passengers have queued and the return trip can be made immediately

(2) no passengers have queued and it is necessary to wait until one arrives for the return trip

(3) the taxi finds itself in a queue of taxis waiting for passengers to make the return trip.

The extreme cases (1) and (3) are undesirable from the passenger's and the taxi operator's points of view respectively. It will be assumed that case (2) is encountered most often on the average.

The average time that a taxi must wait for a passenger in case (2) can be computed from the wait time - headway relationships of public transit. From Kulash[11], the average wait time for transit buses arriving randomly (i.e. exponential distribution) at rate λ per hour is $\frac{1}{\lambda}$. Similarly, the average time a taxi waits for a passenger to arrive at either terminal, assuming case (2) is $\frac{2}{\lambda}$ since the arrival rate of passengers at each terminal is $\frac{\lambda}{2}$. The entire service rate μ is therefore equal to

$\frac{1}{\frac{1}{4} + \frac{2}{\lambda}} = \frac{4\lambda}{\lambda+8}$ passengers per hour. Since the service time distribution is primarily uniform (for large values of λ), the second moment correction factor is 1/2 (as was the case for the one way shuttle service). Once more the multiserver delay formula (4.3) is applied as follows:

$$\text{average time spent waiting for a taxi} = \frac{1}{2} \times 60 \times \frac{\text{p(all servers busy)}}{\mu S-\lambda}$$

$$= 3o \times \frac{p(\text{all servers busy})}{\frac{4\lambda N}{\lambda+8} - \frac{\lambda}{2}} \text{ minutes} \qquad (4.15)$$

where N = number of taxis in service

λ = total arrival rate (passengers per hour)

and p(all servers busy) is tabulated in Wagner[12]

Sample Calculation

For N = 10 cabs

λ = 64 passengers per hour

$\frac{\lambda}{2}$ = 32 passengers per hour

$\mu = \frac{4\lambda}{\lambda+8} = \frac{256}{72} = 3.56$ passengers per hour

$\rho = \frac{\lambda}{2\mu} = \frac{64}{7.12} = 9$

p(all servers busy) = .67

From equation 4.15

$$\text{average time spent waiting for a taxi} = \frac{30 \times .67}{35.6 - 32}$$

$$= 5.56 \text{ minutes}$$

The delay curves for the balanced shuttle service are shown in Figure 4.11. These curves are very similar in shape to those for the one way shuttle (Figure 4.10). However, the productivities of the two way shuttle are about twice those of the one way shuttle because the two way shuttle was assumed to involve no deadheading. The two way system handles approximately twice as many people for the same fleet size and level of service.

4.6 Summary of Fleet Performance for the Basic Demand Patterns

A comparison is made in Table 4.3 of taxi fleet performance under the different demand conditions. Regardless of the demand configuration

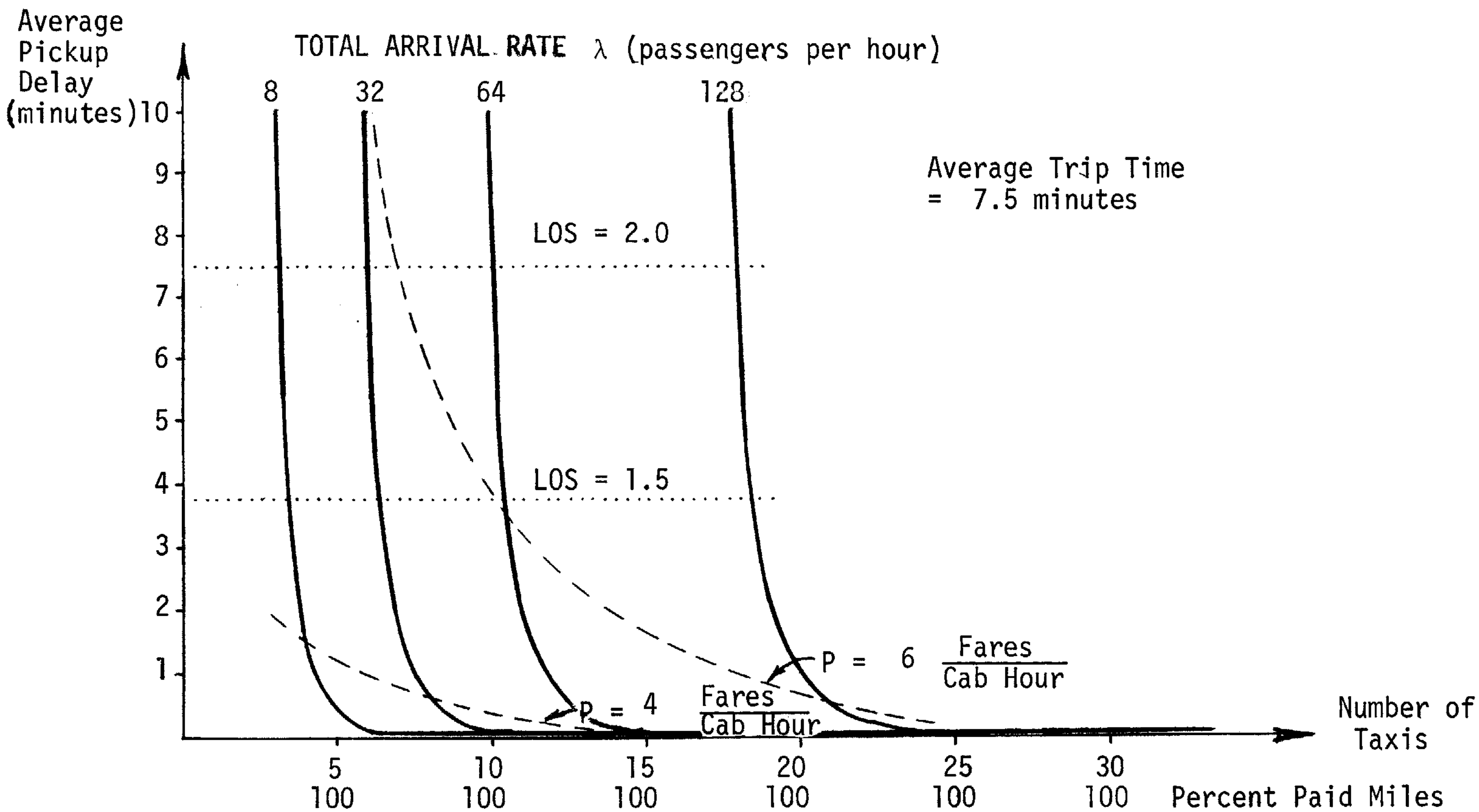


FIGURE 4.11 : QUEUING MODEL OF BALANCED TWO WAY SHUTTLE SERVICE

TABLE 4.3 : COMPARISON OF TAXI FLEET PERFORMANCE UNDER THE DIFFERENT DEMAND CONDITIONS

DEMAND PATTERN	MOST EFFICIENT OPERATING POINT	PRODUCTIVITIES ACHIEVABLE (for an average trip time of 7.5 minutes)*	PERCENT PAID MILES THEORETICALLY ACHIEVABLE**	LEVEL OF SERVICE ACHIEVABLE
1) MANY-TO-MANY	Knee of Delay Curve	2 - 4 $\frac{\text{fares}}{\text{cab hour}}$	80 - 90%	about 1.5
2) MANY-TO-ONE				
a) Radially In-bound Flows	Knee of Delay Curve	about 4 $\frac{\text{fares}}{\text{cab hour}}$	50%	about 2.1
b) Radially Out-bound Flows	Knee of Delay Curve	about 4 $\frac{\text{fares}}{\text{cab hour}}$	50%	about 1.1
c) Balanced Radial Flows	Knee of Delay Curve	2 - 4 $\frac{\text{fares}}{\text{cab hour}}$	85 - 95%	about 1.5
3) ONE-TO-ONE				
a) One Way Shuttle Service	Knee of Delay Curve	2 - 4 $\frac{\text{fares}}{\text{cab hour}}$	50%	about 1.1
b) Two Way Shuttle Service	Knee of Delay Curve	4 - 8 $\frac{\text{fares}}{\text{cab hour}}$	100%	about 1.1

* the assumed average trip time has a very great influence on achievable productivities

** does not include mileage necessary for travel to and from garage, cab stands, etc.

being serviced the most efficient operating point for a taxi fleet is within the "knee" of the delay curve. If more taxis are added to the fleet only marginal improvements in level of service will be realized, whereas if taxis are removed from the fleet, passenger delays will escalate rapidly. Notice that a high percent of paid miles is achievable in combination with good productivities only when the demand pattern is balanced and there is no net flow of passengers in either a linear or a radial direction in the service area. Furthermore, overall fleet performance (productivity, percent paid miles and LOS) tends to improve as the demand pattern becomes more and more concentrated. In moving, for example, from a many-to-many pattern to a balanced many-to-one pattern to a two way shuttle service, aggregate fleet performance improves at each stage.

4.7 Synthesizing the Performance of a Taxi Fleet for Any Given Demand Pattern

Given a demand pattern for a real taxi operation it is possible to estimate fleet performance by first breaking down the demand pattern into its basic elements and then estimating fleet performance for the elemental parts. Overall fleet performance can be predicted by interpolation with the knowledge that aggregated operations always perform better than independent operations.

A second, more accurate way of determing overall fleet performance if to perform a computer simulation of the fleet operation for the given demand pattern. In the computer simulation, random numbers are used to generate taxi trip patterns in real time, similar to those actually observed. The computer then assigns individual trip-makers to taxis and the performance of the fleet is monitored. Computer simulations can be a valuable tool in optimizing the performance of a real taxi fleet.

4.8 Comparison of the Performance of Taxi and Dial-a-Ride Fleets

It is of considerable interest to compare the performance of a taxi fleet operating on an unshared ride basis with that of a fleet operating on a shared ride basis. Much research has been done on Dial-a-Ride fleet performance at MIT during the past seven years and some of the results of this work will be used in the comparison[13].

One very interesting result of the MIT Dial-a-Ride research is a simple formula which is very useful for estimating fleet requirements to service a particular area. This formula was calibrated from simulation results for a realistic Dial-a-Ride demand distribution (which combined many-to-several and many-to-many travel patterns). It expresses a linear relationship between demand density and fleet density with level of service appearing as a parameter[14]:

$$\frac{N}{A} = \frac{0.68 + 0.072D}{(LOS-1)^{1/2}} \qquad \text{[DIAL-A-RIDE]} \qquad (4.16)$$

where N = number of Dial-a-Ride vehicles operating

A = service area size in square miles

D = demand density in demands per square mile per hour

LOS = mean level of service experienced by the user

$$= \frac{\text{Total System Time (wait + travel)}}{\text{Direct Driving Time (by auto)}}$$

As cautioned in the reference noted, however, this formula is applicable only in the range of its calibration.

Taxi systems (unshared ride) appear to have operating behavior similar to Dial-a-Ride systems (shared ride) as represented by formula 4.16.

By replotting the taxi fleet performance results of Figure 4.5 (which apply only for many-to-many demands), near-linear relationships were discovered between taxi fleet density and demand density for a fixed level of service. These relationships are shown in Figure 4.12.

An approximate linear model in the same form as equation 4.16 was calibrated, using the relationships shown in Figure 4.12 while giving particular weight to the line having the LOS parameter value of 1.5. The model is as follows:

$$\frac{N}{A} = \frac{0.32 + 0.26D}{(LOS-1)^{1/2}} \qquad \text{[TAXIS]} \qquad (4.17)$$

where N = number of taxis in operation

A = service area size in square miles

D = demand density in demands per square mile per hour. The demand pattern is strictly many-to-many

LOS = mean level of service experienced by the user.

Provided that the many-to-many queuing model (developed earlier in equation 4.8) proves to be a reasonable representation of taxi fleet performance, equation 4.17 can be used to predict the number of taxis required to provide transportation of a specified level of service in a service area of given demand density (many-to-many demands). It is quite accurate for a LOS close to 1.5.

There is a remarkable similarity between equation 4.16 for Dial-a-Ride fleet performance and equation 4.17 for taxi fleet performance. But equation 4.16 was developed through computer simulation while equation 4.17 was based upon a queuing model. This would suggest that queuing behavior is a phenomenon underlying the performance of both taxi and Dial-a-Ride fleets.

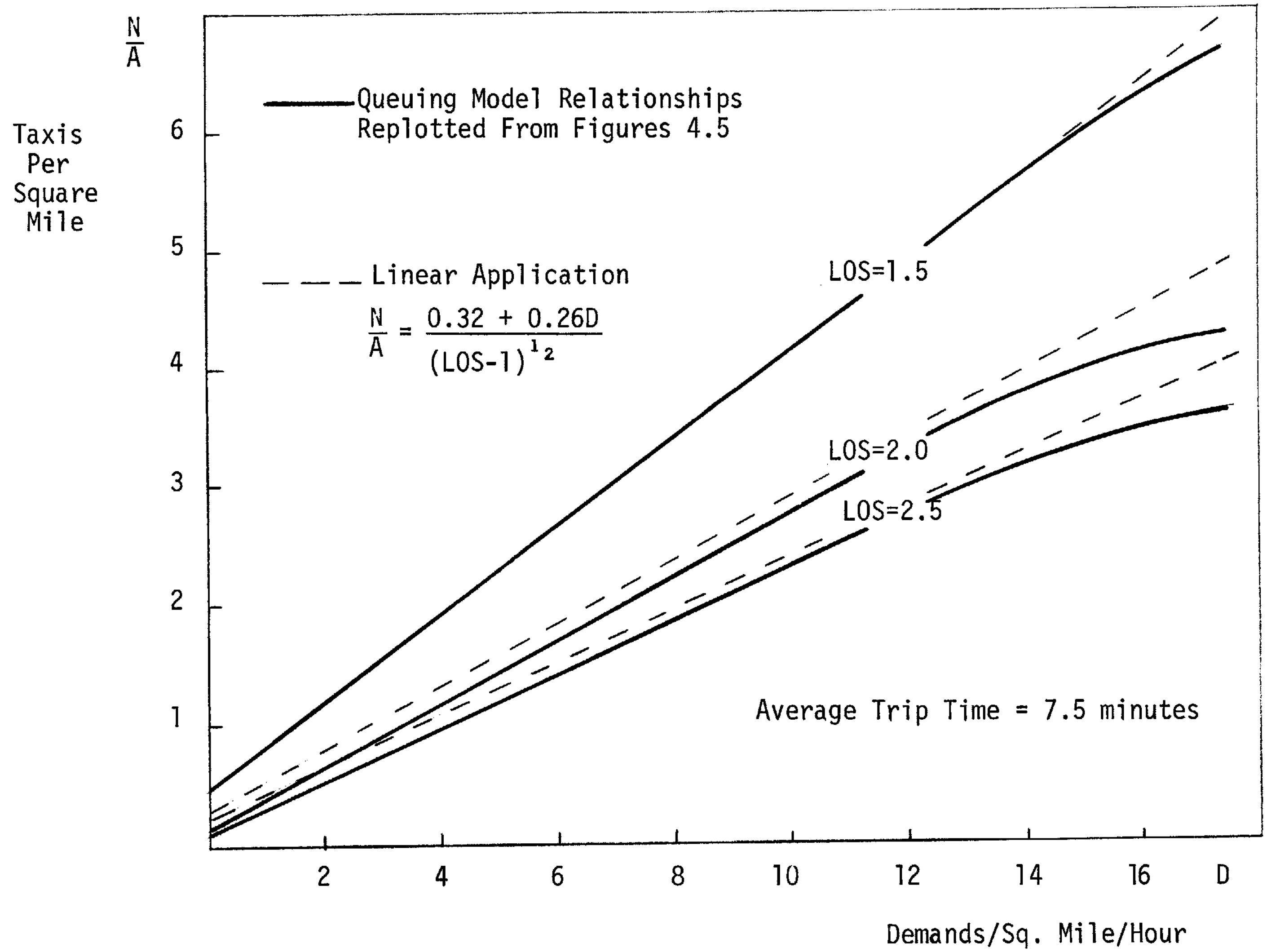


FIGURE 4.12 : APPROXIMATE LINEAR MODEL OF TAXI FLEET PERFORMANCE FOR MANY-TO-MANY DEMANDS

Further simulation research should be carried out to verify the queuing nature of both shared and unshared ride demand responsive transportation services.

One very important basis for the comparison of fleet performance of an unshared ride system (e.g. taxi) with a shared ride system (e.g. Dial-a-Ride) is vehicle productivity. In going to a shared ride system, vehicle productivities are increased (approximately doubled) while service levels are reduced. The significance of this tradeoff is that passengers can be given door-to-door service at lower cost provided that they are willing to share the vehicle with other passengers and to accept longer service times (wait time plus travel time). The lower fares of ride sharing systems result because approximately the same hourly operating costs are spread over a larger number of passengers.

An appreciation of this tradeoff can be gained by looking at Figure 4.13 which compares taxi and Dial-a-Ride productivities at different demand densities. It is important to notice that the productivity curve depicted for Dial-a-Ride assumes a LOS of 2.5 vehicles while the taxi productivity curves are for a LOS of 1.5. Curves for other service levels could also be shown but the service levels selected are felt to be typical of the respective systems. Only theoretical results are shown, but the range of productivities illustrated is similar to those achieved in real-world taxi and Dial-a-Ride systems.

The productivities of both taxi and Dial-a-Ride fleets increase with increasing demand density but saturation limits are soon approached asymptotically.

Figure 4.13 is also very useful for showing the range of demand

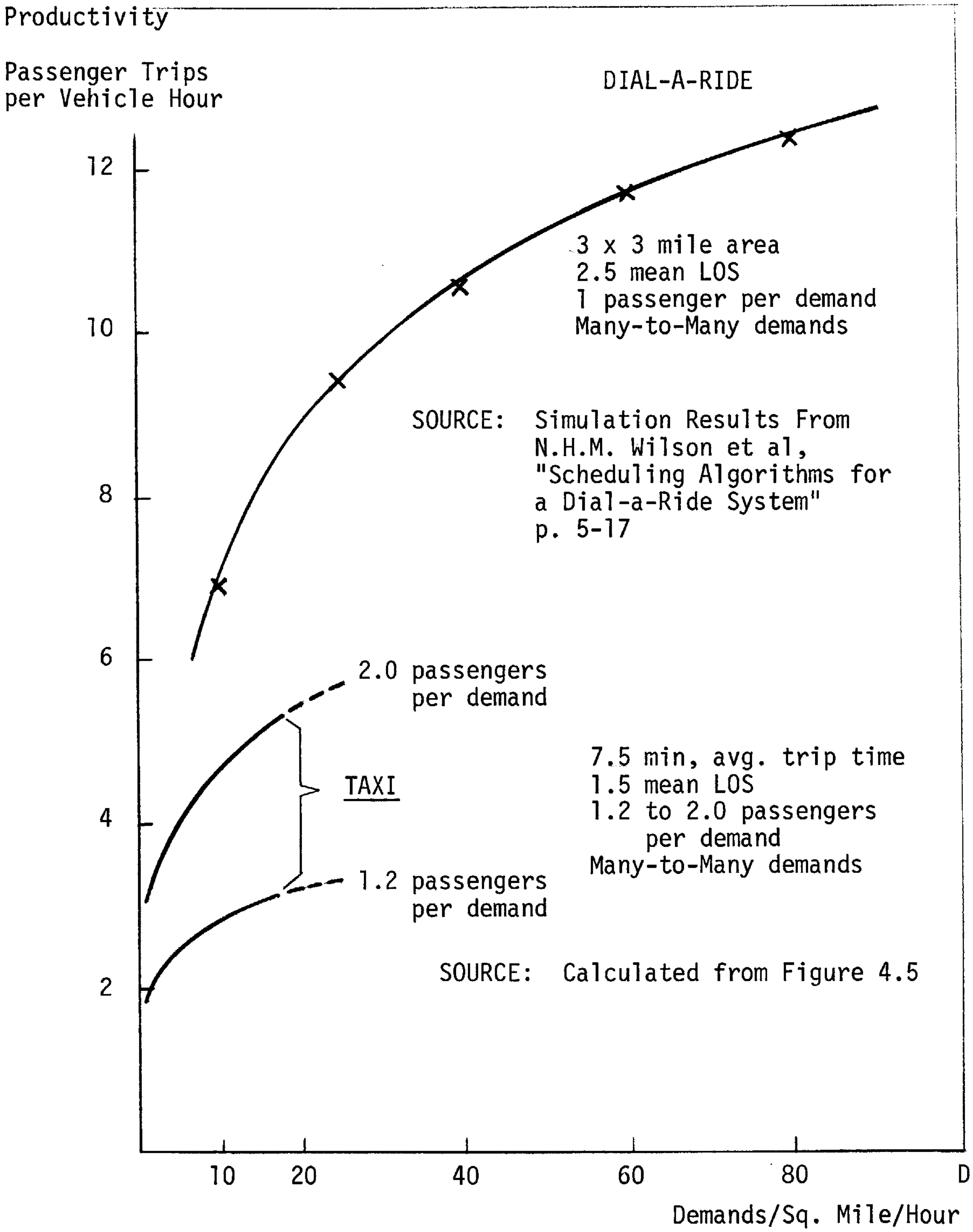


FIGURE 4.13 : COMPARISON OF TAXI AND DIAL-A-RIDE PRODUCTIVITIES FOR VARIOUS DEMAND DENSITIES

densities over which it is most advantageous to operate a particular mode. Above demand densities of about 80 demands per square mile per hour, fixed route bus service is an economically viable operation. Below 80 demands per square mile per hour, however, fixed route service becomes inefficient but Dial-a-Ride is able to operate at high and economical productivities At the low end of the demand density scale, taxis dominate because Dial-a-Ride is unable to sustain productivities that will permit the charging of fares lower than taxi fares.

In the intermediate demand density range (from about 10 to 60 demands per square mile per hour), however, the domination of either taxis or Dial-a-Ride is unclear and depends very much on the relative magnitude of the operating costs of the two systems. The relative operating costs of taxi and Dial-a-Ride systems are discussed in the next section.

4.9 Relative Cost of Operating Taxi and Dial-a-Ride Fleets

Taxis are a relatively low cost form of public transportation. The hourly operating cost of a taxi detailed in Table 4.4 is about half the hourly operating cost of a Dial-a-Ride bus as given in Table 4.5. Including the taxi driver's tips as wages, a taxi costs from $3.85 to $7.35 per hour to operate while a Dial-a-Ride vehicle costs from $7.00 to $12.00 per hour. (assuming transit wages for the driver).

There are three major reasons for such a large difference in operating costs:

(1) Both systems are very labor-intensive with wages accounting for about two-thirds of the operating costs. The wage scales for Dial-a-Bus drivers and dispatchers are about twice the hourly earnings of taxi

TABLE 4.4 : TAXI REVENUES AND COSTS

REVENUE PER TAXI HOUR

TOTAL REVENUE	\$4.00 to \$6.00
Driver Tips	.40 to \$1.20
	\$4.40 to \$7.20 per taxi hour

COST PER TAXI HOUR

Driver Commission	\$2.00	to \$3.00
Other Operating Costs	\$1.45 to \$2.10	\$2.15 to \$3.15
TOTAL COST	\$3.45	\$6.15

PROFIT/LOSS	\$0.85 profit to .15 loss per taxi hour

Assumptions:

Average Fare	=	\$2.00
Taxi Productivity	=	2.0 to 3.0 fares per taxi hour
Tipping Rate	=	10 percent to 20 percent of fare
Driver Commission	=	50 percent of fare
Average Trip Length	=	2.5 to 3 miles
Other Operating Costs	=	12¢ to 14¢ per mile
Percent Paid Miles	=	40 percent to 50 percent

TABLE 4.5 : DIAL-A-RIDE OPERATING COSTS

COSTS PER BUS HOUR*

Driver Wages **	$3.00 to $5.00
Vehicle Operating Cost	$2.00 to $3.00
Dispatching and Communications	$1.00 to $2.00
Overhead	$1.00 to $2.00
TOTAL COST	$7.00 to $12.00 per bus hour

Driver Wages include fringe benefits

Vehicle Operating Cost includes depreciation, insurance, gas, oil, maintenance, tires and registration

Dispatching and Communications includes dispatcher and operator wages and fringe benefits, radio equipment capital and operating costs, telephone, hydro and other terminal costs

Overhead includes costs for administration and marketing

*Cost Estimates were derived by examining the operating cost breakdowns for past and existing Dial-a-Ride operations at Columbus, Ohio; Bay Ridges, Ontario; Regina, Saskatchewan; Ann Arbor, Michigan; Columbia, Maryland; and Batavia, New York. See "Operational Experiences with Demand-Responsive Transportation Systems" by Prof. Daniel Roos, a paper presented at the Highway Research Board Meeting, January 1972, Washington, D.C. Also available at the MIT Department of Civil Engineering as Research Report R72-2, January 1972, Cambridge, Mass.

** Wages for transit drivers were assumed here. The use of taxi drivers could reduce these figures.

drivers and dispatchers. Bus driving has almost become a "prestige" job[15] (largely through the pressure of labor unions) while taxi driving has not. If taxi companies were to operate the Dial-a-Bus fleets, however, reductions in the stated operating costs could be expected due to the lower wage scales of the taxi industry.

(2) The vehicles used for Dial-a-Ride are more expensive to purchase and operate (because they have from two to ten times the passenger capacity of a taxi). Taxi systems take full advantage of relatively low cost and widely available automotive technology.

(3) Dispatching costs are much lower per vehicle for taxis than for Dial-a-Ride because of scale effects. Most Dial-a-Ride experiments have been operated with from 1 to 6 vehicles while taxi fleets of 10 to 100 vehicles are very common. Very high dispatcher/operator productivities (i.e. calls handled per hour) are achieved in taxi systems. Once Dial-a-Ride fleets become established and expand in size, the unit costs of dispatching could decrease significantly. Computerization on the other hand could cause dispatching costs to increase.

The relatively low cost of operation of taxi systems represents a distinct advantage which taxis have over DAR and other public transit systems and for this reason more consideration should be given to taxi or taxi-like systems for providing new public transportation services.

4.10 Summary

The analyses presented in this chapter give insight into the performance of an unshared ride taxi fleet and indicate how a number of factors (demand pattern and density, fleet size, service area size, trip time and speed) affect this performance.

A series of analytic models have been used to demonstrate fleet performance for the basic taxi demand patterns - many-to-many, many-to-one and one-to-one. The phenomenon assumed for each of these models is queuing. Although there was insufficient data about taxi fleets to conclusively validate both the models themselves and the assumptions made in developing these models it was found that the many-to-many model predicted the observed average waiting times of Belmont Taxi patrons quite closely. Computer simulation work should nevertheless be carried out to further verify the analytic models presented.

The theoretical fleet performance models suggest that there is significant margin for improvement over today's dispatching efficiencies. Manually dispatched fleet typically achieve between 40 and 50 percent paid miles. The models, on the other hand, suggest that it may be possible to achieve over 60 percent paid miles if the fleet is very closely controlled, a control which is possible through today's computer and communications technology.

The queuing models point out the superior efficiencies and service levels that can be provided by monopolistic taxi service. A single large fleet can provide better pickup service at a higher percentage of paid miles than can a number of smaller fleets (with the same total number of vehicles as the large fleet).

But the above-mentioned gains in efficiency can be achieved through cooperative dispatching where several taxi companies operating within the same service area pool their dispatching operations. Unfortunately this concept will appeal to very few companies because it involves sharing their phone order clientele with that of competitors. In Europe, the greater efficiencies of centralized cooperative dispatching have been recognized in several cities. Copenhagen, for example, uses a single dispatcher for all 1200 taxis operating in the city and the system is reported to provide very good pickup for all points within the city.

Another interesting result of the analyses is that fleets which operate at low demand densities such as in suburban areas are unable to achieve the same high levels of efficiency (percent paid miles) and productivity as are fleets operating at higher demand densities. Similarly, fleets which serve a very high proportion of many-to-one or one-to-one demands have a significant efficiency advantage over taxi fleets which handle predominantly many-to-many demands. Concentration of demand is always to the advantage of the taxi company and its patrons.

The models presented in Chapter 4 can be used to estimate taxi fleet performance for any given combination of demand patterns and intensities. If more accurate performance estimates are required, however, computer simulation is a very useful technique and is recommended.

There are a number of similarities between the performance of a taxi fleet (unshared ride) and a Dial-a-Ride fleet (shared ride). Both systems demonstrate near-linearity between demand density and fleet density for a specified level of service. The phenomenon which is felt to relate the behavior of the two systems is queuing.

A major difference between the unshared taxi and Dial-a-Ride systems is the vehicle productivity. For the same demand density being served, Dial-a-Ride (at a LOS of 2.5) has a productivity of 2 to 3 times that of the non ride-sharing taxi (at a LOS of 1.5).

In choosing between taxi and Dial-a-Ride systems, operating costs are an important consideration. Dial-a-Ride costs between $7.00 and $12.00 per vehicle hour to operate while taxis have an hourly operating cost between $3.85 and $7.35 per vehicle. It is therefore strongly recommended that taxi service, as either a shared ride or unshared ride mode, be considered more frequently as an alternative for providing new public transportation services.

The next chapter discusses applications of computers to the taxi industry with particular emphasis on computerized dispatching. Through the proper use of computers it will be possible to provide better taxi service at lower cost.

Notes on Chapter 4

1. Wagner, H.M., Principles of Operation Research Prentice-Hall Inc., 1969, p.861
2. Ibid, pp. 865-867
3. Ibid, pp. A76-A78
4. Wilson, N.H.M. et al, Scheduling Algorithms for a Dial-a-Ride System Urban System Lab Report TR-70-13, MIT 1971 p. 5-41
5. Meyer, R.F. and Wolfe, H.B., "The Organization and Operation of a Taxi Fleet" Naval Research and Logistics Quarterly, June 1961 pp. 137-150
6. A taxi is considered to be "free" if upon completion of a trip, there are no passengers waiting to make a return trip.
7. Meyer and Wolfe, Ibid, pp. 141
8. The percent utilization is the percentage of time that the taxi is occupied with a fare. Percent utilization therefore equals $100\lambda\bar{t}$.

9. This result follows from equation (4), page 139 of Meyer and Wolfe

10. Wagner, H.M. Ibid, pp. A76-A78

11. Kulash, Damian: "Routing and Scheduling in Public Transportation Systems" PhD Thesis, MIT, 1971, p.33

12. Wagner, H.M., Ibid, pp. A76-A78

13. see for example chapter 5 of "Scheduling Algorithms for a Dial-a-Ride System" by Nigel Wilson et al

14. Wilson et al, Ibid p. 5-41

15. In the '71-'72 Transit Fact Book (American Transit Association), p. 13, the average annual earning per transit employee in 1971 (most of whom are bus drivers) was estimated to be $10,014. In the five year period from 1966 to 1971 the average annual growth rate of earnings per transit employee was a very high 8 percent. Since the transit industry is very labor-intensive, this high annual increase in wages is an important consideration in assessing the cost of future transit-operated systems.

CHAPTER 5 THE USE OF COMPUTERS IN TAXI DISPATCHING AND OPERATIONS

The electronic computer has greatly influenced many areas of transportation and has great potential for improving taxi operations. The impact of the computer could eventually revolutionize the taxi industry with an impact equal to or greater than that caused by the advent of the two-way radio in the late 1940's and early 1950's.

Computers have an ability to process large quantities of data in a very short period of time and are capable of accurately and rapidly making real time dispatching decisions such as selecting the closest cab, or redistributing the taxi fleet in anticipation of future service requests.

The chapter begins by describing two recently installed computer dispatching systems which represent a pioneering effort in the taxi industry. The following section, 5.2 describes the information inputs required by a dispatching computer and very briefly indicates the way in which this information is used. Computerized taxi dispatching has a number of advantages, disadvantages and possible implementation problems. These are outlined in sections 5.3 through 5.5 in order to present an objective view of computerized dispatching, its strengths and weaknesses. The following section suggests that certain types of taxi companies have more to gain from computerized dispatching than others and describes the ideal environment.

Computerized dispatching, however, is just one of a number of ways a taxi company can take advantage of new systems and communications technology. Other ways are pointed out very briefly in section 5.7. The final section of the chapter presents a summary of the most important concepts.

5.1 Computerized Dispatching Systems in Operation at the Present Time

During the past year at least two taxi companies have turned to computers to improve their taxi operations. Yellow Cab of Los Angeles with a 700 cab fleet is currently using two NCR Century 100 computers linked to eight NCR visual display terminals[1]. As each telephone order is taken, the pickup address is keyed into the computer. The computer then determines in which of the city's 200 numbered zones the callers are located and selects the closest available cab for each order. Information is displayed on a screen in front of the dispatcher who then contacts the appropriate driver by radio and gives him the pickup instructions. Not only does the computer assist the dispatcher, but it also makes a record of all calls handled and the utilization of each cab.

The second computer installation is at the Royal Cab Company of Davenport, Iowa where a fleet of 21 cabs operates with ride sharing. The computer is an IBM system 3/6 which not only tells the dispatcher which cab should make the pickup but also indicates what the fare will be. The caller is told over the telephone the exact amount of the fare and can use this information to decide whether or not he wants to make the trip.

The computer-calculated fare system (which is based on distance travelled) replaces an older inequitable system of zoned fares. In fact, according to the owner Robert Cherry, fares for 80 percent of all trips have been reduced.

A great deal of work has been done at MIT and elsewhere to develop sophisticated computer algorithms and programs for Dial-a-Ride, which is basically a shared-ride system. The shared ride dispatcher has a much more complex task than the dispatcher of an unshared ride operation. For every new passenger requesting service the dispatcher must rank the vehicles in order of how quickly they can make the pickup. Then a decision must be made as to which vehicle can make the pickup without violating the travel time constraints of each of the passengers already on board. The difference between shared-ride dispatching and standard taxi dispatching is in this requirement for continuously monitoring the travel times of each passenger on board to see that the individual service time guarantees are not violated. Shared ride dispatching is also complicated by the fact that many vehicles can be considered as candidates to make the pickup while under the taxi system only a few vehicles will be considered. Computerized dispatching is almost a necessity for large shared-ride fleets if each vehicle is to operate at high levels of productivity.

We turn now to a discussion of computerized dispatching for regular unshared ride taxi service.

5.2 How the Taxi Dispatching Computer Operates

The taxi dispatching computer works by simulating in real time the position of each taxi in its memory. Whenever the taxi is in motion, either in the process of transporting a passenger or in returning to a stand, the computer simulates the journey of that cab. When a customer makes a service request the computer can indicate to the dispatcher not only which cab will be able to reach that customer first but also how long the customer will have to wait for the pickup to occur. (This is selection criterion #2 as discussed in Chapter 3, section 3.1.)

Periodic fixes on the actual current location of each cab are a vital input to the computer. Updates of both cab location and status must be made at least at the following times:

(1) whenever a cab picks up or drops off a fare (this applies to both phone orders and street work)

(2) whenever a cab arrives back at a stand

(3) whenever a cab goes on or off duty for any reason

and (4) whenever a cab is experiencing unusual delays in traffic congestion.

If automatic vehicle monitoring equipment (AVM will be described in section 5.7) is not being used to provide positional inputs to the computer, then full driver cooperation will be required for position-reporting. The lack of accurate position-reporting by the drivers does constitute a problem in the operation of today's taxi fleets, and may become even more of a problem with computerized dispatching systems. Fortunately, however, location checks can be built into the computer system that will inform the dispatcher whenever an inconsistency occurs between the expected position of a cab and the position actually reported by the driver. The dispatcher can then question the driver further about his position.

5.3 Advantages of Computer Dispatching

The major advantages of computer dispatching are as follows:

(1) Improvement in Passenger Service

Passengers benefit through faster and more reliable pickups which computerized dispatching brings. Furthermore, the caller can be told as he is making his request, how long it will be before a cab arrives to pick him up. Under such a system the caller will very likely be ready as soon as the cab arrives.

(2) Improvement in Revenue per Mile through Better Dispatching

A well-designed computer dispatching system will be able to make better selections of vehicles to handle the incoming requests. In the last chapter, the queuing models suggested that the dispatching performance of todays taxi fleets (of the order of 40 to 50 percent paid miles) can be significantly improved by more positive control of the fleet. This results in fewer dead miles and therefore lower operating costs. In section 3.4, it was pointed out that for a fleet of 25 taxis, each handling 25 trips per day, a 10 percent reduction in dead mileage saves about $12.50 per day or about $4,500 per year.

(3) Improvement in Revenue per Mile through Reduction in Theft

Some taxi operators estimate that 10 percent or more of the total taxi revenue collected by the drivers is not reported to the company. For a fleet of 25 taxis each handling 25 trips per day at an average fare of $2.00 this represents a total annual loss of $45,600. The improvement in control over the drivers that computerized dispatching brings could significantly reduce losses due to theft. As extra incentive, part of this revenue gain could be turned over to the drivers in the form of an increased commission.

4) Improvements in Vehicle Utilization and Productivity

Because of the more positive control over the fleet, both vehicle utilization and productivities can be improved. One very important result of increased productivity is increased earnings for the commissioned drivers.

(5) Elimination of Dispatching Inequities

It is very easy for the dispatcher to "play favorites" either consciously or unconsciously when assigning calls to drivers. In fact, dispatchers are sometimes induced with weekly payments from certain drivers to give them the most lucrative assignments.

Computerized dispatching eliminates any favoritism in the assignment of calls and gives each driver the feeling that he is being treated equitably.

(6) Providing a Basic Information System

The dispatching computer can be readily adapted to provide a basic management information system, giving daily readouts such as the number of fares handled by each cab and the number of hours each cab is in service. The customer billing process may also be incorporated into larger computer units.

Next we turn to the disadvantages accompanying the use of the computer.

5.4 Disadvantages of Computer Dispatching

The single most significant drawback of the computer system is that it represents an additional expense for the taxi company.

1) Cost of the Computer Installation and Its Operation

The investment in a dispatching computer is worthwhile to the company owner only if the increase in revenue due to theft reduction and the decrease in operating cost through dispatching improvement more than covers the cost of the installation. The minimum cost for a very basic computer dispatching system, capable of dispatching up to 100 vehicles is of the of 20 to 30 dollars a day on a leasing basis[3]. (Other more sophisticated and multi-purpose computer systems may cost from 3 to 5 times this amount to operate.) This cost represents about 2 percent of the daily revenues of a 25 vehicle fleet, or about 1 percent of the day's revenue for a 50 vehicle fleet. This is a small price to pay relative to the cost savings which can potentially be achieved through computerized dispatching.

It is unlikely that the use of first generation taxi dispatching computers will bring about savings in manpower. Operators will still be required to take the phone orders and dispatchers to communicate with the drivers and also to handle computer inputs and outputs.

2) Risk of a Computer or Power Failure

If the dispatching computer fails for any reason, it will be necessary to immediately revert to a manual dispatching operation. The losses incurred while the computer is inoperative will depend upon how efficiently dispatching is carried out in the manual mode.[4]

3) Loss of Flexibility

A computer does not have the flexibility of the human dispatcher who is capable of reacting wisely to most adverse situations that may occur. A good dispatching system will therefore try to combine the computer's capacity for keeping track of the locations, routes and status of all cabs, with the judgment abilities of the dispatcher. The inflexibility of the computer can be offset by enabling the dispatcher to intervene in the system whenever he feels it is necessary.

4) Drivers May Resent Tight Control

Taxi drivers by their very nature prefer to work the hours they choose and like to be able to take time out occasionally during the day. Under computerized dispatching they may feel as if their every move is being monitored and that the new style of fleet operations is very regimented.

In addition to the above disadvantages of computerized dispatching a number of problems may be incurred during implementation.

5.5 Implementation Problems

1) Dispatcher Acceptance

Dispatchers may feel that they are being replaced by a computer rather than just being assisted by it. Consequently they may not give their full cooperation when the new system is being tried out. A good transition to computer-assisted dispatching cannot be properly effected without the full support of the dispatcher.

2) Driver Acceptance

In the same way that the support of the dispatchers is essential for successful implementation, the support and cooperation of the driver is also a necessity. Otherwise, the advantage of computerized dispatching will never be realized.

3) Adaptation of the Computer System

The operating environment associated with each taxi company is different from that of other taxi companies. For example, cab stands are used in different ways by different companies. Anomalies in the regularity of the street grid are unique to a particular service area. Average travel speeds change from one service area to another as does the difference between peak and off-peak travel speeds. It can be appreciated that each computer dispatching system must be closely tailored to the operating environment. It may be three or four months before the installation is running smoothly and the economies of the new computer system are being fully realized.

5.6 The Ideal Environment for a Computerized Taxi Dispatching Installation

Not every taxi company is well-suited to the application of computerized dispatching. There are a number of features which should be considered in determining whether a particular taxi company has good potential for a computer installation.

1) Fleet Size

Large fleets have more to gain from computerized dispatching than do small fleets (of less than 25 vehicles for example). These economies of scale result because as fleet size increases, the cost of the computer becomes a smaller and smaller proportion of total fleet operation costs. Also, the manual dispatching systems of large fleets are not likely as efficient as the manual dispatching systems of smaller fleets. Therefore, the dispatching efficiency improvement which computerization brings is likely to be greater with the larger fleets than with the smaller fleets.

2) Percent of Phone Orders

When the proportion of phone orders is high, the dispatcher's decisions influence the performance of a large fraction of the fleet. Consequently, the margin for performance improvement through computerization is great.

Futhermore, as the proportion of phone orders increases, the completeness of cab location and status information which is centrally available increases. The transition to computerized dispatching (requiring completely centralized data concerning the cabs) is thereby facilitated.

3) Degree of Congestion

Congested parts of the city tend to cause a high degree of variability in taxi travel speeds at different hours of the day. (Average travel speed may swing from 25 miles per hour during off-peak conditions down to 10 miles per hour during peak conditions.) Furthermore, the spatial congestion pattern (i.e. in different neighborhoods of the city) is constantly fluctuating.

Although the human dispatcher is flexible enough to adjust his decisions to congestion variation, it is very difficult and expensive to build this degree of flexibility into a dispatching computer. It is therefore suggested that dispatching computers are more applicable to areas of the city where traffic flows freely and therefore predictably.

NOTE THAT THE COMBINATION OF THE ABOVE THREE FACTORS SUGGESTS THAT COMPUTERIZED DISPATCHING WILL LIKELY BRING THE GREATEST BENEFIT TO LARGE SUBURBAN FLEETS.

4) Efficiency of the Current Fleet Operation

Computerization of dispatching results in tighter control of the fleet and provides the basis for a better information system than existed previously. A loosely-run taxi company that decides to go computer may gain not only from better dispatching but from the tighter control as well.

5) Good Relationships between Management, Dispatcher and Drivers

A new computerized dispatching system has the best chance for success when there are good working relationships within the company. This is an extremely important consideration even though it has not been dealt with in detail in this thesis. The introduction of a computer dispatching system into a company could make existing management problems much worse.

6) Good Radio Communications System

The completeness of the data provided as input to the computer depends heavily upon a good communications link between the dispatcher and the drivers. "Blind spots" may occur in the service area where this radio communication breaks down and the location or status information may not get through to the dispatcher.

7) Potential for Expanding the Service Area

A taxi company that may be able to later expand its service area and fleet has potential for taking greater advantage of the economies of scale inherent in both computerized dispatching and the dispatching process itself (as pointed out in section 4.3).

5.7 Stages in the Automation of Information Handling for a Taxi Company

Computerized taxi dispatching can be viewed as just a single stage in the use of computers and state-of-the-art communications equipment. In a presentation made by the Yellow Cab Company of Los Angeles to the Third Annual Demand Reponsive Transportation Systems Conference (June 12-14, 1972 at the University of Michigan) five steps were identified in the conversion of Yellow Cab operations from the traditional methods:

(a) Installation of data processing equipment for receiving and recording orders for service;

(b) Installation of data processing equipment to match these orders to vehicles (i.e. taxi dispatching);

(c) Use of digital communications equipment for transmitting information from vehicles to dispatching headquarters, automatically relaying vehicle identification and status, while requiring the driver to key in his location;

(d) Use of digital communications equipment for transmitting information from headquarters to vehicles;

(e) Use of AVM (automatic vehicle monitoring) equipment to automatically report the position of each vehicle.

As of the time of the Conference, the first two steps were operational and the company was negotiating for the last three. Step (c) was found to be essential to the efficient operation of the computerized dispatching system because of the large volume of orders being handled (600 orders per hour which entail over 2,400 radio contacts per hour). Digital communication can transmit information much more efficiently (occupying considerably less transmission time per message) than voice communication. It was found that the four clear pairs of radio frequencies were not adequate under voice communication to handle the necessary information flows. Of steps (c), (d), and (e), step (d) was suggested to be of lowest priority.

Automatic vehicle monitoring systems use electronic methods (via triangulation or signal beaming) to automatically provide information on the identity and location of each vehicle of the fleet. High resolution systems are very expensive to install, however, but it is hoped that the cost could be shared by the many public service systems (police, fire, ambulance, taxi, delivery service, transit bus, public utility trucks etc.) which would benefit from the AVM system.

Computer systems can also be of great value to taxi companies for processing internal information (payroll and customer accounts and vehicle maintenance costs, for example) and for monitoring daily fleet performance (by providing readouts for each driver of revenue per shift, revenue per mile, percent paid miles, and miles per gallon of gas). The economies of scale in data processing are such that the use of computers for handling company information is most cost-effective for large fleets.

The contents of this chapter are now summarized.

5.8 Summary

Computers will probably be the next major innovation to revolutionize the taxi industry. They promise a higher degree of centralized control than is currently possible with manual techniques and a greater ability to monitor fleet performance and internal company accounts.

There are a number of stages which can be passed through in automating the information flow of a taxi company - internal accounting, monitoring of taxi driver performance, computerized dispatching, digital communications and automatic vehicle location. The latter stages are more expensive than the former and the application of each successive stage must demonstrate its cost-effectiveness.

It is felt that computerized dispatching will be a very important step in improving the efficiency of a taxi fleet, particularly for large suburban fleets of more than 25 vehicles. The principal advantages are the reduction of wasted mileage and of theft and the improvement of passenger service. The transition to computerized dispatching is not an easy change to make, however, and it is advisable only for strong, well-run companies with a good cooperative spirit between drivers, dispatcher and management. At least two companies are now using computerized dispatching and more will be taking advantage of the rapidly developing new technology in the near future.

The next and final chapter of this thesis sums up the major findings of this research and suggests a number of directions for future development of the taxi industry.

Notes on Chapter 5

1. Article in Computerworld, May 3, 1972 entitled "Getting A Cab Getting a Little Easier in L.A."

2. Article in Computerworld, February 23, 1972 entitled "Cabbie's Helper Lowers Fares, Aids Scheduling".

3. Discussions with George Coleman of Iteration Associates

4. Note that failures in unshared ride dispatching systems are much less likely to be critical than failures in shared ride systems

CHAPTER 6 MAJOR FINDINGS AND RECOMMENDATIONS

This thesis has investigated many features of taxi operations and fleet performance in an effort to come to a better understanding of the role taxis can play in providing urban transportation services. The major findings are now presented and discussed while the recommendations are given at the end of the chapter.

Few people are aware of the size and economic importance of the taxi industry. In New York City, taxis carry nearly a million passengers each weekday. Reliable taxi ridership data is difficult to find but estimates suggest that taxis handle approximately 1.7 billion passengers per year in the United States or almost one quarter of the entire public transportation market. More money is spent annually in the taxicab sector of the economy than in all other public transportation sectors combined.

In spite of the national significance of taxi transportation only a limited about of research has been done on taxis. Two major explanations for this oversight are that:

(1) taxis are private enterprise and have not naturally fallen under the jurisdiction of the public agencies which plan the transportation services for our cities

(2) taxi operators become so involved with keeping their own fleet running efficiently that they fail to recognize a need for large-scale studies of the service their industry provides.

Many comprehensive transportation planning studies have been carried out which either excluded taxis entirely or included only a limited amount of information about their use. (Note, however, that part of this problem is simply that a data base for taxi travel just does not exist.) Individual fleet owners do not have the time nor the resources to do extensive research. Nor does the International Taxicab Association (ITA), which limits its research to surveys of rate structures, taxi registrations by city and taxi operating costs (but some additional research is done in-house).

About half of all registered taxis belong to large city fleets. These fleets operate independently of one another and also independently of fixed-route transit service. Any apparent coordination in the provision of taxi service is the result of supply-demand interactions and not the result of deliberate planning by some public agency. If there is sufficient demand to profitably operate a taxi in a location previously unserved, an operator will recognize it and extend his services to cover that area. The provision of taxi service is purely the result of private enterprise seeking out business opportunities.

The single most important characteristic of taxi service is flexibility - with few exceptions, personal door-to-door service is provided to taxi customers when they want it and where they want it. It is this flexibility which gives taxis the property of smoothing over the gaps in public transportation service where routes do not exist or sufficient frequency is not provided. In many small cities and towns, taxi service is the only form of public transportation available. Taxis provide a vital community service for people not having immediate access to automobile transportation. They are particularly valuable for emergency service under conditions such as inclement weather, automobile breakdowns, injuries in home accidents and the breakdown of transit vehicles. In short, taxis take over where other modes of transportation leave off.

As pointed out in the thesis, exclusive taxi transportation is the only form of public transit that can be provided economically in sparsely-settled suburban and rural areas where transportation demand falls below 20 demands per square mile per hour.

In spite of its unique advantages in serving remote surburban and rural areas, taxi service is most popular as a mode of transportation within the central city areas of the large metropolis. Most taxi travel is anchored to activity centers such as hotels, transportation terminals, office buildings and theatres. This activity center orientation also dominates suburban taxi trips.

The personal nature of taxi service cannot be emphasized too strongly. People have always demonstrated a healthy willingness-to-pay for personal transportation. Horse-drawn taxis were common in the early 1900's and the use of taxis dates back in time at least as far as the Roman Empire. Today, taxi service has all of the flexibility advantages but few of the headaches associated with the personal automobile which never stops gaining popularity in the United States.

6.1 Taxi Operations

In examining the operation of the modern taxi fleet, two important statistics were found to be of prime importance to company operators for monitoring the efficiency and economic performance of the fleet - the percentage of paid miles and the revenue per mile travelled. The former (usually in the range of 40 to 50 percent) indicates how effectively both drivers and dispatchers are working to reduce "dead" miles, while the latter (usually varying between 30 and 40 cents per mile) is considered as an index of revenue relative to cost. Many operators, particularly those having only a small percentage of street work have found their total daily revenues to be an invariant, not to be augmented simply by putting additional cabs on the street. Consequently, their motivation becomes one of maximizing the revenue per mile, an objective which translates directly into one of maximizing the percentage of paid miles.

One of the major determinants of the type of taxi operation (apart from fleet size) is the location of the service area. If the fleet is suburban, phone orders account for a high percentage (up to 80 percent) of the trips. If several fleets are operating competitively in the same suburban service area, company reputation becomes very important and operators are found to be extremely concerned about pickup time responsiveness, cab appearance and driver courtesy.

Downtown fleets on the other hand, experience mostly street work - customers either walk to a cab stand or hail an empty cab on the street. Customers are usually not particular about the cabs they hail and take the first one available. Consequently downtown operators do not find themselves so compelled to worry about the appearance and condition of their fleet.

Because the majority of taxi trips focus on activity centers, cab stands are an important element of taxi operations. Most municipalities (taxi regulation and control is a local matter) do not allow cruising and require cabs to proceed to a cab stand when idle. If cab stands are poorly located or if drivers do not make proper use of these stands, fleet performance will suffer from needlessly wasted mileage.

Dispatching lies at the very heart of fleet control but the radio dispatcher usually has direct control only over the phone orders. Because of the high percentage of phone orders, suburban fleets tend to be very centrally controlled with the dispatcher making most of the logistical decisions whereas downtown operations tend to be very de-centralized with the dispatcher doing only a small proportion of the overall decision-making.

The dispatcher has an extremely demanding task - for suburban operations in particular he is the key to fleet efficiency. But the importance of his role declines as the proportion of phone orders gets smaller and smaller. The dispatcher decides

(a) which vehicle should service each caller

and (b) how to redistribute taxis not advantageously to meet future demands.

Dispatching efficiency depends greatly upon how taxis are selected by the dispatcher to handle the incoming service requests. Three alternative vehicle selection criteria were developed and presented. Knowledge of these criteria is essential for the computerization of the dispatching process.

In spite of the proportionately low dispatching cost (about 6 percent of the total operating cost) dispatching exerts leverage on a much larger proportion of operating costs.

6.2 Fleet Performance

A number of models were developed to simulate the performance of fleets operating in 3 different demand configurations - many-to-many,

many-to-one and one-to-one. These basic demand patterns are the elemental components of the taxi demand patterns experienced in the real world.

Queuing was hypothesized to be the basic phenomenon behind taxi fleet performance and was found to predict passenger pickup times for the Belmont taxi fleet (a suburban operation) quite closely. The model was not, however, as accurate in predicting the percentage of paid miles experienced by the fleet. The queuing delay curve was found to be a common characteristicsin the servicing of each type of demand pattern. For a service area of a particular demand density, the queuing delay curve indicates how phone order pickup delay varies with fleet size.

A recommendation is made, however, that more research using computer simulations of fleet performance should be carried out to conclusively verify the queuing nature of taxi fleet performance.

The queuing models developed suggest a number of important features of taxi fleet performance:

(1) As the density of demands for taxi service increases, fleets are able to operate more efficiently - at a higher percentage of paid miles, a better level of service, and in some cases higher productivities than before. This suggests that suburban fleets which operate at very low demand densities should be permitted to charge higher fares than their downtown counterparts.

(2) For a given number of taxis operating in a service area it is preferable from efficiency considerations to minimize the number of independent dispatching units (which also entails minimizing the

number of taxi fleets). One or a few large fleets can offer quicker service to phone orders and less "dead" mileage (and therefore lower operating costs) than many small fleets.

(3) Cooperative dispatching systems should be considered by independent fleets operating within the same service area. By pooling their dispatching operations, customer service and operating costs can both be significantly improved. (This recommendation is difficult to implement,however, because taxi companies tend to be fiercely independent and proud of their own operations. Pooled dispatching would submerge fleet identity in the servicing of phone orders.)

6.3 Taxis and Ride Sharing

Taxis appear to be a transportation resource that is underutilized. This underutilization occurs because taxis are operated primarily as an unshared ride operation and the fares charged are relatively high (about two dollars on the average). Various sources indicate that on the average 1.2 to 2.0 persons are carried with each taxi trip. But because of the queuing nature of taxi service, taxis are engaged with a fare less than 50 percent of their time on duty. (Any attempts to increase this utilization would have a drastic impact on fleet availability and phone order pickup times.)

Because typical fleet productivities are between 2 and 3 fares per cab hour, taxis generally carry only about 3 to 6 passengers per cab hour. Research indicates that with ride sharing, this productivity could be doubled.

No recommendation is being made that taxis no longer offer exclusive service, merely that taxis extend the range of services currently offered to the travelling public.

It is suggested that there are two markets for taxi service - one for exclusive taxi service at an average fare of about two dollars (the market which is currently being served) and one for shared ride taxi service at an average fare of about one dollar (a market which very few taxi companies cover). One must speculate that a small proportion of current taxi ridership might switch to the shared-ride market if shared-ride services were made available.

The question remaining, however, is what is the size of the ride-sharing market? This market has been tested very little - by the few taxi companies that currently offer shared rides and recently by a number of Dial-a-Bus demonstration projects. These Dial-a-Bus projects have had difficulty stimulating the market to the point where the operation became self-supporting. Very few of these projects however, had economic self-sufficiency as a single objective (since there are many other objectives in public transportation which must also be weighted heavily). Consequently fares were often set far below the break-even level.

In the provision of shared ride services, taxis have a number of very strong advantages over transit-operated Dial-a-Bus:

(1) The hourly operating costs for taxis ($3.85 to $7.35 per hour including tips as wages) are about half the hourly operating costs for transit-operated Dial-a-Bus ($7.00 to $12.00 per hour)

(2) Experienced taxi operators are well-established all over the country. Ride sharing would simply operate as an extension of the service they now offer, and

(3) Taxi drivers are thoroughly familiar with the topography of their service area, with the streets and house numbers.

However, there are also a number of disadvantages to having taxis operate a ride-sharing service:

(1) Many taxi operators are not favorably disposed to the idea of ride sharing

(2) Taxis become subject to ICC regulation if the vehicles are to carry more than 6 passengers.[1] This limit constrains the hourly productivities that would be achievable under ride-sharing, and

(3) Ride sharing would require a new method of fare calculation which could not likely make use of the taximeter.

This third consideration suggests that a computer might be used to calculate fares based upon airline distance travelled and vehicle occupancy. The fare-calculation feature could be built into a taxi-dispatching computer in much the same way as the Royal Cab operation at Davenport, Iowa.

6.4 The Potential for Computerization

The use of computers is starting to make inroads within the taxi industry and could revolutionize taxi operations. Individual fleets will increasingly find the computer an asset in setting up information systems to monitor the daily performance of the fleet.

Computerized dispatching has great potential, particularly in the operation of large suburban fleets having in excess of 25 vehicles. The computer is capable of keeping track of the locations and occupancy of large numbers of cabs and has the ability to predict which cab will be able to make a pickup first. Computerized dispatching brings about central control which will result in faster, more reliable pickup service, fewer dead miles travelled and less theft on the part of the drivers. However, each installation must demonstrate that the savings it brings will more than cover the costs. The ultimate test of the viability of computerized dispatching is to install it and compare net revenues both before and after the installation.

Computerized dispatching is felt to have even more potential for ride-sharing operations where the decision-making process of the dispatcher is complicated by service time guarantees for each passenger being carried. The computer becomes very attractive as a dispatching aid in shared-ride systems and becomes almost a necessity if the fleet is large. The computer also has the flexibility to carry out unshared-ride and shared-ride dispatching simultaneously.

6.5 The Need for Further Taxi Research

Taxis provide a unique and much-needed transportation service. But a better understanding of this service is required if taxis are to be able to assume an even greater role in urban transportation of which they are capable. Unfortunately, very little research on taxis has been carried out because of the private and fragmented nature of the industry. The following recommendations are therefore made:

(1) The Federal Government should make funding available to the International Taxicab Association to assist in collecting data about the industry and to make ongoing studies.

(2) The Federal Government should undertake a major study of the

taxicab industry. Specific issues to be examined include:

(a) the desirability of ride-sharing

(b) the feasibility of centralized cooperative dispatching

(c) degree of competition desirable within the industry

(d) medallions and free entry

(e) the potential for special community services.

(3) The queuing models of fleet performance presented in Chapter 4 should be verified by computer simulation. In particular, more analyses of the percent paid miles theoretically achievable should be carried out. This will give further insight into the economic advantage of computerized dispatching.

(4) More research is needed on how to make more effective use of computers and digital communications equipment in the taxi industry.

(5) The cost effectiveness of applying each of the alternative vehicle selection criteria presented in section 3.2 should be further examined.

Taxis are a valuable urban transportation resource. Transportation planners need to make themselves more aware of the unique capabilities of taxi systems.

Notes on Chapter 6

1. The Motor Carrier Act of 1935, as amended Title 49 United States Code, Section 303(b). Exempted from this Act are taxicabs, or other motor vehicles performing a bona fide taxicab service having a capacity of not more than 6 passengers and not operated on a regular route or between fixed termini.

APPENDIX A: BELMONT CAB COMPANY

This appendix describes a taxi company in the Boston area, its operation and its dispatching system. Very little, if any information about the operation of a taxi company has ever appeared in the transportation literature. One of the major purposes of the investigation which follows is to examine an existing company to see what type of demand pattern its taxis serve, what productivities and levels of vehicle utilization are being achieved and what standard of service is being afforded taxi users.

The Belmont Cab Company operates in the town of Belmont, Massachusetts which is situated about 8 miles northwest of downtown Boston. An appreciation of the location of Belmont relative to Boston and other neighboring communities can be gained by looking at Figure A1.

Taxi service is currently provided for the town by 2 companies - Belmont Cab Company with 21 taxis and Morse Taxi with 9 vehicles. The license granted to the two companies permits each to pick up customers from the streets within Belmont. All other taxi companies can respond to phone orders in Belmont but are not allowed to do street work in the town.

Description of the Service Area

Because Belmont is predominantly a residential community with very few areas of commercial activity, most of the requests for taxi service are made by phone. But the taxi trip pattern is strongly polarized by the activity centers which are shown in Figure A2. Belmont Center, Waverly Square (location of Belmont Cab Headquarters), Cushing Square and Watertown Square are the four major commercial centers in the

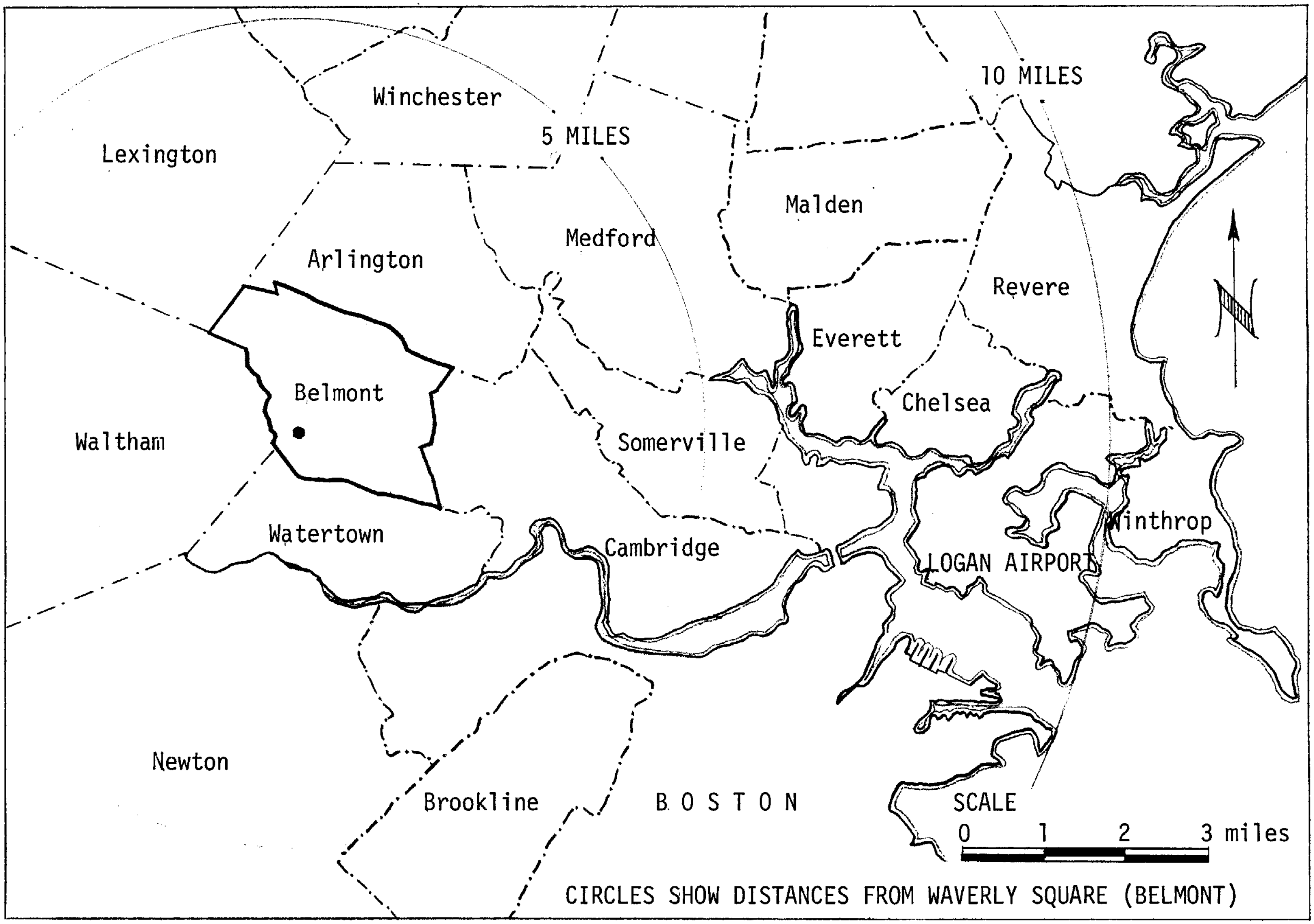


FIGURE A1 : LOCATION OF BELMONT IN THE BOSTON AREA

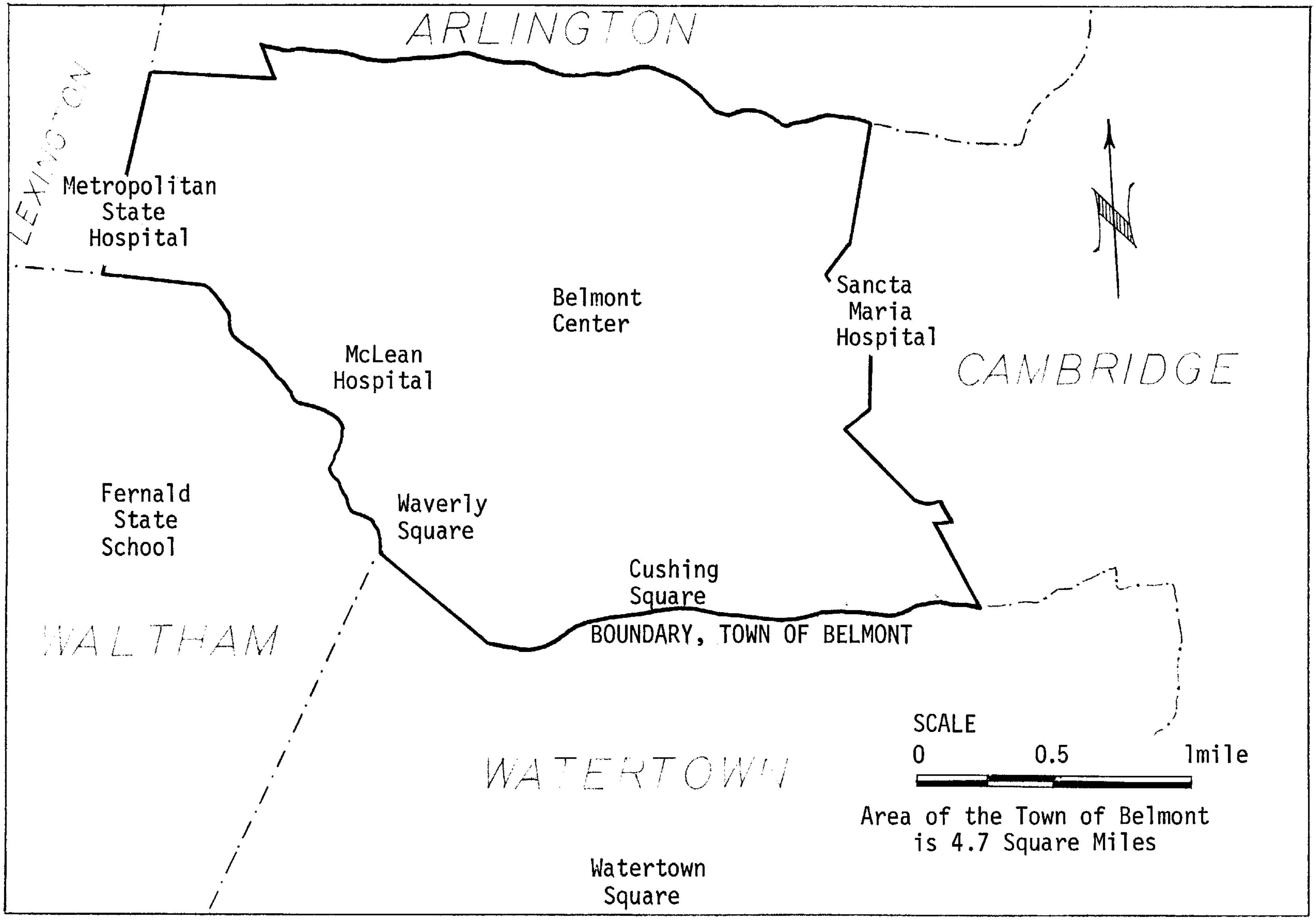


FIGURE A2 : ACTIVITY CENTERS IN THE BELMONT AREA

Belmont area. Three hospitals, the McLean Hospital (psychiatric), the Metropolitan State Hospital (psychiatric) and the Sancta Maria Hospital are strong taxi traffic generators - particularly the McLean Hospital which is close to Waverly Square. Finally, the Fernald State School (for retarded children) is responsible for many taxi trips.

Figure A3 shows the locations of the 22 Belmont Taxi cab stands in the areas of commercial activity (see also Figure A5). The number of cab stands at each location is approximately proportional to the number of taxi trip ends at that location.

The town of Belmont covers an area of 4.7 square miles and measures about 2-1/2 miles long by 2 miles wide. It can be crossed in about 7 minutes, driving at the speed limit. The off-peak travel time contours measured in minutes from Waverly Square are illustrated in Figure A4. Being sufficiently remote from downtown Boston, Belmont experiences only light congestion during peak hours.

Most of the land area of Belmont is residential, primarily with single family homes, but there are many multiple units towards the southern boundary of the town. Figure A5 depicts the population density of the area. The sparsely-populated sector to the north and west contains the most exclusive homes of Belmont. According to the 1970 census, properties range in value from an average of about $30,000 near the Southern boundary to about $60,000 in the north and west sector. Many of the families in the Belmont area own two or more cars.

The business and commercial areas of Belmont are shown with hatched markings and as previously mentioned, each of these areas has a cab stand. MBTA bus service links each of the commercial areas to the rapid transit station at Harvard Square to the east. Belmont Taxi

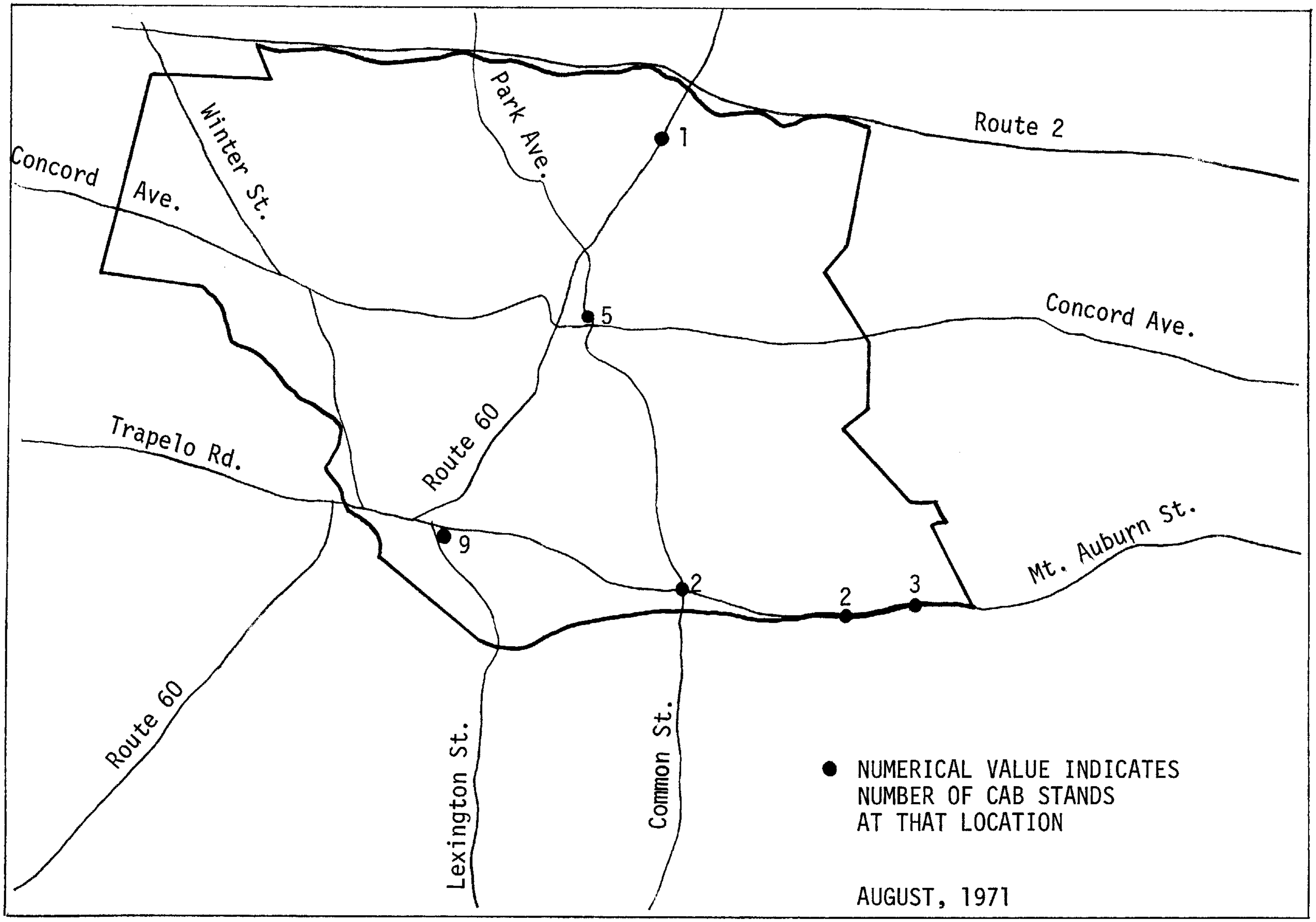


FIGURE A3 : BELMONT TAXI, CAB STAND LOCATIONS

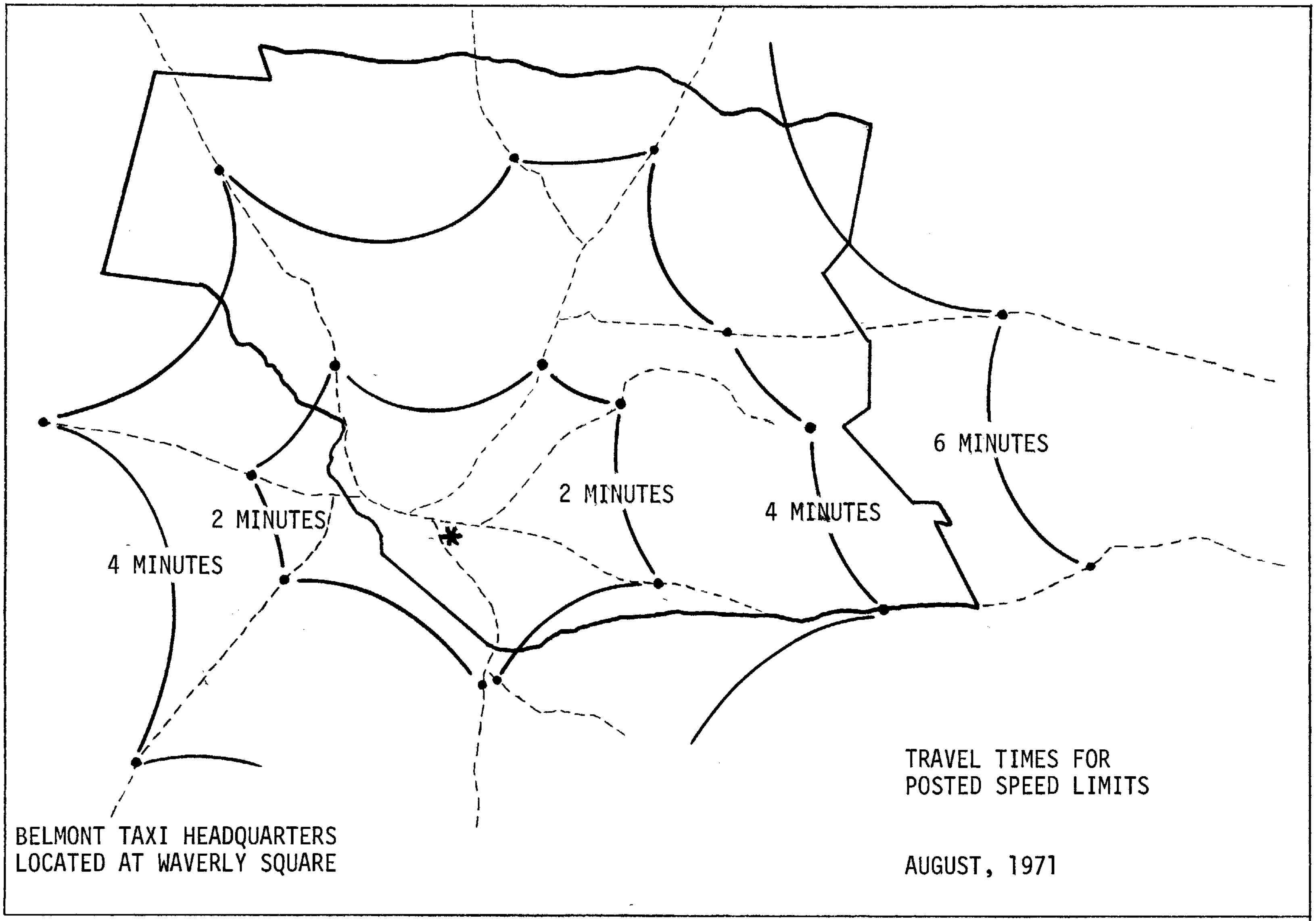


FIGURE A4 : RADIAL TRAVEL TIMES (OFF PEAK) FROM WAVERLY SQUARE

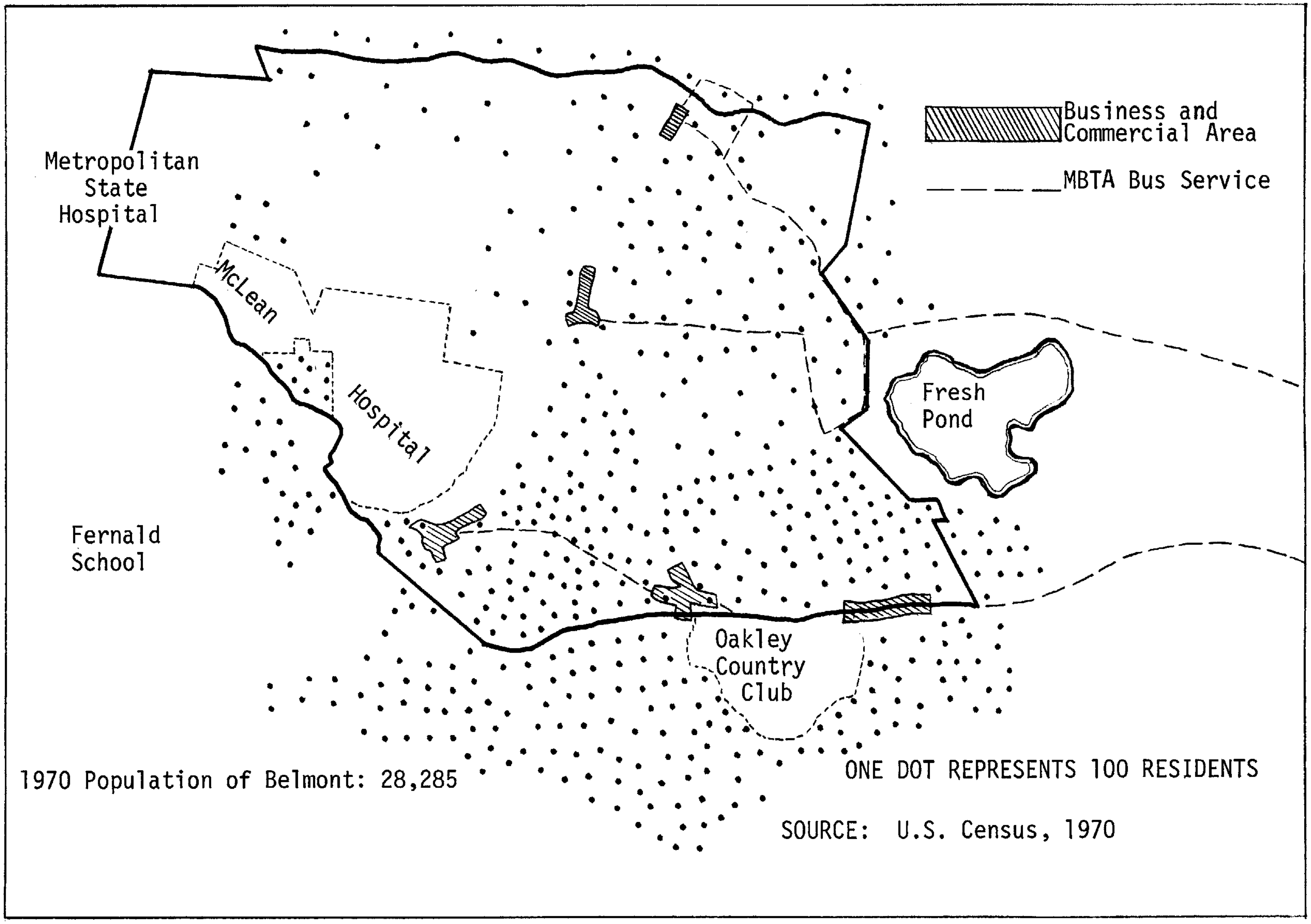


FIGURE A5 : BELMONT AREA POPULATION DENSITY AND PUBLIC TRANSIT SERVICE provides a distributor service for bus passengers, particularly at the end of the line in Waverly Square and also in Belmont Center.

Belmont Cab Operations

The headquarters of Belmont Cab is situated in Waverly Square. The dispatcher not only controls the fleet but he takes phone orders as well. One of the advantages of the dispatcher answering the phones is that he is able to quote pickup times to the customers. His knowledge of vehicle locations allows him to predict pickup times very reliably.

The dispatcher uses a simple visual aid to assist him in keeping track of the fleet, a dispatching board. The wooden board measures about 2-1/2 feet long by 9 inches wide and has 3 rows of hooks (about thirty in total). The phone orders for each cab are placed face upward on a particular hook as they are assigned to that cab. Any street work done by a cab is radioed in to the dispatcher who writes out the order and puts it on the correct hook. At a glance the dispatcher can see the last assignment for each cab and can determine the approximate location of all cabs.

As calls come in, the dispatcher writes down the customer's origin, destination and in the case of an advance order, the time at which the cab is requested. (Advance orders are placed on a special hook and are assigned to drivers as the orders come due.) The dispatcher then tries to determine the closest available cab to make the pickup. The radio is sometimes used to ask if any cabs are near a certain location.

As soon as the pickup information has been radioed to the nearest cab, the dispatcher marks down the number of that cab on the order and places the order on the correct hook of the dispatching board, thereby updating his location record.

Frequent use is made of the radio by cab drivers to advise the dispatcher of changes in location and in job status. Drivers radio in:

(1) whenever they pick up or drop off a customer

(2) whenever they are approaching the Belmont area, returning empty after a distant trip

(3) whenever they go off duty either temporarily or for the day.

One of the most important operating rules adopted by the company is that drivers proceed to the nearest taxi stand as soon as they become free, and they wait there for further instructions. If necessary, the dispatcher re-distributes the idle vehicles to locations where the demand is highest.

The daily performance of the fleet and of individual drivers is monitored by reviewing the cents per mile statistic (total day's revenue collected divided by the total day's miles travelled). A return of 40 cents per mile would be considered as very good performance while a return of 33 cents per mile would be considered as poor performance.

If the performance statistic for the entire fleet is several cents below the objective of 40 cents per mile then the dispatcher is probably not doing an efficient job. A day-to-day variation of 2 or 3 cents in the cents per mile statistic for the individual drivers is to be expected however, for even the most consistent drivers have good days and bad days.

The following summary lists the techniques used by Belmont Cab to maintain a high level of fleet efficiency:

(1) The dispatcher has a visual aid from which he can determine the locations and status of each cab.

(2) Cab drivers are in constant radio communication with the dispatcher.

(3) The dispatcher attempts, whenever possible, to give two calls in sequence to a cab. This matching of taxi trips end-to-end is one of the best methods for reducing dead mileage and increasing taxi utilization.

(4) When drivers return empty from outside the Belmont area, they advise the dispatcher of their location well before they enter the demand-intensive area.

(5) Idle taxis are not permitted to cruise the streets but must return to the closest cab stand, thereby eliminating wasted mileage.

(6) Cab stands are situated in key locations in the business centers and at the ends of bus lines where they are most likely to attract customers.

(7) The dispatcher anticipates demand by re-routing his taxis to the most appropriate locations.

(8) The dispatcher carefully screens all incoming calls. Trip requests well outside the service area are referred to another taxi company. Calls which are likely to result in a no-show are discouraged by quoting long pickup times.

(9) Any activities which result in taxis being temporarily taken out of service (gas and oil stops, cab wash, lunch and coffee breaks) are scheduled for off-peak hours.

(10) The dispatcher, having driven a cab himself, is thoroughly familiar with the service area - the streets, house numbers and clientele, and can provide drivers with quick assistance over the radio.

(11) The weekday dispatcher is also in charge of hiring and firing the drivers. They respect him not only as their manager but also for his capability and equity as a dispatcher. This aspect is of prime importance

for a smooth, efficient taxi operation.

Results of a One-Day Survey of Belmont Cab Company

In order to gain a more thorough appreciation of the demand served by Belmont Cab, the utilization of the fleet and the level of service afforded the taxi users, the operation was monitored for a one day period - Tuesday, August 31, 1971. All incoming calls and street orders were recorded from 5:30 a.m. when the company opened to 12:30 a.m. the following night.

The following information was noted for each taxi trip:

1) origin and destination
2) time the order was received
3) whether the order was initiated by phone, from a cab stand or from the street
4) cab to which the trip was assigned
5) time of pickup and delivery.

The waybills of each driver (containing the day's trip fare and mileage records) were also reviewed for fare and mileage statistics.

The survey was conducted during an off-peak time of the year (as shown by Figure A6). (Taxis, like other forms of public transportation experience winter peaking.) The use of taxis is strongest during the week with ridership declining significantly on Saturday and Sunday.(See Figure A7.) The ridership on Tuesday, the day on which the survey was taken is about average for a weekday.

The Demand Served

A total of 391 taxi trips were made during the 19 hour service

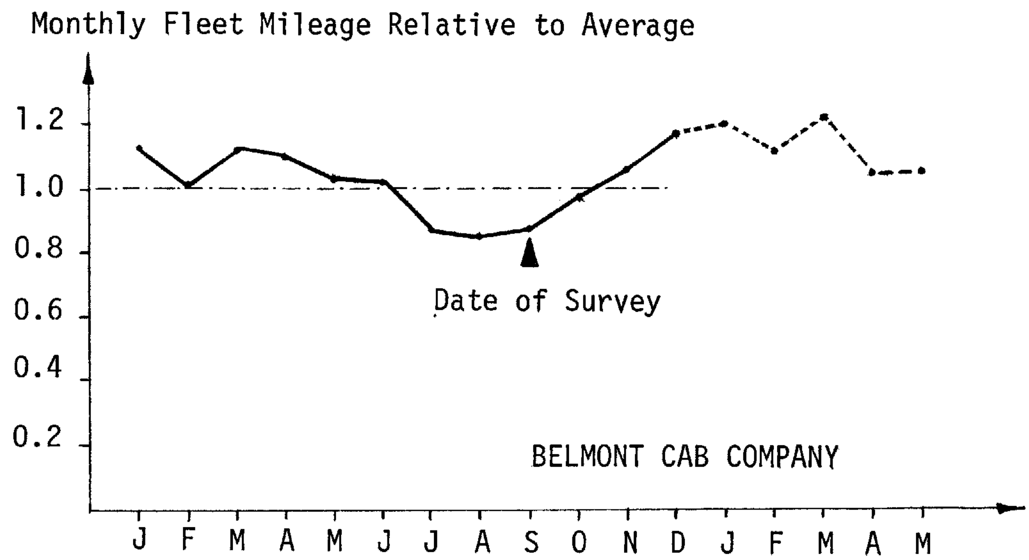


FIGURE A6 : SEASONAL VARIATION IN TAXI TRAFFIC, 1971

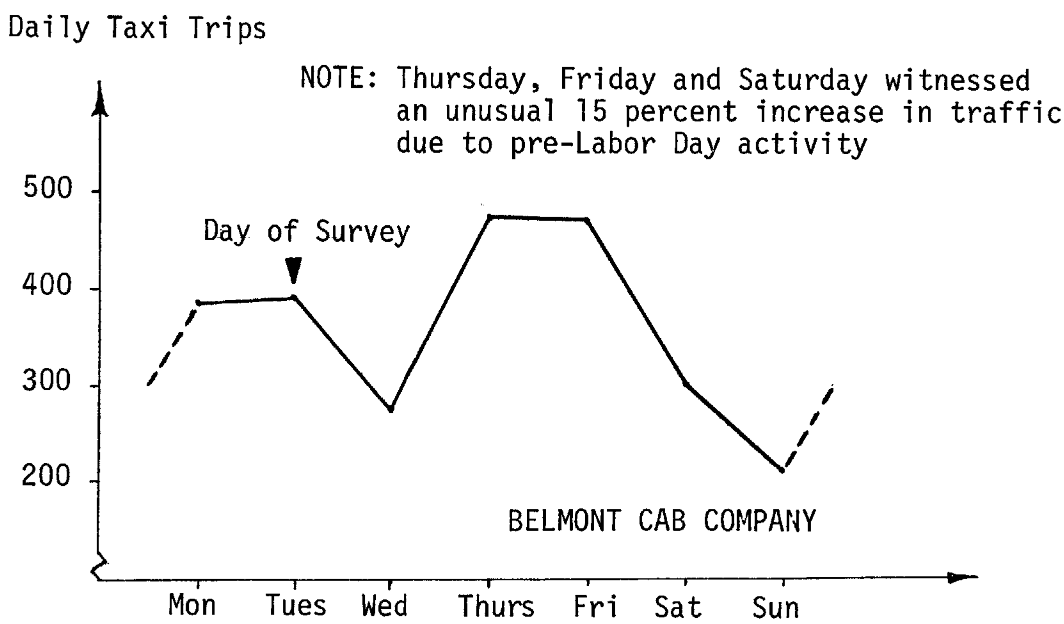


FIGURE A7 : TRAFFIC PEAKING DURING WEEK OF AUGUST 30 TO SEPTEMBER 5, 1971 period (an average of 21 calls per hour). Figure A8 shows the pattern of incoming calls. The peak hourly demand occurred in the morning from 8:30 a.m. to 9:30 a.m. when 43 calls were handled. Slight early afternoon peaking is also evident. A maximum of 15 cabs were in service at any time.

As mentioned previously, activity centers are major generators and attractors of taxi trips. On the survey Tuesday, 79 percent of all trips either originated or terminated at an activity center. An appreciation of the trip generation pattern for the survey day can be gained by looking at Figure A9. The dominance of activity centers is immediately apparent.

The telephone was used to initiate 61 percent of the taxi trips. (38 percent were stand pickups and less than 1 percent were the result of street hailing.) This predominance of phone orders in Belmont is in marked contrast to downtown Boston where about 20 percent of the taxi trips are the result of a telephone order.

To gain an appreciation of how taxi trip patterns vary from hour to hour during the day they were plotted and are shown in Figures A10 through A19. Each of the figures covers a two-hour period except the last one which covers a single hour. Taxi trips are shown by an arrow.

Figure A10 shows the early morning taxi activity centered on Waverly Square - mostly working people travelling at the beginning or end of their shift. The peak period taxi activity is displayed on the next diagram. Strong one-to-one and many-to-many taxi patterns are evident. The mid-morning period (Figure A12) is characterized by a strong flux of trips toward Cambridge and Boston. Although one might have expected an increase of taxi travel during the noon lunch hours, the two-hour period from 11:30

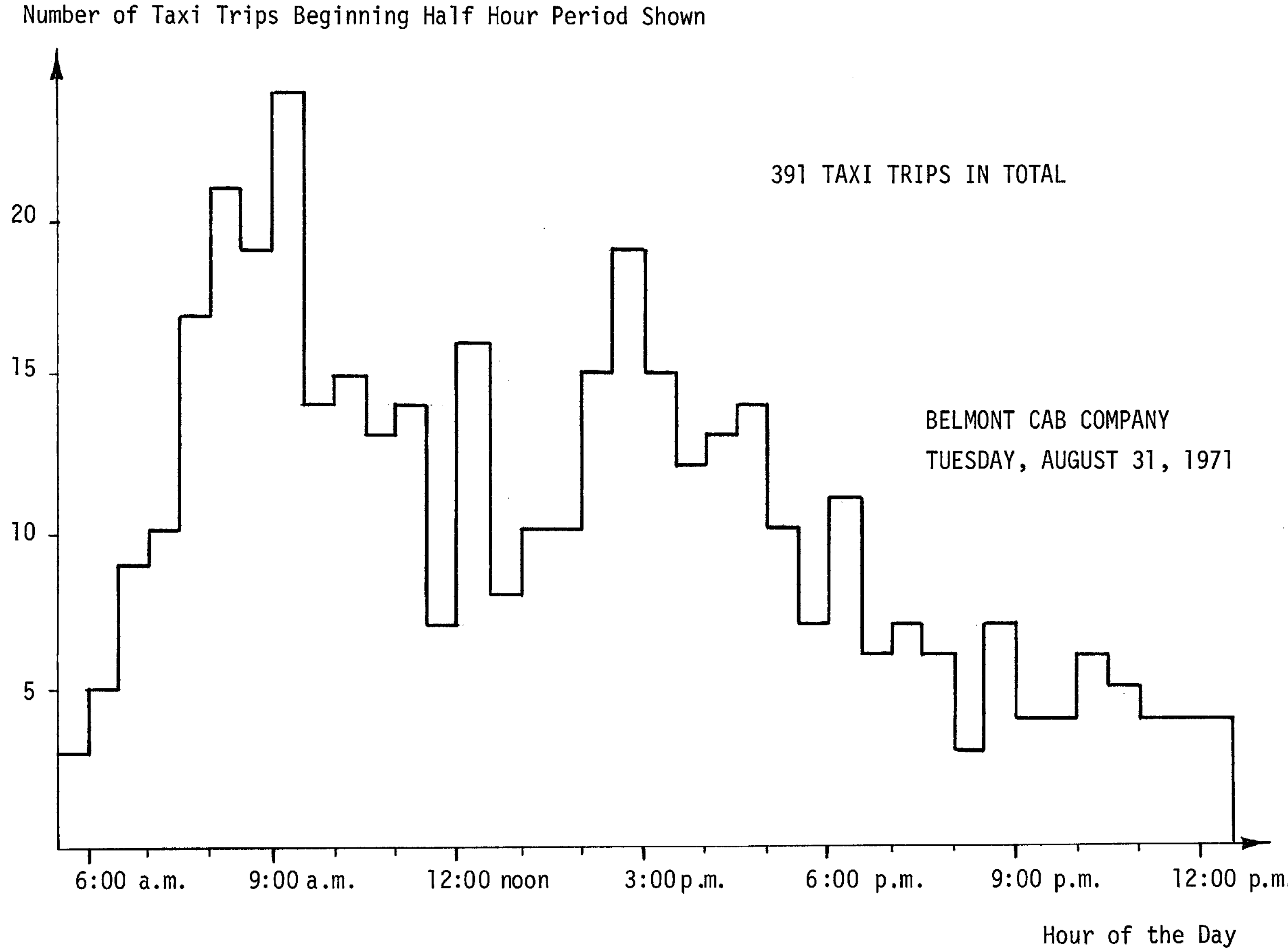


FIGURE A8 : DISTRIBUTION OF TAXI TRIPS BY HOUR OF THE DAY

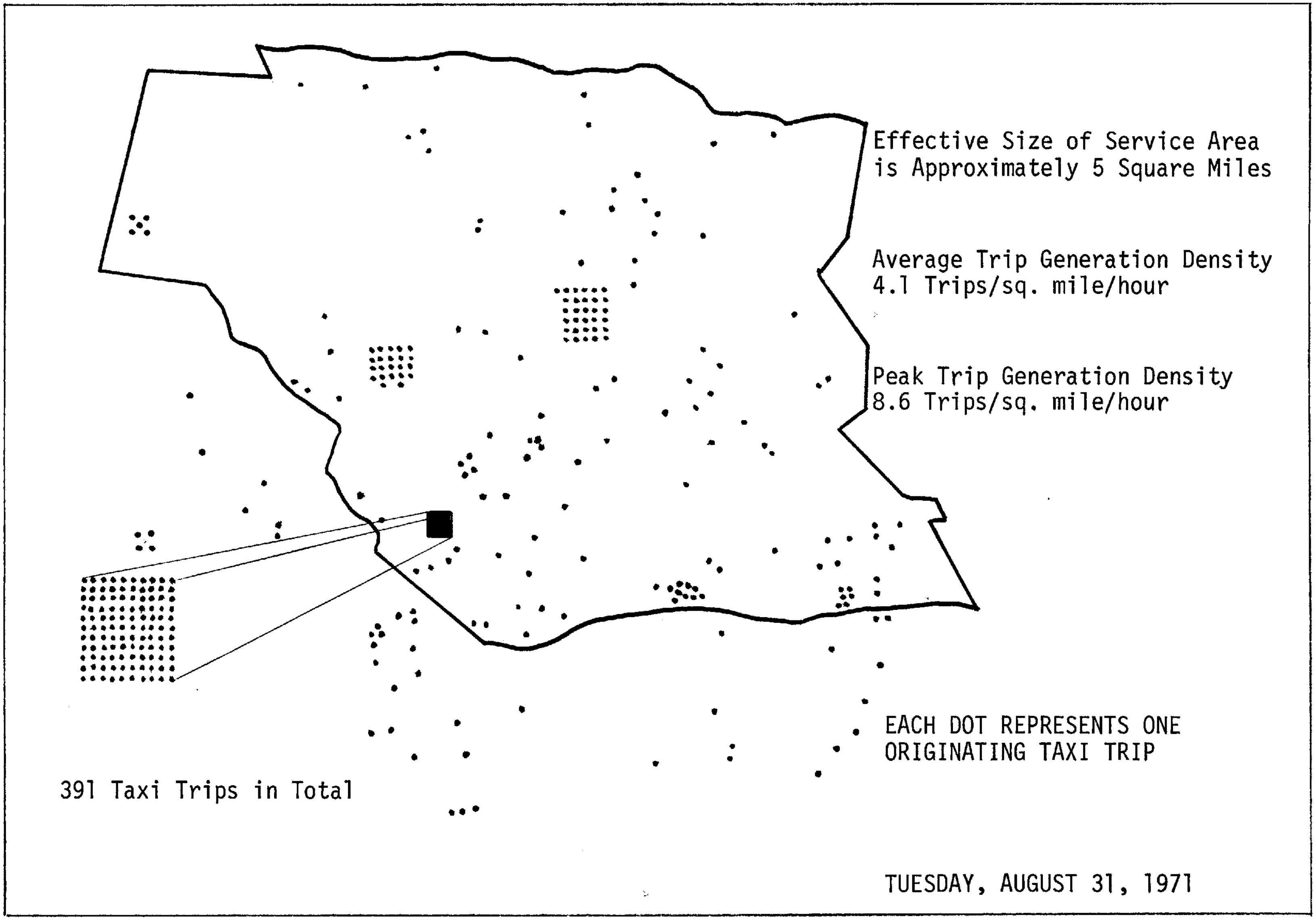


FIGURE A9 : BELMONT TAXI TRIP ORIGIN PATTERN OVER A ONE DAY PERIOD

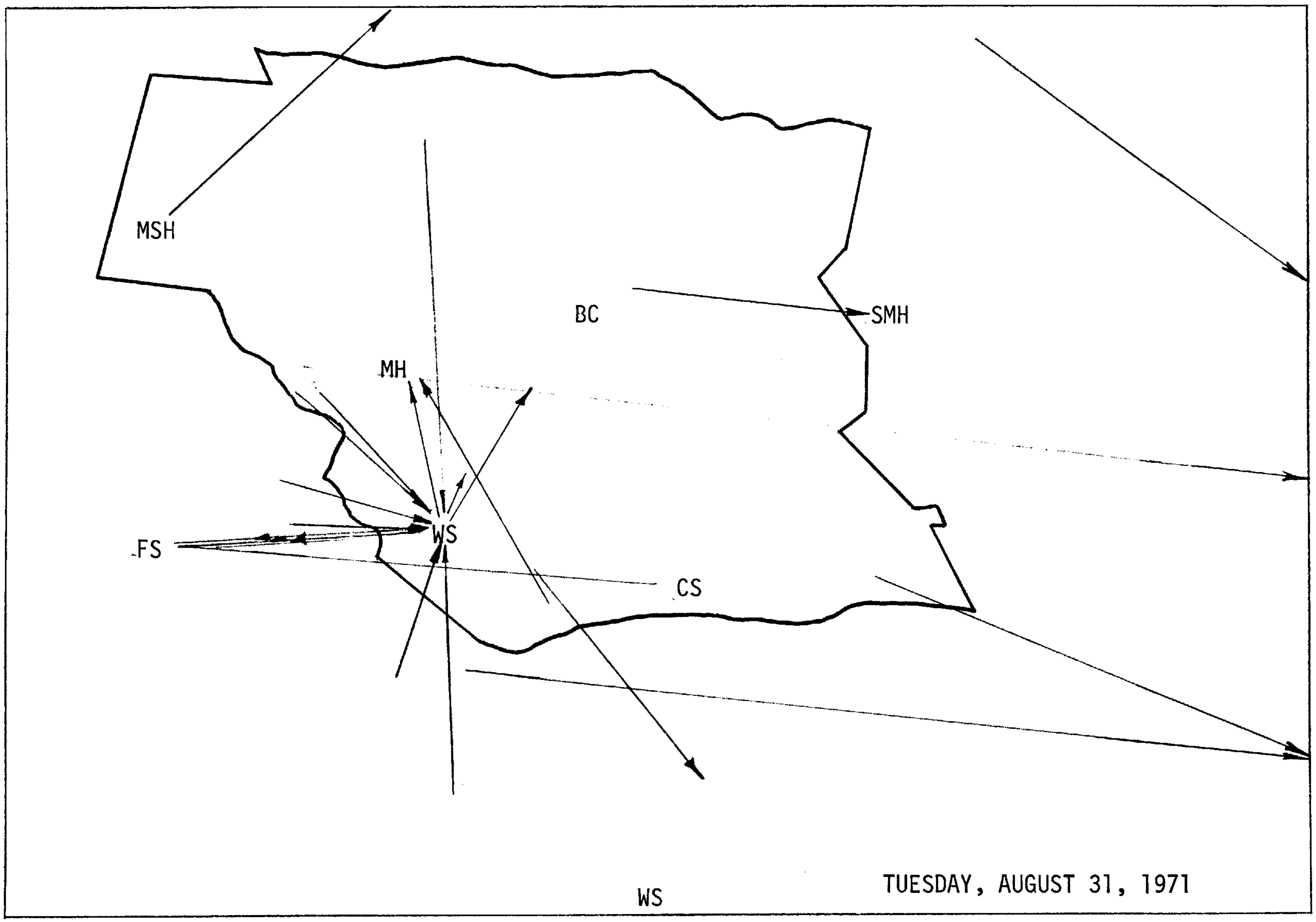


FIGURE A10 : BELMONT TAXI TRIP PATTERN, 5:30 a.m. TO 7:30 a.m.

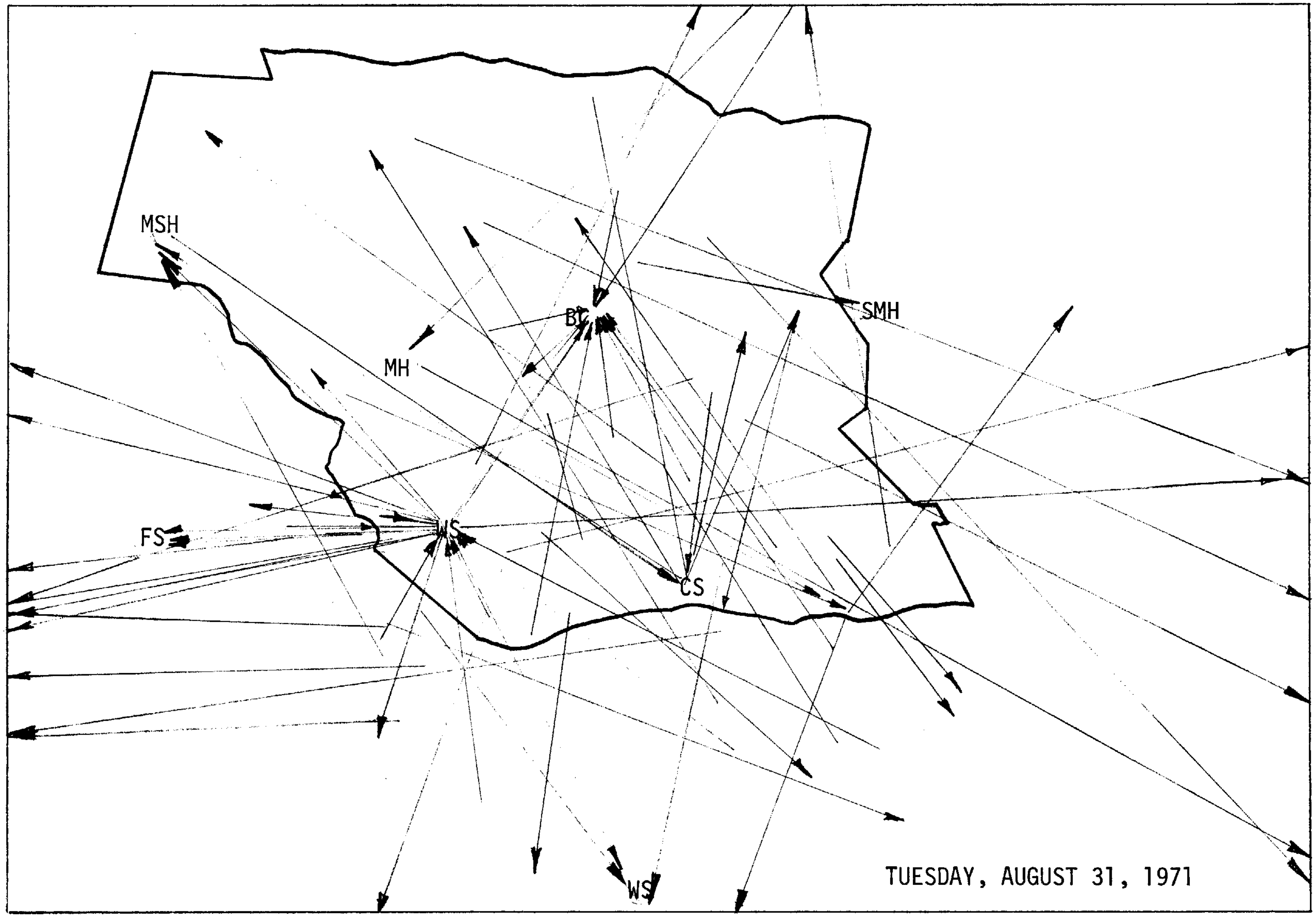


FIGURE A11 : BELMONT TAXI TRIP PATTERN, 7:30 a.m. TO 9:30 a.m.

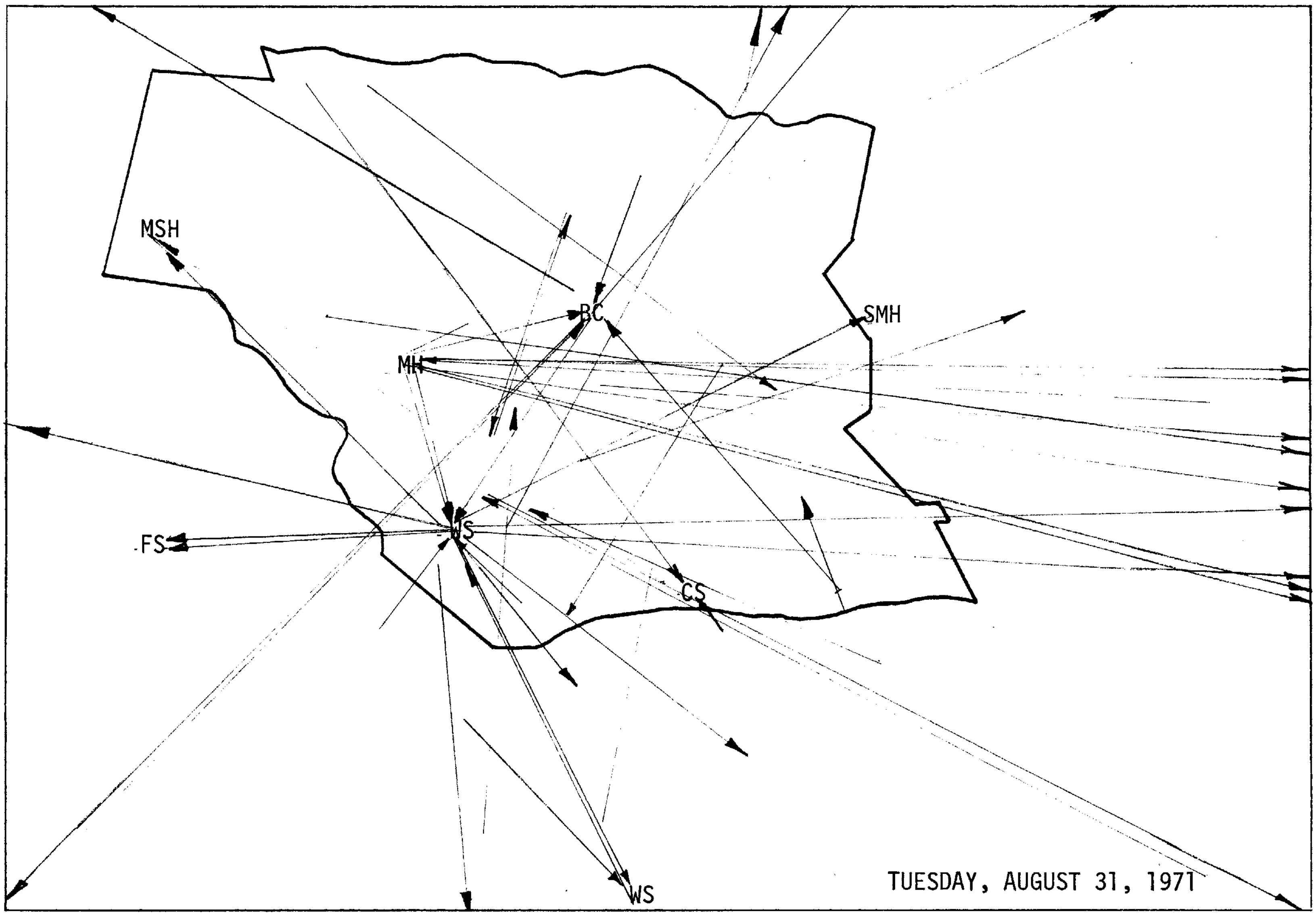


FIGURE A12 : BELMONT TAXI TRIP PATTERN, 9:30 a.m. TO 11:30 a.m.

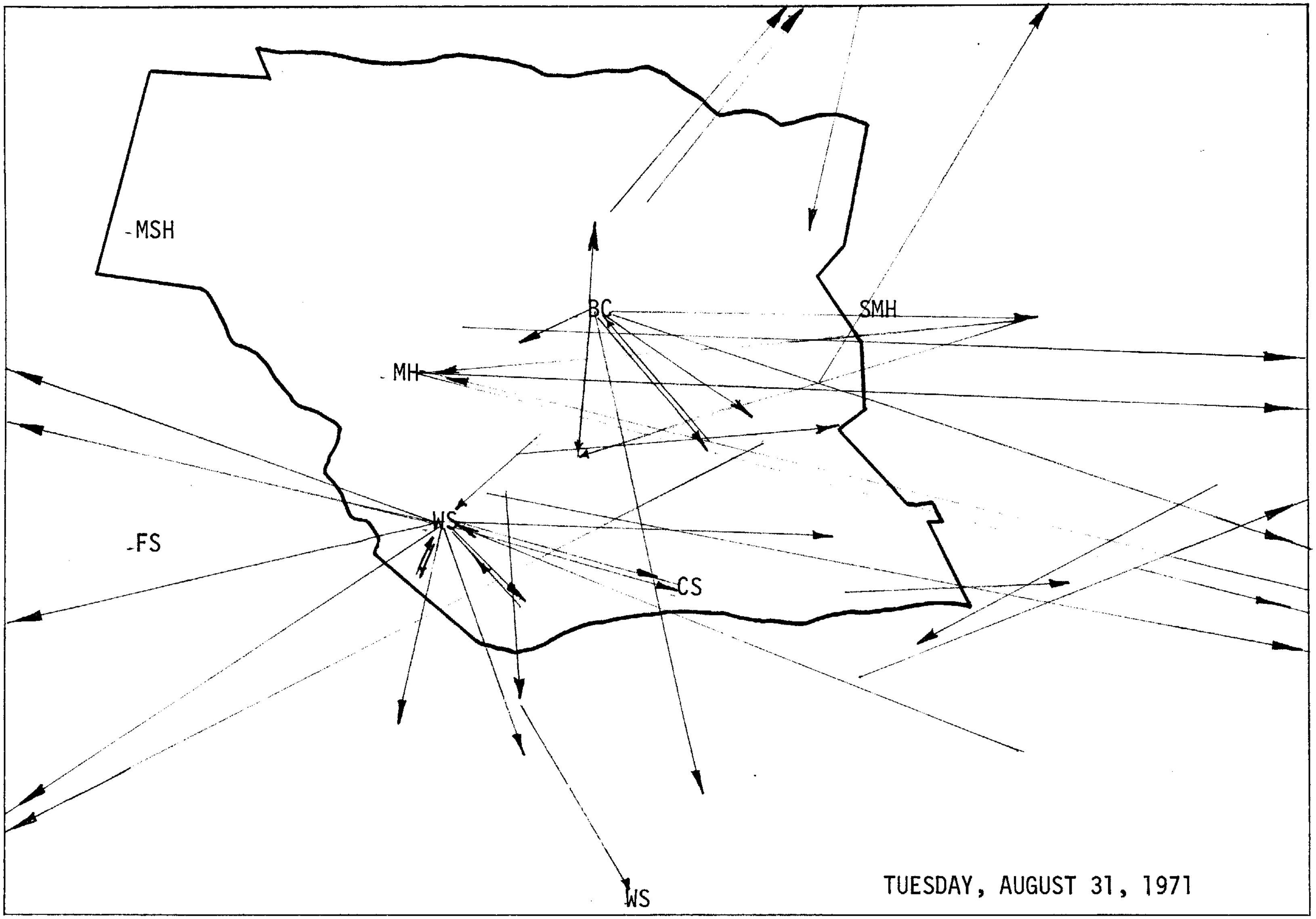


FIGURE A13 : BELMONT TAXI TRIP PATTERN, 11:30 a.m. TO 1:30 p.m.

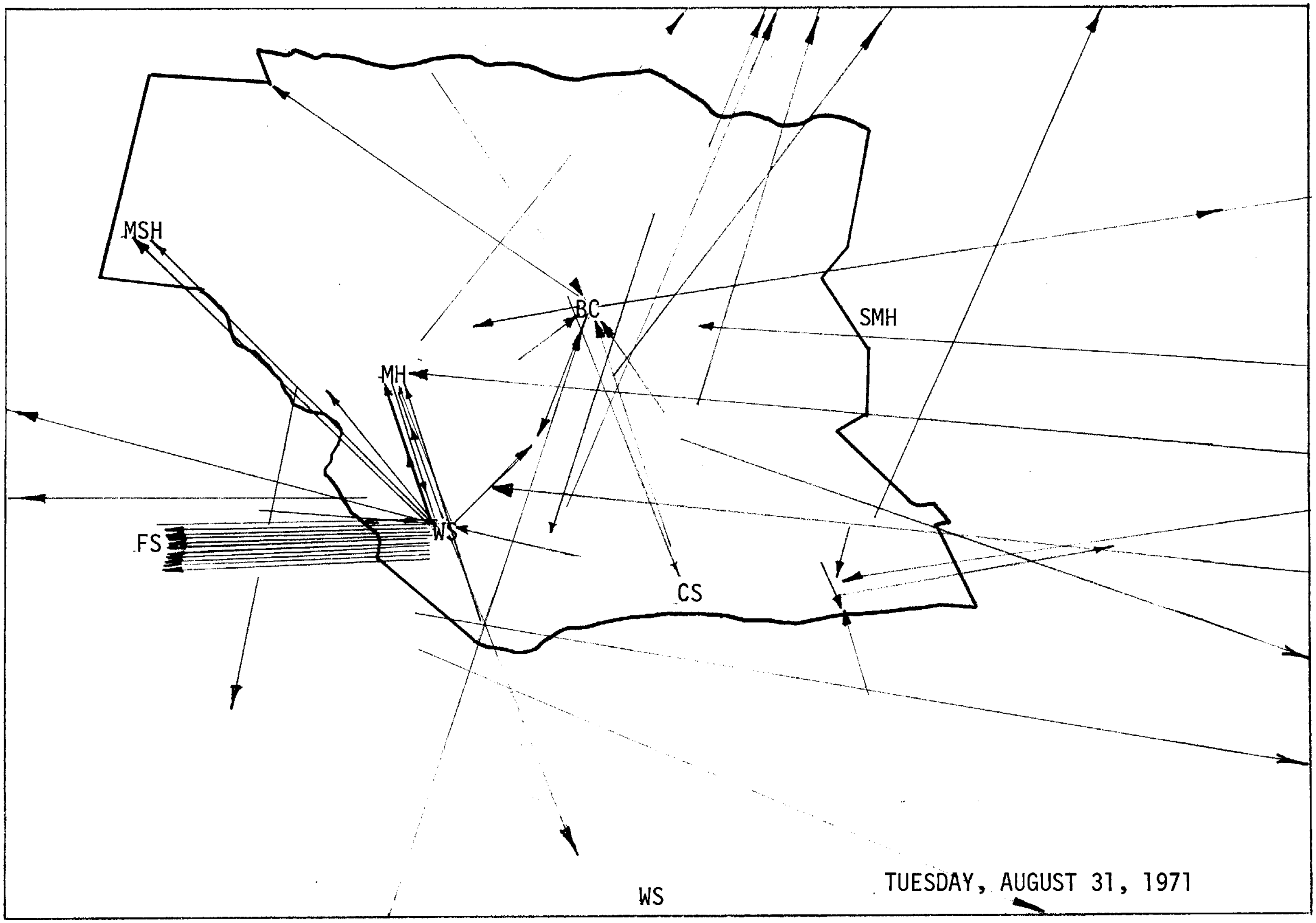


FIGURE A14 : BELMONT TAXI TRIP PATTERN, 1:30 p.m. TO 3:30 p.m.

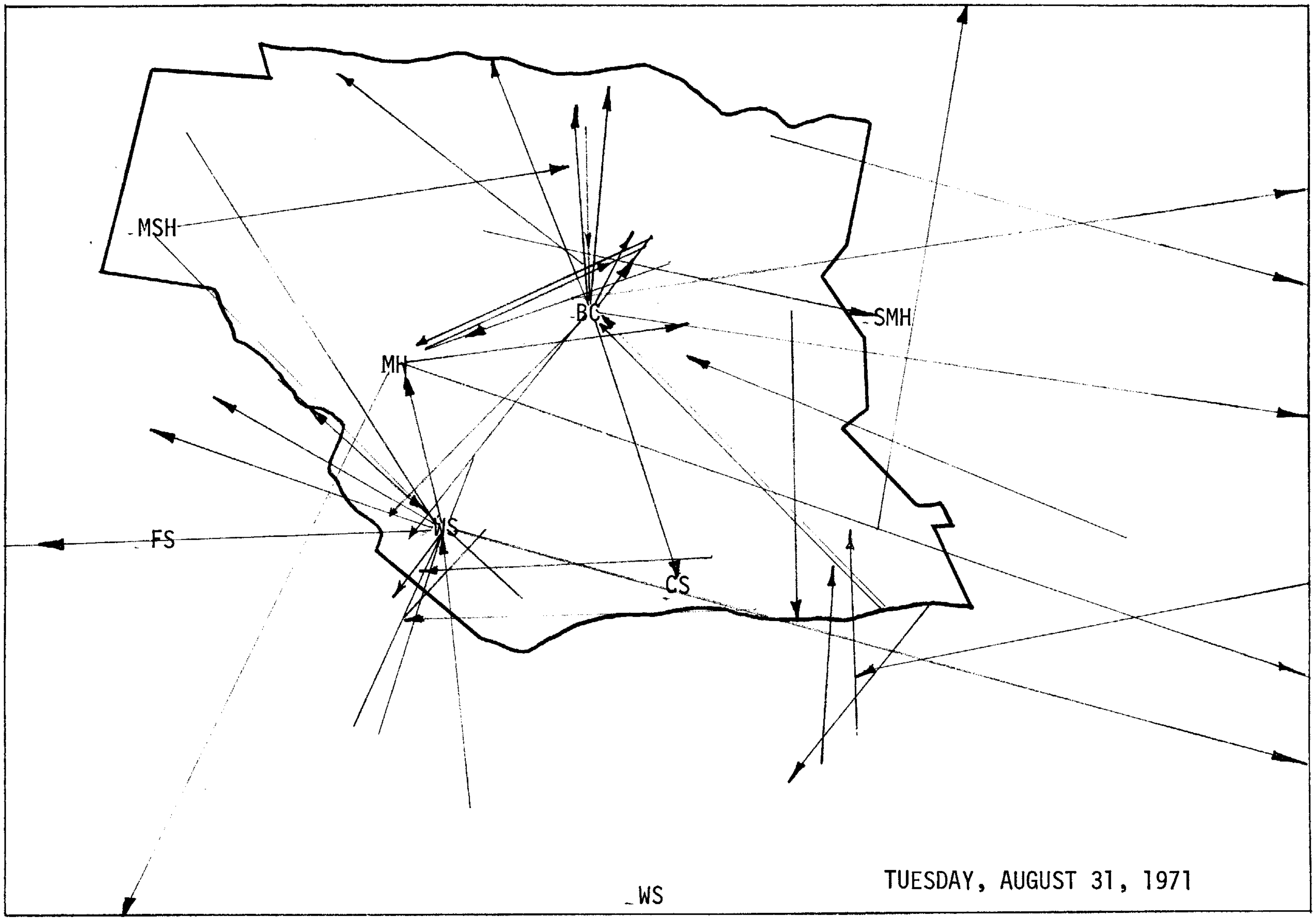


FIGURE A15 : BELMONT TAXI TRIP PATTERN, 3:30 p.m. TO 5:30 p.m.

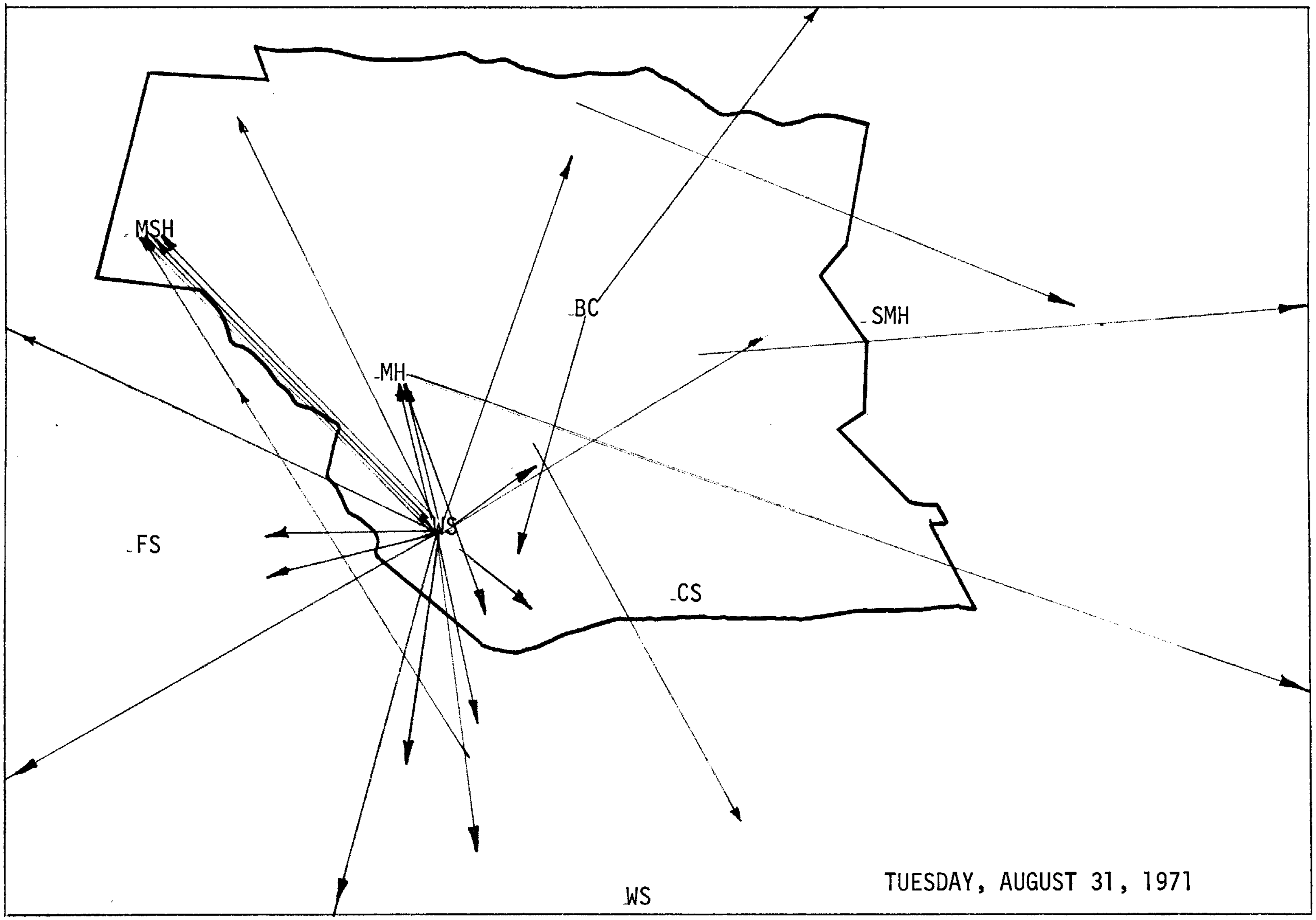


FIGURE A16 : BELMONT TAXI TRIP PATTERN, 5:30 p.m. TO 7:30 p.m.

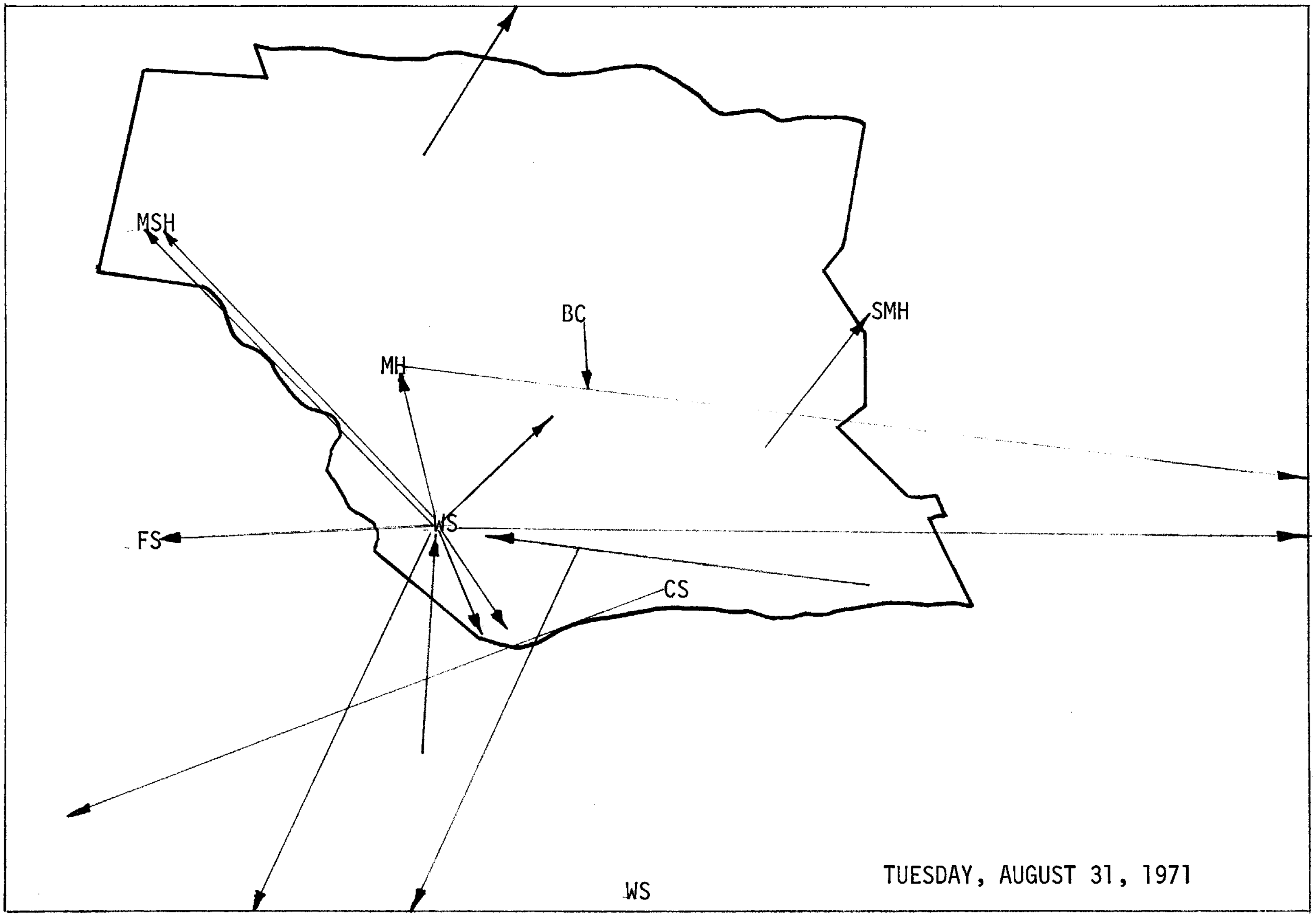


FIGURE A17 : BELMONT TAXI TRIP PATTERN, 7:30 p.m. TO 9:30 p.m.

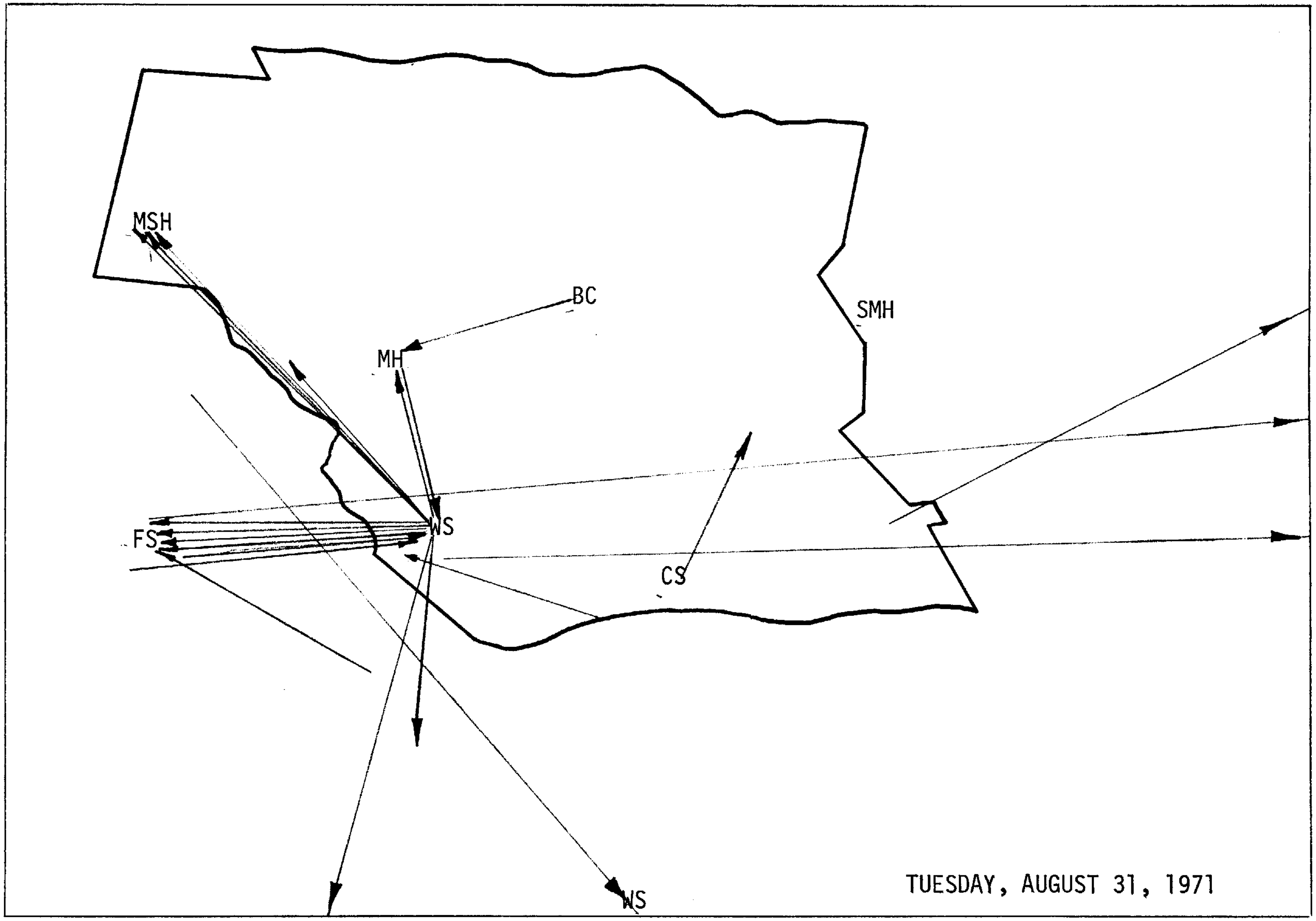


FIGURE A18: BELMONT TAXI TRIP PATTERN, 9:30 p.m. to 11:30 p.m.

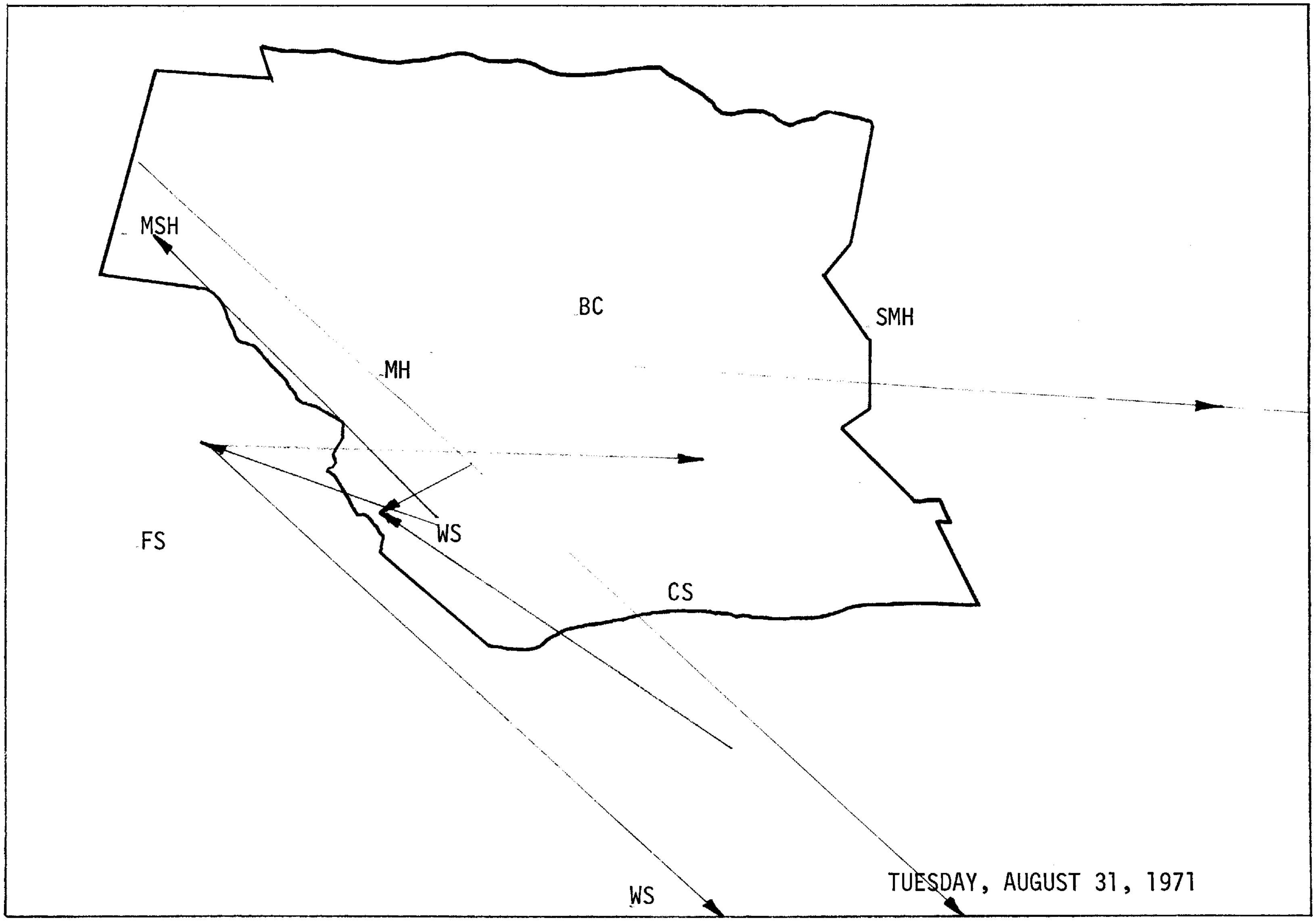


FIGURE A19 : BELMONT TAXI TRIP PATTERN, 11:30 p.m. TO 12:30 a.m.

a.m. to 1:30 p.m. shown in Figure A13 witnesses less taxi traffic than any other two-hour period of the regular working day (refer also to Figure A8). The early afternoon period (Figure A14) is marked by shift changes for employees at both the Fernald School and the McLean Hospital. This type of activity would lend itself strongly to ride sharing which is permitted in Belmont but not at reduced fares. Taxi trip-making in the late afternoon (Figure A15) is not as busy as one might have expected it to be, being a peak hour for work trips. Futhermore, a comparison of morning (Figure A11) and afternoon (Figure A15) peak hours does not reveal any strong reversal of trip patterns. Figures A16 through A19 show declining ridership in the evening period. Waverly Square seems to dominate the evening trip patterns. The period from 9:30 p.m. to 11:30 p.m. shows another shift change at the Fernald School and the Metropolitan State Hospital. Many of these taxi riders are nurses.

In addition to plotting the taxi trips, a study of the symmetry of trip-making was also carried out. A high degree of imbalance of some of the activity centers was noticed. Waverly Square, for example, had 110 outbound taxi trips during the survey day but only 36 inbound trips. On the other hand, the Fernald School had 26 inbound taxi trips but only 4 outbound trips. The McLean Hospital taxi trips were relatively well-balanced but the two other hospitals, the Metropolitan State and the Sancta Maria both had net inflows of taxi trips (11 and 15 respectively). Although one can speculate on the reasons for the asymmetric trip patterns, a user survey would be required for verification.

Operationally, symmetric demand into and out of an activity center is to be preferred to asymmetric demand. When demand is symmetric there is a better chance of matching incoming and outgoing taxi trips end-to-end provided trips are being generated and attracted at a sufficiently high rate.

Very few activity centers external to the Belmont service area are consistent taxi trip attractors. Logan airport does however, attract a small proportion of the trips on a regular basis. On the day of the survey 5 trips to the airport were made,accounting for a little over 1 percent of Belmont Cab's trips for the day.

Trip Length Characteristics and Fares

As can be appreciated from the trip pattern maps (Figures A10 through A19) the taxi trips varied in length from less than half a mile to more than 10 miles (e.g. trips to Logan Airport). Although drivers do not keep a record of the length of each trip, a good proxy for trip length is fare.

Taximeters calculate fares on the basis of road distance travelled and also as a function of the amount of time the taxi spends travelling slower than a given speed. In Belmont the fare structure at the time of the survey was 50¢ for the first 2/5 mile, 10¢ for each additional 1/6 mile and 10¢ for each minute during which the taxi is travelling less than 11 miles per hour. (See Figure A20) In an uncongested town such as Belmont, the clock rate (10¢ per minute) accounts for a very small proportion of the total fare (probably about 10 percent) because the taxis spend only a small proportion of time travelling at less than 11 miles per hour. Consequently the trip length distribution would be very similar in shape to the fare distribution. The fare distribution obtained during the survey day is shown in Figure A21. The average fare

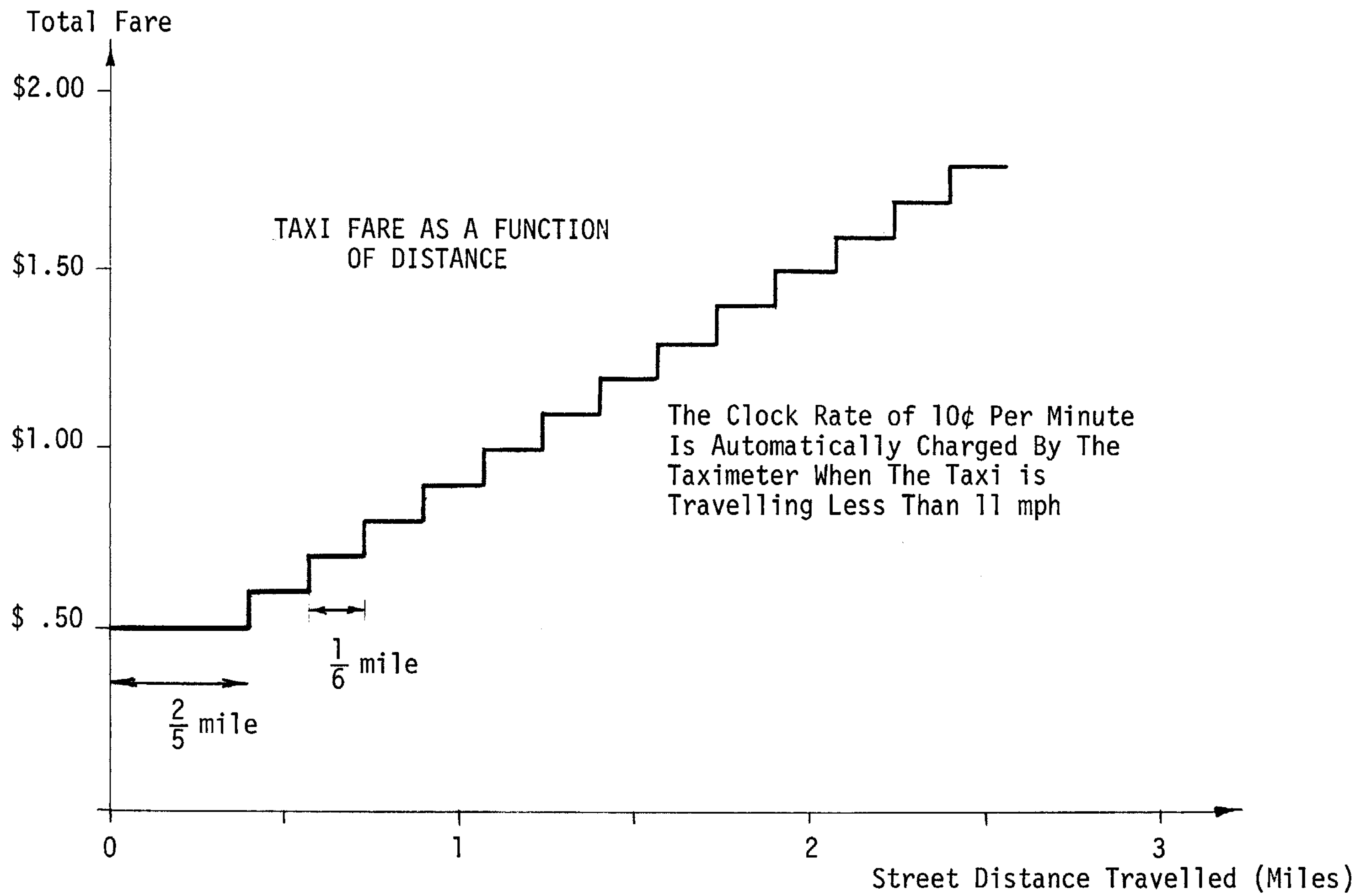


FIGURE A20 : TAXI FARE STRUCTURE FOR BELMONT, AUGUST 1971

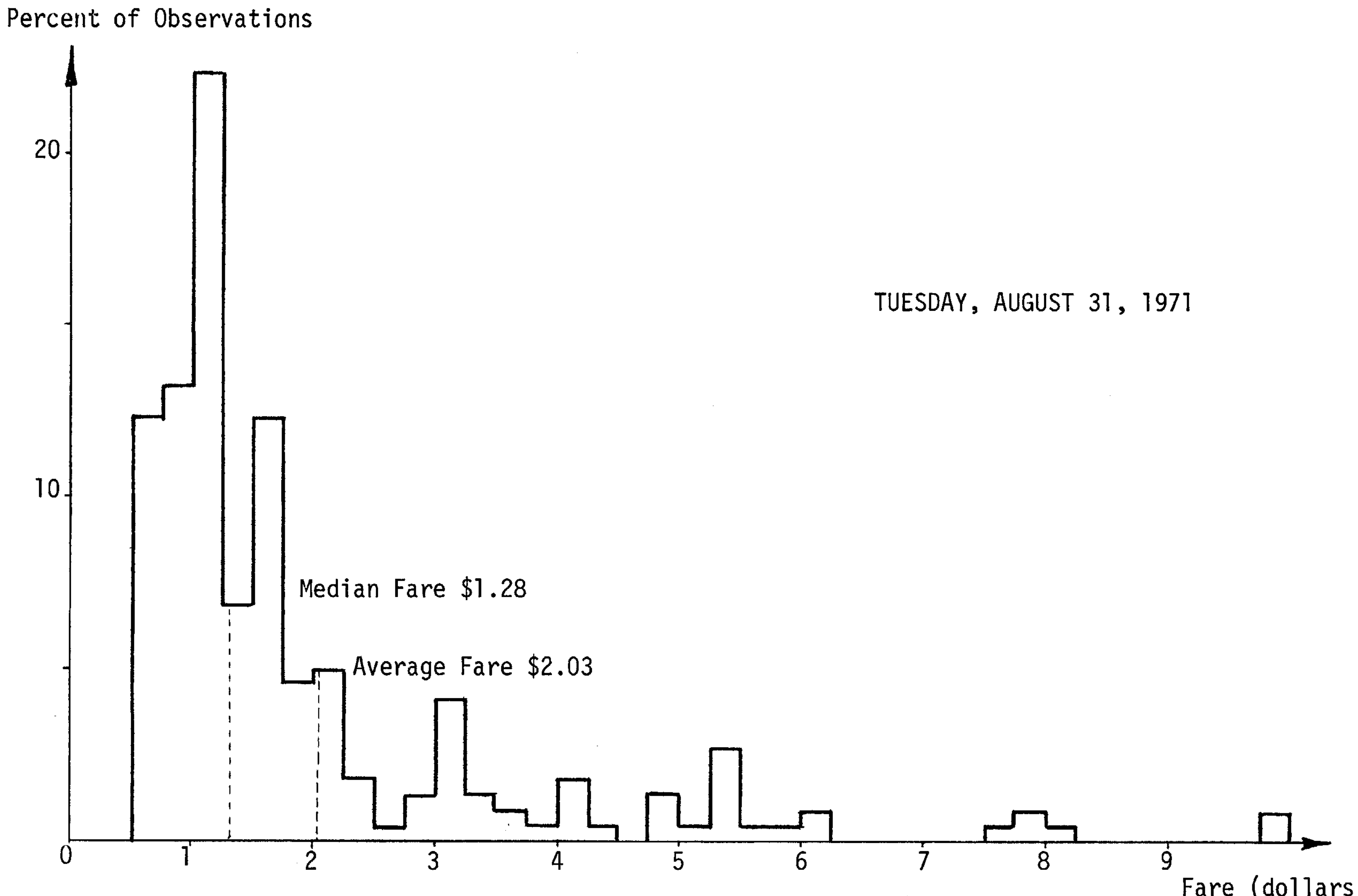


FIGURE A21 : FARE DISTRIBUTION, BELMONT CAB COMPANY was $2.03. The fare distribution is basically exponential. As trip length increases, people become less willing to travel by taxi or to travel at all. It can also be seen that relatively short trips costing 50¢ are not taken as frequently as trips costing slightly more than $1.00. For very short trips people will walk rather than take a taxi.

If fares are translated into distance, and assuming 10 percent clock-time, the average trip length is about 2.5 miles and the trip length which occurs most frequently is about 1-1/2 miles.

Service Characteristics

One of the most impressive features of the service offered by Belmont Cab is the pickup time as illustrated in Figure A22. During the survey day 95 percent of the pickups occurred within 12 minutes. Customers were picked up in 5-1/2 minutes on the average. This high standard of pickup reliability is a feature that must be greatly appreciated by Belmont Cab patrons. This reliability reflects a very high standard of dispatching performance and a fleet which is more than adequate in size to handle the demands.

Figure A23 shows the travel time distribution for taxi trips taken during the survey day. The shape of this distribution is very similar to that of the fare distribution displayed earlier. The average travel time in the cab was found to be 8.1 minutes. The travel times occurring most frequently were in the neighborhood of 4 minutes.

Knowing that the average taxi trip covers a distance of about 2.5 miles and that the average duration for the trip is about 8 minutes, it can be concluded that the block (door-to-door) speed of trips by Belmont Cab is about 19 miles per hour.

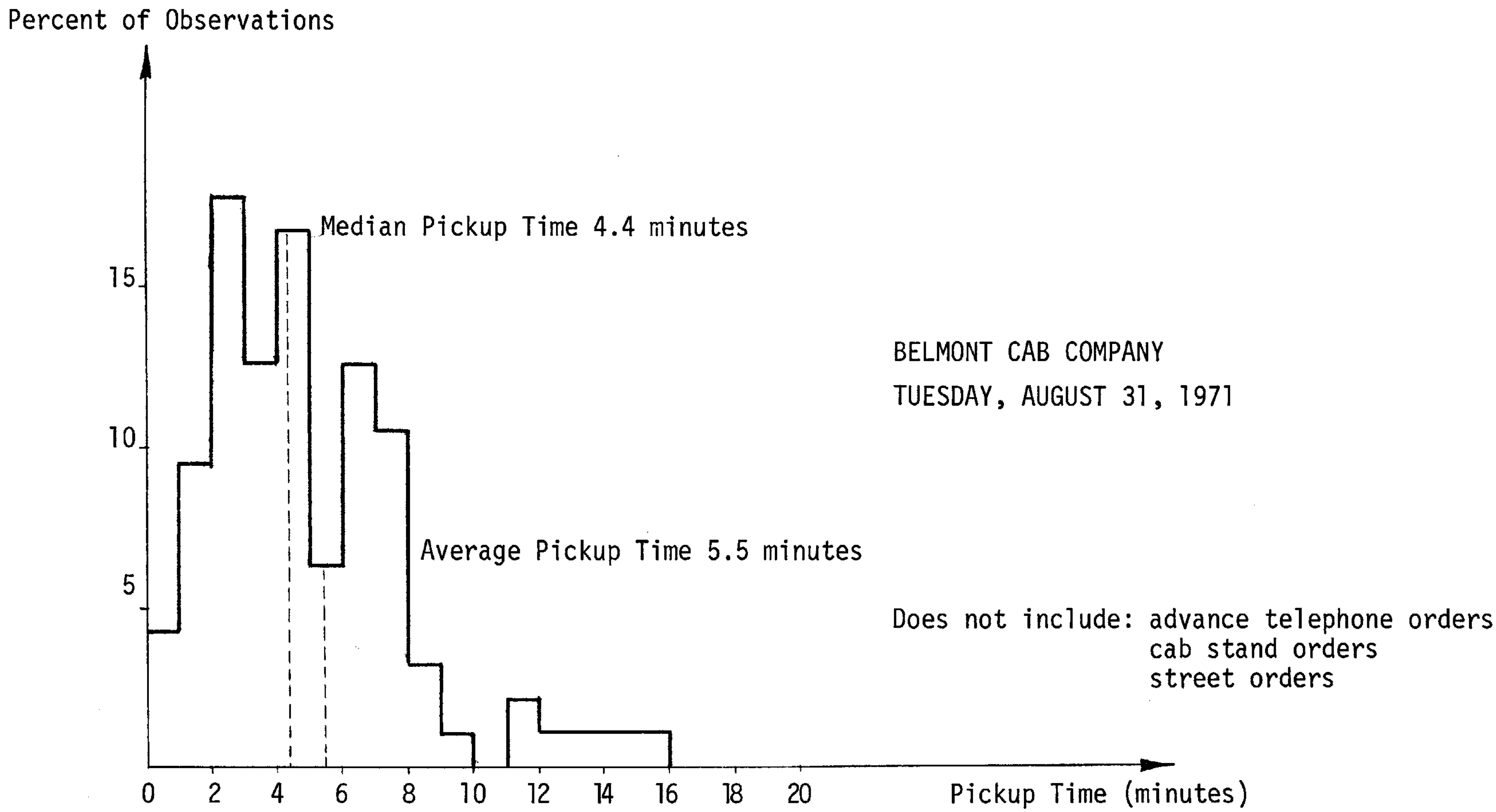


FIGURE A22 : DISTRIBUTION OF PICKUP TIMES FOR PHONE ORDERS

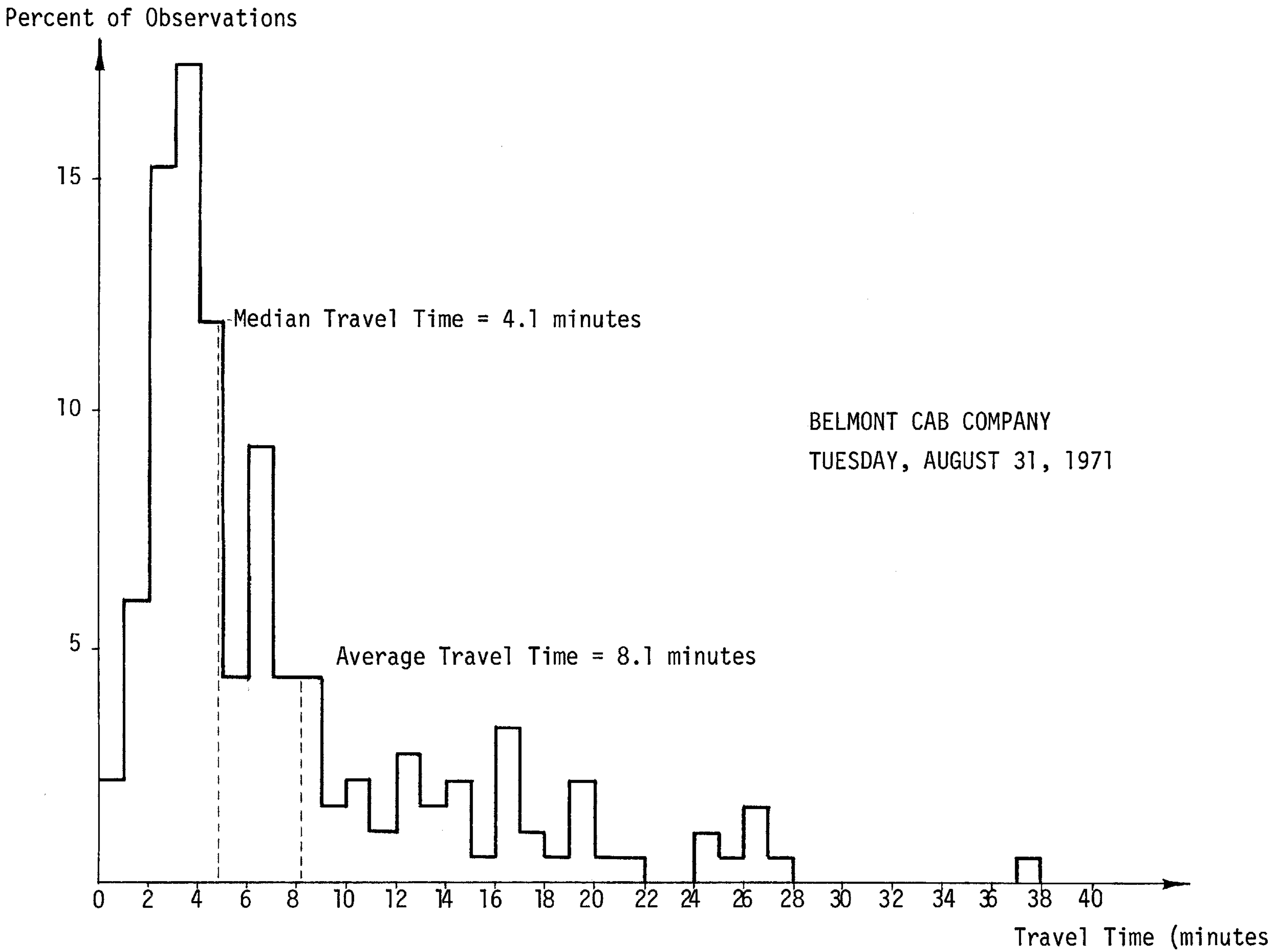


FIGURE A23 : TRAVEL TIME DISTRIBUTION

Fleet Productivity and Driver Utilization

A maximum of 15 vehicles were used on the Tuesday to handle the 391 trips. Figure A24 shows the relationship between driver hours and calls handled. Drivers worked a total of 180 hours. The day's productivity was therefore $\frac{391}{180}$ = 2.2 fares per vehicle hour.

On the average, Belmont taxis are occupied 2.2 $\frac{\text{fares}}{\text{hour}}$ x 8.1 $\frac{\text{minutes}}{\text{fare}}$ = 18 minutes per hour. However, an additional $\frac{61}{100}$ $\frac{\text{phone orders}}{\text{total fares}}$ x 4.4 $\frac{\text{minutes travel to pickup}}{\text{phone order}}$ X $\frac{\text{2.2 fares}}{\text{hour}}$ = 6 minutes per hour is required on the average to pick up customers. Thus, drivers are occupied in picking up and delivering a passenger only 6 + 18 = 24 minutes out of the hour. Some of the remaining time out of the hour (probably an additional 6 minutes) is spent returning to a cab stand. From this analysis it appears that the cab drivers are underutilized. However, if a smaller fleet were used, many of the passengers requesting service during the peak hours would either experience delays in being picked up or not get service at all.

Productivity during the peak hour was 3 fares per hour, travel time 9 minutes and pickup time 5 minutes. The proportion of phone orders increased to 68 percent. Therefore, average hourly travel time = 3 x 9 = 27 minutes per hour and average hourly pickup time = $\frac{68}{100}$ x 5 x 3 = 10 minutes per hour. Driver utilization is therefore increased to about 47 minutes per hour.

A better appreciation of changes in driver utilization during the day can be seen by looking at Figure A25. This figure gives a record of the utilization of two Belmont Cab vehicles.

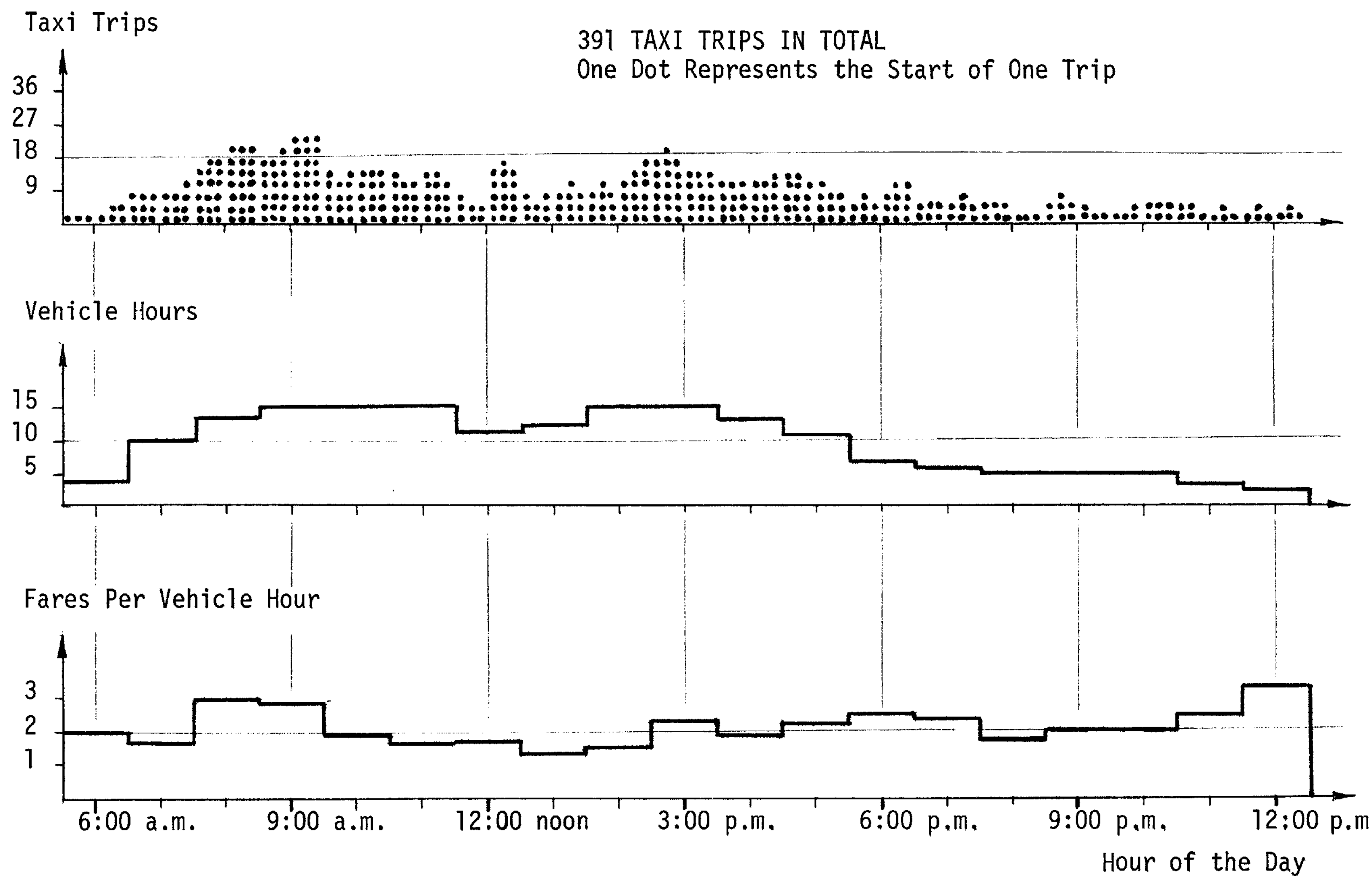


FIGURE A24 : BELMONT TAXI FLEET UTILIZATION AND PRODUCTIVITY, TUESDAY AUGUST 31, 1971

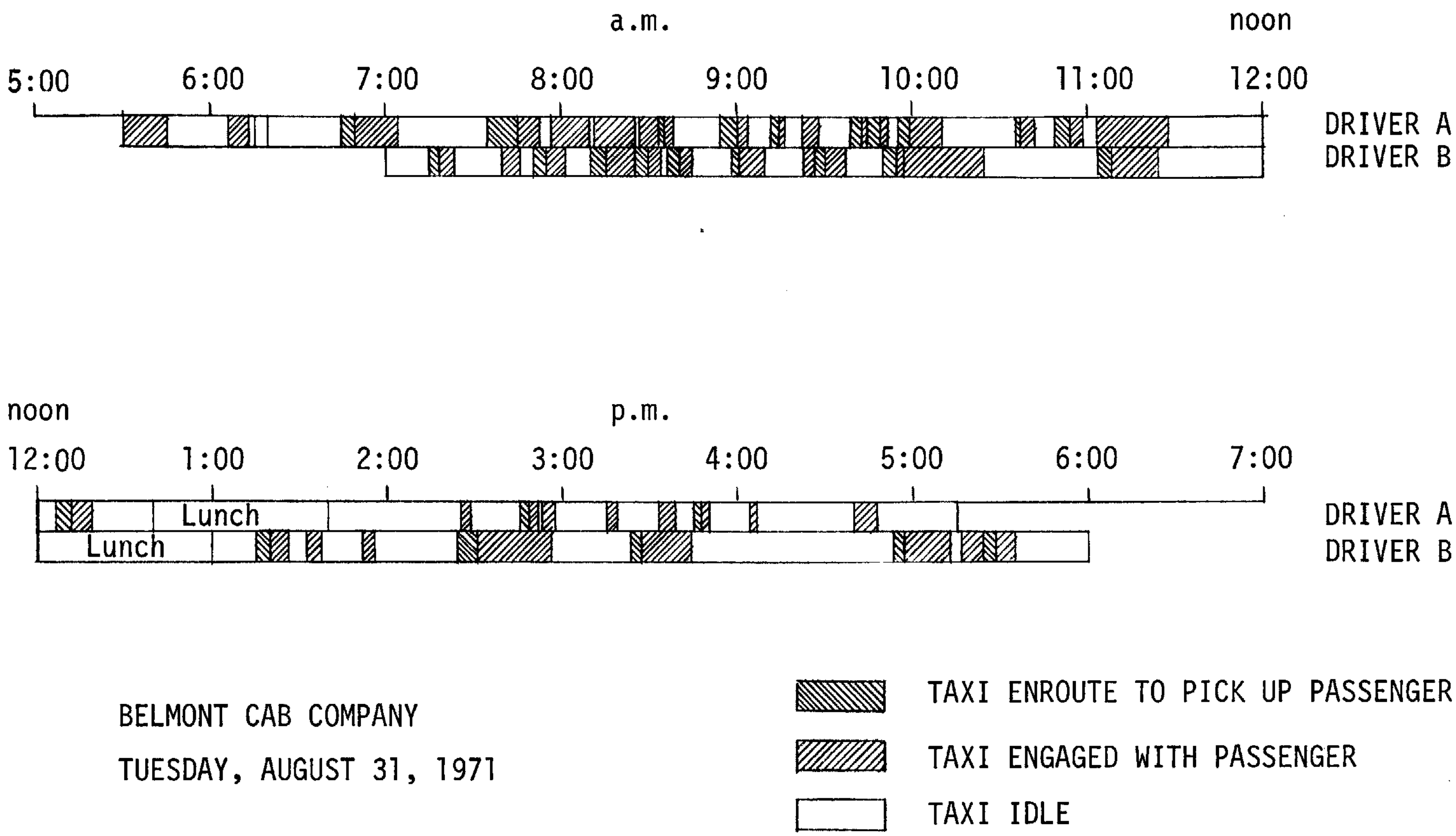


FIGURE A25 : UTILIZATION OF CAB DRIVER HOURS

Driver A worked for 10-3/4 hours of which 63 minutes was spent driving to make pickups and 3 hours 6 minutes was spent with passengers. (28 fares in all.) The percent of time Driver A was occupied was therefore $\frac{249 \text{ minutes}}{645 \text{ minutes}}$ = 39 percent. Driver B was employed for 10 hours - 64 minutes in pickup time, 3 hours 6 minutes in travel time with 20 fares. The percent of time Driver B was occupied was therefore $\frac{250 \text{ minutes}}{600 \text{ minutes}}$ = 42 percent.

Although it would appear that such low utilization rates are wasteful, Chapter 4 shows that utilization can be increased only by sacrificing phone order pickup times and cab availability.

Final Comments

The Belmont Taxi Company may not be completely representative of the entire industry, but the monitoring of its operation has given valuable insight into the workings of a taxi company and the service it provides.

APPENDIX B: TAXI OPERATING COSTS AND REVENUES

National Averages in Cents per Mile

	1969	1970
Revenues		
Cab receipts	32.61*	31.36*
Operating Costs		
Drivers	16.38	17.48
Gasoline	2.24	2.34
Tires	0.26	0.30
Labor Cost	1.19	1.18
Parts Cost	0.69	1.04
Insurance (PI and PD only)	1.40	1.67
Depreciation	1.51	1.66
Dispatching and Overhead**	4.86	2.83
Total Operating Cost	28.53	28.50
Dispatching Costs		
Cost per phone order	12.76	10.38
Labor cost per phone order	9.81	8.57

* Although these revenues were reported two and three year ago when fare structures were lower, the author suspects some under-reporting in these figures

** This cost category was not given in the original source but has been obtained by subtraction. An unexplained drop in this cost category from 1969 to 1970 should be noted

SOURCE: Taxicab Management National Survey of Taxis

APPENDIX C: PROPERTIES OF SOME TRIP LENGTH DISTRIBUTIONS

A number of taxi trip length distributions are encountered in this thesis. Included are the following:

(1) linear

(2) Manhattan

(3) triangular

(4) exponential.

An illustration of each of these distributions is given in Figure C1. Since each distribution is a probability density function, the total area under each curve is equal to one.

The three properties that will be derived for each distribution are the mean, the variance and the second moment. Given a trip length distribution, the mean represents the average trip length, the variance represents the spread of trip lengths away from the mean and the second moment gives the moment of inertia which the distribution has about the vertical axis passing through the origin.

1) Linear Trip Distribution

The linear trip distribution can often be used to approximate a taxi trip length distribution as can be appreciated by looking at Figure A23. The linear trip distribution also results from travel along a given line segment where the trip origin and trip destination are each located randomly along that line. This distribution is also used to generate the Manhattan distribution.

The linear trip distribution $f(\ell) = \frac{2}{a}(1 - \frac{\ell}{a})$ contained in (o, a) has as its mean or expected value of trip length:

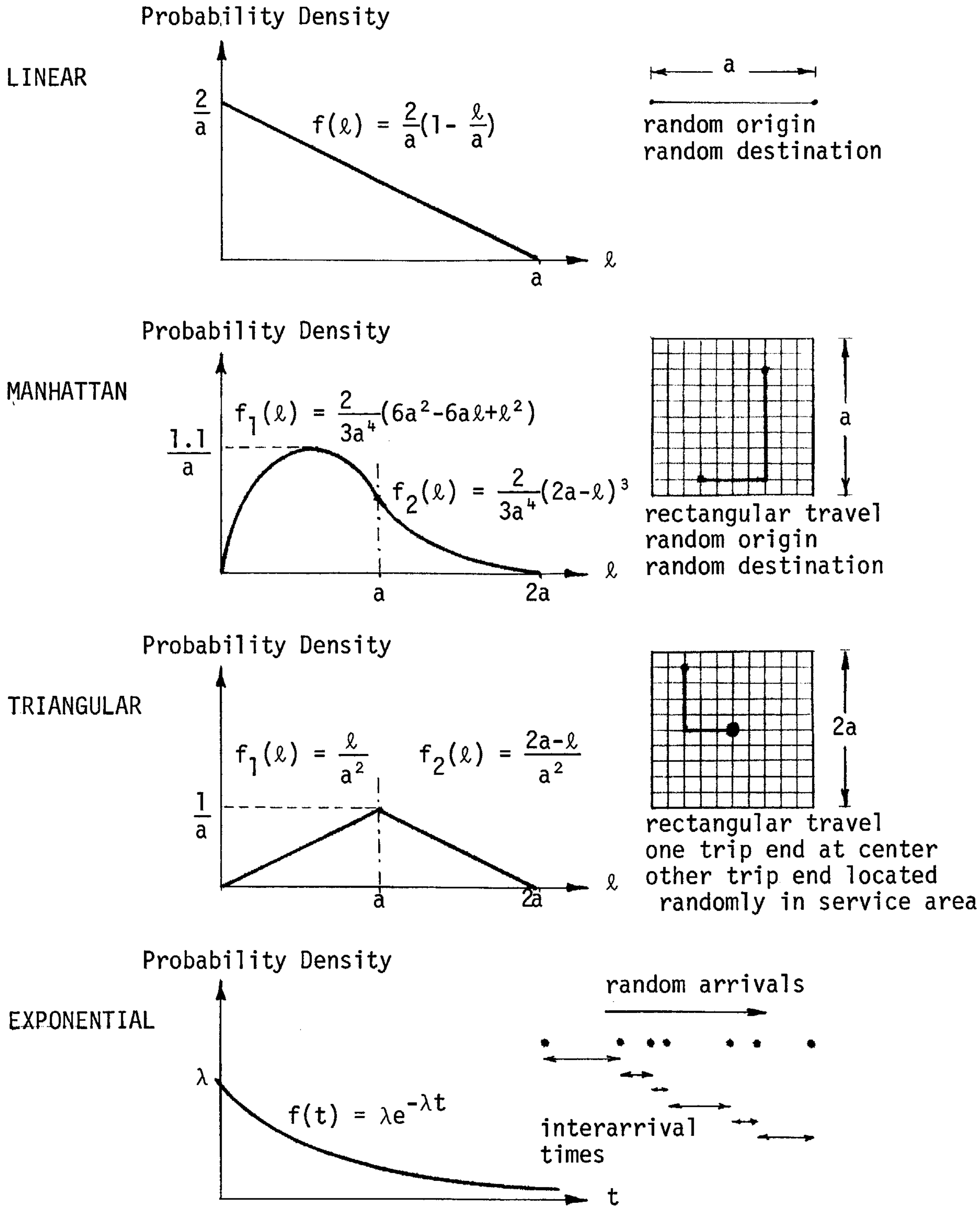


FIGURE C1 : TRIP LENGTH DISTRIBUTIONS

$$E(\ell) = \int_{o}^{a} \ell f(\ell) d\ell$$

$$= \frac{2}{a} \int_{o}^{a} \ell (1 - \frac{\ell}{a}) d\ell$$

$$= \frac{a}{3}$$

The second moment is:

$$M_2 = E(\ell^2)$$

$$= \int_{o}^{a} \ell^2 f(\ell) d\ell$$

$$= \frac{2}{a} \int_{o}^{a} \ell^2 (1 - \frac{\ell}{a}) d\ell$$

$$= \frac{a^2}{6}$$

The variance can be derived directly from the mean and the second moment.

$$\text{Var} = E(\ell^2) - [E(\ell)]^2$$

$$= \frac{a^2}{6} - \frac{a^2}{9}$$

$$= \frac{a^2}{18}$$

2) <u>Manhattan Trip Distribution</u>

The Manhattan trip distribution results from travel in a square or rectangular service area which has a rectangular grid of streets. When trips are confined to the streets of the service area and both trip origin and trip destination occur randomly throughout the service area, a Manhattan trip distribution is generated. This distribution is also very useful for approximating the trip length distributions observed for real taxi systems.

A mathematical derivation of the Manhattan trip distribution for a rectangular service area is given in the DART study[1].

For a square service area of dimensions a x a the distribution is made up of two functions:

$$f_1(\ell) = \frac{2\ell}{3a^4}(6a^2-6a\ell+\ell^2) \qquad \text{in } (o, a)$$

$$f_2(\ell) = \frac{2}{3a^4}(2a-\ell)^3 \qquad \text{in } (a, 2a)$$

Its mean is:

$$E(\ell) = \int_o^a \ell f_1(\ell)d\ell + \int_a^{2a} \ell f_2(\ell)d\ell$$

$$= \frac{2}{3a^4}\int_o^a \ell^2(6a^2-6a\ell+\ell^2)d\ell + \frac{2}{3a^4}\int_a^{2a} \ell(2a-\ell)^3 d\ell$$

$$= \frac{7}{15}a + \frac{a}{5}$$

$$= \frac{2}{3}a$$

The second moment is:

$$M_2 = E(\ell^2)$$

$$= \int_o^a \ell^2 f_1(\ell)d\ell + \int_a^{2a} \ell^2 f_2(\ell)d\ell$$

$$= \frac{2}{3a^4}\int_o^a \ell^3(6a^2-6a\ell+\ell^2)d\ell + \frac{2}{3a^4}\int_a^{2a} \ell^2(2a-\ell)^3 d\ell$$

---

1. Institute of Public Administration and Teknekron Inc., Demand-Actuated Road Transit - Performance and Demand Estimation Analysis Study for the U.S. D.O.T., 1969 pp. 79-80

$$= \frac{14}{25} a^2 + \frac{11}{45} a^2$$

$$= \frac{5}{9} a^2$$

Using the mean and the second moment, the variance is:

$$\text{Var} = E(\ell^2) - [E(\ell)]^2$$

$$= \frac{5}{9} a^2 - \frac{4}{9} a^2$$

$$= \frac{1}{9} a^2$$

3) Triangular Trip Distribution

The triangular distribution describes trip lengths for many-to-one or one-to-many travel in a square service area with a rectangular street grid. One of the trip ends is located at the center of the service area while the other is randomly located in the square.

Like the Manhattan distribution the triangular distribution is described by two functions:

$$f_1(\ell) = \frac{\ell}{a^2} \qquad \text{in } (o, a)$$

$$f_2(\ell) = \frac{2a-\ell}{a^2} \qquad \text{in } (a, 2a)$$

It has a mean of:

$$E(\ell) = \int_o^a \ell f_1(\ell) d\ell \quad \int_o^{2a} \ell f_2(\ell) d\ell$$

$$= \frac{1}{a^2} \int_o^a \ell^2 d\ell + \frac{1}{a^2} \int_o^{2a} (2a\ell - \ell^2) d\ell$$

$$= \frac{a}{3} + \frac{2a}{3}$$

$$= a$$

The second moment is:

$$M_2 = E(\ell^2)$$

$$= \int_0^a \ell^2 f_1(\ell)d\ell \quad \int_0^{2a} \ell^2 f_2(\ell)d\ell$$

$$= \frac{a^2}{4} + \frac{11}{12}a^2$$

$$= \frac{7}{6}a^2$$

The variance is:

$$Var = E(\ell^2) - [E(\ell)]^2$$

$$= \frac{7}{6}a^2 - a^2$$

$$= \frac{a^2}{6}$$

4) <u>Exponential Distribution</u>

The exponential function $\lambda e^{-\lambda t}$ is most useful for describing the interarrival times of random arrivals. However, it is also of value for simulating the length distribution of taxi trips.

The mean is calculated as follows:

$$E(t) = \int_0^{\infty} tf(t)df$$

$$= \lambda \int_0^{\infty} te^{-\lambda t}dt$$

$$= \frac{1}{\lambda}$$

The second moment is:

$$M_2 = E(t^2)$$

$$= \int_0^\infty t^2 f(t)dt$$

$$= \lambda \int_0^\infty t^2 e^{-\lambda t} dt$$

$$= \frac{2}{\lambda^2}$$

And the variance:

$$\text{Var} = E(t^2) - [E(t)]^2$$

$$= \frac{2}{\lambda^2} - \frac{1}{\lambda^2}$$

$$= \frac{1}{\lambda^2}$$

Summary

The properties of the trip distributions are summarized in Table C1. Knowledge of the relative variances and second moments of the distributions is of particular value for applying the queuing theory of Chapter 4.

TABLE C1 : COMPARISON OF TRIP LENGTH DISTRIBUTIONS

DISTRIBUTION	Functional Form	Range	Mean	2nd Mom.	Var.	As a Function of Mean m: Mean	2nd Mom.	Var.
Linear	$\frac{2}{a}(1-\frac{\ell}{a})$	in (o, a)	$\frac{a}{3}$	$\frac{a^2}{6}$	$\frac{a^2}{18}$	m	$\frac{3}{2}m^2$	$\frac{m^2}{2}$
Manhattan	$\frac{2\ell}{3a^4}(6a^2-6a\ell+\ell^2)$	in (o, a)	$\frac{2a}{3}$	$\frac{5}{9}a^2$	$\frac{a^2}{9}$	m	$\frac{5}{4}m^2$	$\frac{m^2}{4}$
	$\frac{2}{3a^4}(2a-\ell)^3$	in (a,2a)						
Triangular	$\frac{\ell}{a^2}$	in (o, a)	a	$\frac{7}{6}a^2$	$\frac{a^2}{6}$	m	$\frac{7}{6}m^2$	$\frac{m^2}{6}$
	$\frac{2a-\ell}{a^2}$	in (a,2a)						
Exponential	$\lambda e^{-\lambda t}$	in (o, ∞)	$\frac{1}{\lambda}$	$\frac{2}{\lambda^2}$	$\frac{1}{\lambda^2}$	m	$2m^2$	m^2

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