A Practice of Smart City

INTELLIGENT TAXI DISPATCH SERVICES WITH REAL-TIME TRAFFIC AND CUSTOMER INFORMATION

智慧城市的行业实践

——基于实时交通路况与用户需求的城市出租车智能调度服务

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内 容 简 介

自从 IBM 首先提出智慧地球的理念，各国政府部门不断重视并推动相关领域的探索与研究。新加坡是智慧城市建设的先行者和实践者，其在城市智能交通领域的建设成就为世界瞩目。本书重点围绕作者在新加坡工作和学习中积累的多篇 SCI/EI 收录论文，以新加坡城市出租车的运营现状为背景，向读者详细展示智慧城市建设过程中，基于实时交通路况与用户需求的城市出租车智能化调度服务的研究进展与最新成果。

本书的读者对象为智能交通与物联网技术相关研究人员，高校物流专业、交通工程专业教师和研究生。

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SUMMARY

Taxis play an important role in offering personalized door-to-door service within the transport sector. Fast and efficient fleet dispatching is essential for the provision of quality customer service in a competitive taxi operation network. This book aims at developing effective dispatch strategies to improve taxi-booking services.

A satellite-based taxi dispatch system, which tracks taxis using the Global Positioning System technology for automatic vehicle location, is currently widely deployed in Singapore. Based on the booking surcharges, there are generally two categories of taxi bookings: current and advance. Current bookings are requests that taxi should reach the customer immediately or within half an hour, and advance bookings are requests made at least half an hour in advance.

The existing taxi dispatch system employed by taxi operators in Singapore to handle current bookings is based on the nearest-coordinate method, i. e. the taxi assigned for each booking is the empty one with the shortest, direct, straight-line distance to the customer location. However, the taxi assigned under this system is often not capable of reaching the customer in the shortest possible time. An alternative dispatch system has been proposed, whereby the dispatch of taxis is determined by real-time traffic conditions and the taxi assigned the booking job is the one with the shortest-time path. The effectiveness of both the existing and proposed dispatch systems was investigated through microscopic traffic simulations. This book presents and analyzes the results from a simulation model of the Singapore Central Business District (CBD) network. Results of the simulations have shown that the proposed dispatch system is capable of being more efficient in dispatching taxis more quickly; leading to more than 50% reductions in passenger pick up time and average travel distance.

Whilst for an advance booking demand under the existing dispatch system, the existing system broadcasts the booking information immediately to the island-wide taxi network in Singapore, involving both occupied and empty taxis. The job is

assigned to the first taxi driver who bids for it. Obviously, under this dispatch system, advance bookings are handled on a case-by-case basis; and each booking demand (customer trip) is treated/assigned independently. Consequently, the taxi supply resource, in terms of occupancy time, may not be significantly utilized. Therefore, a novel trip-chaining strategy for taxi advance booking based on a customized algorithm of the Pickup and Delivery Problem with Time Window (PDPTW) problem has been proposed. The idea is to chain several bookings with demand time points which are spread out within a reasonable period of time, and with each pick-up point coinciding with or within close proximity to the previous drop-off location. Based on the simulation results, the proposed system for taxi advance bookings could reduce the taxi fleet size by up to 87.5%, in serving the same level of advance booking demands. This will not only result in a more reasonable fare structure for taxi services to encourage users to book taxis in advance and discourage last-minute requests, but also bring benefits to customers, drivers and taxi companies.

The trip-chaining strategy proposed in this study will have the potential to change the concept of the taxi booking service currently operating in Singapore. To further validate these proposals for both current and advance booking services in real life, a survey with a sample size of 600 respondents has been carried out to investigate users' responses. The opinions regarding the users' booking behavior, taxi arrival time and booking surcharge structure have been polled. More than 75.5% of the respondents who use current-booking service want or expect taxi to arrive as soon as possible. On the condition that they can plan the trips earlier, 75.3% of the respondents are willing to shift to use advance-booking service if the advance-booking fee is cheaper than the current booking fee, and 92.7% of the respondents are willing to obtain a taxi through advance booking when advance-booking service is cheaper than street hailing. The survey results have justified the value and feasibility of strategies proposed in this book.

BIOGRAPHY OF THE AUTHOR

Dr Wang Hao is currently the Associate Dean of School of Management, Ningbo Institute of Tech., ZheJiang Univ. He got his PhD degree from The Logistics Institute-Asia Pacific and Dept. of Civil Engineering of National University of Singapore. He graduated from Tsinghua University and Dalian University of Technology in China with M. Engg and B. Engg respectively. He was a senior consultant in Integrated Decision Systems Consultancy Pte Ltd (IDSC) in Singapore and its Chief Representative in Greater China area. He was also holding concurrent appointment as the General Manager at Jiangsu Topasia Logistics Consulting Co. Ltd in China. Before he joined IDSC, he has been a consultant in MAEDA consultancy Pte Ltd in Japan, and a research engineer in National University of Singapore.

Dr Wang worked in engineering logistics, intelligent transportation and operation research consultancy for many years. His areas of expertise include vehicle routing planning, fleet management, demand forecasting, large-scale microscopic traffic simulation, Supply Chain Management (SCM) and government policy for strategic logistics planning.

Dr Wang is also active in education and training of Modern Logistics & SCM. He is the certified trainer for International Purchasing & Supply Chain Management (IPSCM) Program promoted by United Nations/WTO as well as the certified trainer for National Logistics Professionals Training Program by China Federation of Logistics and Purchasing (CFLP). Dr Wang is the editor & author for IPSCM Program's supplementary teaching material in China.

CONTENTS

CHAPTER 1
INTRODUCTION

Taxis play an important role in offering personalized door-to-door service within the transport sector. The convenience of a comfortable and direct transportation service provided by taxis is of which mass rail transit (MRT) or buses cannot compete with. Over the years, the demand of taxi as a mode of transport has increased substantially in many cities in Asia. In Singapore, the number of trips (person trip) taken by taxi is as high as almost one million every day, which is comparable to the number of trips taken by MRT (LTA Report 2002). Meanwhile in some other metropolitan cities like Hong Kong, taxis currently form about 25% of the traffic stream in the urban area. In some critical locations, taxis form as much as 50% to 60% of the traffic stream (Transport Department 1986-2000). Evidently, taxis make considerable demand on limited road space and contribute significantly to traffic congestion even when empty (cruising to look for customers). Hence, optimization of the taxi fleet management and operation appears evocatively needed, which will reduce traffic congestion in urban area as well as improve the customer service.

1.1 RESEARCH BACKGROUND

As an important transportation mode, taxis can now be accessed/hired in public at designated taxi stands, through roadside hailing or utilization of taxi-booking services. Amongst these means, the best match between taxi demand and supply, with minimal empty cruising times in search of passengers can be brought about by an efficient taxi booking and a dispatch system. Moreover, even though taxis can be hailed anywhere on the street or waiting at taxi stands, it may be difficult to obtain a taxi during peak hours when the demand for taxis is high, or during shift changing periods.

A satellite-based taxi booking and dispatching system, which tracks taxis using the

Global Positioning System (GPS) technology for automatic vehicle location, is currently widely deployed in Singapore. With the aid of the real-time GPS-based dispatching system, the vacant taxis on the road network are tracked in the prevailing taxi dispatch system (Lee 1998; Cheng 2000).

Based on the booking surcharges, there are generally two categories of taxi bookings, current and advance. Current bookings are those where the customer makes bookings less than half an hour before the taxis are required to reach him or her (most current bookings require taxi companies to dispatch taxis immediately or as soon as possible), whilst, advance bookings are requests made at least half an hour in advance. For current bookings, the booking job is assigned to the taxi that has the shortest straight-line distance to the customer location, whereas for advance booking, the customer is assigned to the taxi driver who bids for the job within the shortest period of time.

With the advances of wireless communication, automatic vehicle location and geographic information system (GIS) technologies, the implementation of many new modes of taxi booking has been made taxi-booking services more convenient for customers. Consequently taxi booking has become the preferred choice for an increasing number of taxi customers, over street hailing and queuing at taxi stands, especially during peak demand period or at locations where empty taxis are hard to access. With the growing emphasis on customer satisfaction, it is essential for taxi operators to constantly upgrade their systems and facilities to ensure high quality services.

1.2 SCOPE AND OBJECTIVES

Traditionally, many economists have examined the models and economics of urban taxi services under various types of regulation, such as entry restriction and price control in an aggregate way. Recently, urban taxi services were modeled in a network context. At the same time, realistic methods have been proposed to describe vacant and occupied taxi movements in a road network as well as taxi drivers' search behavior for customers (Yang *at el*. 2002).

In addition to those analytical modeling approaches, increasing awareness has been

drawn to improve service quality in practical taxi operations. In particular, this book involves the study of the taxi dispatch system engaged to handle taxi bookings by taxi operators in Singapore, with the intention to improve taxi dispatch services considering real-time traffic and customer information. The area of interest deals with the taxi booking services only, in which the service quality of an operator can be measured via the dispatch system. Hence other forms of taxi hiring, such as through street hailing and queuing at taxi stands, are beyond the scope of this study.

The objective of this book is to propose and verify innovative strategies for GPS-based taxi booking and dispatching system. However, the technical aspects such like how GPS works will not be dealt with specifically. Instead, attention is paid at developing models for taxi fleet management, coupled with GPS and Intelligent Transportation Systems (ITS) application on taxi dispatching in Singapore.

1.3 GAP AND OPPORTUNITY

1.3.1 Current Booking

The existing dispatch procedure for current bookings is based on the nearest-coordinate method, that is, the taxi assigned the job for a particular booking is the one that is the nearest in terms of straight-line distance to the customer location. However this assigned taxi may not essentially be the taxi that is capable of reaching the customer in the shortest possible time. There have been instances when the assigned taxi happens to be just on the opposite side of the road from where the customer is located. In order to get to the customer, the taxi driver has to make a U-turn at the next available intersection where U-turning is allowed, and this intersection happens to be some distance away. A similar problem is also encountered on one-way streets, where the taxi-driver must travel a long way before turning back to reach the customer. Thus, a taxi might be very near the customer in terms of direct straight-line distance, but it has to travel a longer time-path than a taxi approaching from a longer direct distance.

Therefore, it is possible to further improve the level of service by implementing a

dispatch system that will efficiently ensure a best match for each taxi booking. This means that the proposed system will be capable of locating a taxi that will be able to reach the customer within the possible shortest time for each taxi booking. It is hypothesized that a dispatch system based on real-time traffic conditions will be able to ensure that the taxi assigned the booking job is in fact the fastest taxi to be able to reach the customer, bringing a closer match between taxi supply and demand (in terms of service time), and thus increasing customer satisfaction and reliance on taxi-booking services. With a decrease in travel time to reach each booking customer, the empty cruising times of the taxis may also be reduced as well. This study is in line with Land Transport Authority's (LTA) objectives to improve taxi services to provide car-like services, through periodic evaluation of the performance of taxi operators and the usage of GPS technology to better match demand and supply (LTA 1996).

1.3.2 Advance Booking

Whilst for an advance booking demand under the existing dispatch system, the booking information is broadcasted immediately to the island-wide taxi network in Singapore, involving both occupied and empty taxis. The job is assigned to the first taxi driver who bids for it. Obviously, under this dispatch system, advance bookings are handled on a case-by-case basis; and booking demands (customer trips) are treated/assigned independently. Consequently, the taxi supply resource, in terms of occupancy time, may not be significantly utilized.

Hence, an alternative strategy for taxi advance booking might be explored, which can take the full advantage of the information available before hand, to arrange/dispatch the taxi fleet in a more systematic manner and thus to reduce operating cost. Currently in Singapore, the surcharge of an advance booking is higher than that of a current booking. If operating cost (such as the taxi vehicle resources required and the empty cruising time caused) to deal with advance booking services is decreased significantly, then the advance-booking surcharge can be reduced or even waived to encourage more users. This could potentially change the concept of the taxi booking service in Singapore, not only resulting in more reasonable fare structures for taxi services, but also bring benefits to customers, drivers and taxi companies.

1.4 METHODOLOGY OF STUDY

In this research, a hybrid analytical-simulation approach, consisting of a customized microscopic simulation model for modeling taxi fleet movements and background traffic conditions, embedded with an analytical routing decision model to provide sensible routing plans, was proposed. Hence, the objectives of this study have actually been pursued via theoretical analyses and computer simulations using realistic road networks. Although the proof of the pudding is in the eating, it is unlikely that any authority and taxi company will allow a real-life experiment without sufficient encouragement from simulation results using realistic models.

First, the analytical model was focusing on the strategies/rules to dispatch taxi under the two different booking requests, i. e., (1) to search the most suitable taxi, which can reach the customer within the shortest time possible in response to current-booking demands, (2) to efficiently generate a set of reasonable fleet routing plan with a low operating cost to meet advance-booking demands. The details will be addressed in Chapters 3 and 4.

Subsequently, simulation models were built incorporating the strategies proposed, to evaluate their performances under simulated traffic environment. Simulation modeling is an increasingly popular and effective tool for analyzing a variety of dynamic problems, which are not amenable to study by other means. Traffic problems are characterized by the interaction of many system components or entities. These problems are usually associated with complex processes, which cannot readily be described in analytical terms. Often, the behavior of each entity and the interaction of a limited number of entities may be well understood and can be reliably represented logically and mathematically. However, the complex, simultaneous interactions of many system components cannot be adequately described in mathematical or logical forms. The numerical results from simulation provide the analyst with detailed quantitative descriptions of what is likely to happen. The graphical and animated representations of the system functions can provide insights so that the analyst can gain an understanding of why the system is behaving this way. Hence, simulation modeling was used to test the strategy

proposed for its usefulness in improving taxi dispatching.

Detailed reviews on state-of-the-art simulation programs are presented in Chapter 2 PARAMICS, a microscopic simulation tool that provides suitable interface for adding user-developed routines to the main simulation process was chosen for modeling taxi behaviors. Simulation runs were performed on a selected network chosen from the Central Business District (CBD) in Singapore.

Evaluations on the performance of different systems were then made based on their efficiencies in taxi dispatch services, in terms of travel times, travel distances and number of taxis required to serve the demands. For current-booking services, additional sensitivity analysis was also carried out to investigate the influence of taxi densities in the network.

To further validate these proposals for both current and advance booking services in real life, a survey with a sample size of 600 respondents was carried out to investigate users' responses. The opinions regarding the users' booking behavior, taxi arrival time and booking surcharge structure were polled, to justify the value and feasibility of strategies proposed in this book.

1.5 ORGANIZATION OF BOOK

This book consists of six chapters that are organized as follows:

A general introduction and the background, objectives, scope and methodology of this study, as well as an outline of this book are given in Chapter 1.

Chapter 2 provides an overview of previous work in modeling urban taxi service and current status of taxi booking and dispatching operations in Singapore. Related literature of shortest path approaches in transportation model, route scheduling/planning as well as the review and selection of traffic simulation models are then presented.

Subsequently, a new method of taxi dispatching system with instantaneous traffic information is proposed and evaluated in Chapter 3. The selected results derived from simulation are also described.

Following the study of taxi current bookings, an innovative dispatch strategy was

proposed in Chapter 4 to improve the ad hoc' taxi advance booking services. This practical problem is defined as STAR (Singapore Taxi Advance Reservation) in this study, which is a special version of Pickup and Delivery Problem with Time Window, a well-known NP-hard routing problem. The proposed strategy for the STAR problem was then evaluated through traffic simulation in this chapter.

To further validate the strategies proposed in Chapters 3 and 4, Chapter 5 reports a survey from taxi users' viewpoint with a sample size of 600 respondents. The opinions regarding the users' booking behavior, taxi arrival time and booking surcharge structure have been polled. A comprehensive analysis of the survey results is then demonstrated, which justifies the value and feasibility of these strategies in real life.

Finally, in Chapter 6, conclusions from this study are presented. Research contributions and recommendations for future study are appended at the end.

CHAPTER 2 REVIEW OF TAXI OPERATION AND RELATED RESEARCH

In this chapter, the state-of-the-practice of taxi booking/dispatching operations in Singapore will be presented first, followed by an overview of previous work in modelling urban taxi service. Related literature in route scheduling and planning are then reviewed, where shortest path algorithms in transportation models and heuristics for vehicle routing problems are examined. Review and selection of traffic simulation models are also given in this chapter.

2.1 CURRENT STATUS OF TAXI BOOKING AND DISPATCHING SYSTEMS IN SINGAPORE

2.1.1 Overview of Taxi Services in Singapore

Taxi services first evolved in Singapore in the 1950s, in the form of pirate taxis and school taxis, operating without any proper licenses (Chin 1998). It was only in the 1960s that the government began issuing taxi licenses to individuals and companies. Comfort Transportation Pte Ltd (Comfort Taxis) was the first official taxi company launched in 1970 with aid from the government.

The taxi fleet size grew steadily with the demand over the years, and in 1980s, the use of radiophones to handle taxi bookings was implemented to reduce the empty cruising times of taxis. The taxi fleet of 10,000 was also organized into three separate companies, which are NTUC Comfort, Yellow Top and Singapore Airport Bus Service. Only 3,000 of these taxis were equipped with radiophones at that time.

By 1990, the number of taxis fitted with radiophones went up to 6,000 out of the 11,000 taxi fleet size. This fleet of 11,000 was being managed by five taxi