壅塞交織路段之駕駛行為分析與最佳化之匝道儀控模式

研　究　生：蔡肇鵬　　指 導 教 授：卓訓榮博士

國立交通大學運輸科技與管理學系博士論文

摘要

高速公路入口匝道之車流管制理論應用自 1960 年代開始，已經具有數十年之實際執行經驗，並獲有一定成效，包括交通壅塞之紓解與旅運時間之節省等。本文即針對高速公路分離式連接集散道路 (Separated connecting collector-distributor roadway) 單一交流道路段分析其車流特性與研究建立最佳匝道儀控模式。其影響匝道儀控成敗因素包括有車道變換行為(Lane-changing behavior)、車間距離 (Headway)、車流量、車流速率、車流密度、交織率 (Weaving rates)、主線下游車流狀況及入口等待車輛長度等。本研究之交織路段容量預估模式係應用可接受間距 (Gap acceptance) 透過 Renewal Processes 尋求臨界間距 (Critical gap) 及最佳線性規劃原則等建立動態容量預估模式並作為最佳化匝道儀控容量控制之依據。匝道儀控模式最佳號誌時制之建立，係假設於匝道儀控期間任何時間變化之交通需求 (Traffic demand) 是處在均一壅塞情況下，應用需求-容量模式 (Demand-capacity model) 於本研究之分離式連接集散道路交織路段進行模擬與實證。經應用現場實際調查之交通資料加以分析得知本研究之行車特性係包括 100% 之車道變換行為及 49.29%之交織行為 (Weaving activities) 下進行，所得最佳匝道儀控率 (Metering rates) 及號誌時制，能獲得高速公路主線車流量與行車速率提升及總等候長度最少之效果，並可紓解已壅塞之車流。

Driver Behaviors Analysis and Optimal Ramp Metering Control on the Congested Weaving Sections

Student：George, Cheo-Peng Tsai **Advisor：Ph.D Hsun-Jung Cho**

Department of Transportation Technology and Management

National Chiao Tung University

Abstract

This dissertation examines the conditions for which ramp metering can be beneficial to the overall system in terms of travel time savings for a simple traffic corridor that consists of a freeway and a set of parallel arterial connected by separated connecting collector-distributor (C-D) roadway and entrance ramps and/or loop-ramps. The purpose of this study focused on the traffic flow characteristics and capacity analysis, and ramp metering control for the separated connecting C-D roadway and freeway on freeway systems. As the performance of ramp metering control is concerned, it depends on various factors, such as the headway, traffic flow rate, density, speed, and flow ratios between each lane, and downstream traffic conditions, etc., and the key factor to the capacity on the interchange systems, is the lane changing activity of traffic operation in freeway weaving sections. This study developed a model to estimate the weaving capacity for the separated connecting C-D roadway on freeway systems based on the renewal processes of gap acceptance and linear optimization. Ramp metering has been emerged as an effective freeway control measure to ensure efficient freeway operations. It focuses on analyzing dynamic and control relationships to arrive at general analytical results regarding optimal metering policies. The analysis assumes that time-varying traffic demands are uniformly congested throughout the control period.

The control model is using demand-capacity model to produce the optimal metering rates and the minimizing total queue length. This study investigates the development macroscopic equation models of ramp metering control signal timing on the separated connecting C-D roadway and freeway systems. It focuses on field data based on these driver behaviors including 50.71% of lane-changing and 49.29% of weaving activities to analyze. The ramp metering control is capable of optimizing mainline traffic by providing metering rates for accesses within the control segments. These results of this study including the ramp metering can increase the freeway mainline traffic flows and speeds, reach minimizing total queue length, and prevent a traffic breakdown by adjusting the metering rate.

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APPENDIX
Glossary of Symbols

Notations:	**Description:**
LCI	Lane-changing intensity
t	Stimulus time
T	Time lag
λ	Constant of sensitivity
x_{n_c}	The position of the n*th* car along a highway
n_c	The position of a car in a line of cars
m, l	Coefficients
a, b, a', b', c', d' *and* β_i	Parameters
x	Space
k	Traffic density, vehicles per kilometer per lane
q	Traffic flow rate, vehicles per hour per lane
u, v	Traffic speed, kilometers per hour
$u(k)$	Empirical speed-density relationship that gives rise to an implicit flow-density relationship
v_f	Free flow speed, kilometers per hour
c_w	Wave speed, kilometers per hour
k_{jam}	Jam density
k_c	Critical density
Q_{ik}	Flow rate of kth i-second interval
N_{ik}	Number of vehicles that pass the reference line during kth $i-$ second interval
i	Time interval in seconds
U_{ik}	Average running speed in kth $i-$ second interval

U_{jm}	The speed of mth vehicle in jth frame in kilometers per hour
n_j	Number of cars in jth frame in kth $i-$ second interval
K_i	The traffic density in kth $i-$ second interval in vehicles per kilometer
L_w	The length of the weaving section in meters
R^2	The coefficient of correlation
R_a^2	The adjusted coefficient of correlation
t_d	The value of t-distribution of regression variables
x_l	The frequency of lane changes, numbers
AD	Average lane density, vehicles per kilometer per lane
AF	Average lane flow rate, vehicles per hour per lane
AS	Average lane speed, kilometers per hour
AHD	Average headway of vehicles in the same lane in a 1-minute interval
VHD	Variance of headway's of vehicles in the same lane in a 1-minute interval
AFR	Average flow ratio
ADR	Average density ratio
ASR	Average speed ratio
LCF	The lane-changing frequency in a 1-minute interval
F_{nj}	Flow rate in lane n (include inside lane i and outside lane o)
F_{ij}	Flow rate in lane i
F_{oj}	Flow rate in lane o
NL_{ioj}	Number of lane changes from lanes i to o during the time

	interval j
NL_{oij}	Number of lane changes from lanes o to i during the time interval j
NL_{nmj}	Number of lane changes from lanes n to m during the time interval j
n_i	Number of vehicles observed during the ith time interval for a given lane
y_i	Vehicles out of n_i change lanes
p_i	The probability will lie between $(\infty, -\infty)$
$\varepsilon_i, \nu_i, \delta_i$	Random error terms
x_{ij}	Independent traffic flow variables represents $\ln(z_{ij})$
Y_i	Logistic transformation of the probability p_i, and lies, as expected, within the range $(-\infty, \infty)$
z_{ij}	Basic traffic variables
μ_i	The mean of the Poisson process for interval i
c_j, α_i	Unknown parameters to be estimated
c	Capacity
V_{CC}	Only to make lane change traffic flow rate from C-D roadway, at capacity
V_{RC}	The merging traffic flow rate from loop-ramp, at capacity
V_{RR}	Only to make lane change traffic flow rate from loop-ramp, at capacity
V_{CR}	The merging traffic flow rate from C-D roadway, at capacity
BAC	Basic Auxiliary lane segment Capacity
BCC	Basic C-D roadway segment Capacity
W_0	The ratios of weaving vehicles to total vehicles in the lane 0

W_1	The ratios of weaving vehicles to total vehicles in the lane 1
L_c	The length of the C-D roadway vehicles
L_r	The length of the loop ramp vehicles
RT	The driver reaction time
TT	The ideal minimum lag required for merging
Ω, Φ	Probability of non-weaving vehicles
τ	Critical lag
η	The probability of the driver of vehicle 2 attempting to weave from lane 1 to lane 0
Q_m	Maximum traffic volume merging into C-D roadway lane 1 or lane 0 stream (vehs/sec.)
Q_p	C-D roadway lane 1 or lane 0 stream volume (vehs/sec.)
$f(t)$	The probability density function of the gaps in the lane 1 or lane 0 stream
$g(t)$	Number of merging vehicles which can enter into a gap of duration t
x_{01}	Observed time headway of rear lag *RL01* for lane 1
y_{10}	Observed time headway of rear lag *RL10* for lane 0
t_{TT01}	Minimum time headway of rear lag *RL01* for lane 1
t_{TT10}	Minimum time headway of rear lag *RL10* for lane 0
t_{av01}	Average time headway of rear lag *RL01* for lane 1
t_{av10}	Average time headway of rear lag *RL10* for lane 0
λ_N and λ_N^{C-D}	Number of lanes on freeway and separated connecting C-D roadway, respectively
$q^{\mu}(n)$	Traffic flow rate enter freeway mainline from upstream boundary

$q^d(n)$	Traffic flow rate leave freeway mainline at downstream boundary
$r(n)$	Freeway ramp metering rates at time period n, vehicles per hour
$s(n)$	Traffic flow rate leave freeway mainline at exit ramp
$q^u_{C-D}(n)$	Traffic flow rate enter separated connecting C-D road from upstream boundary
$q^d_{C-D}(n)$	Traffic flow rate leave separated connecting C-D road at downstream boundary
$Q(n)$	Number of vehicles existing in the freeway section at time n
$Q_{C-D}(n)$	Number of vehicles existing in the separated connecting C-D road at time n
$r_{C-D}(n)$	Loop-ramp metering rates at time period n, vehicles per hour
$s_{C-D}(n)$	Flow rate of traffic leave separated connecting C-D road at exiting loop-ramp
n	Time slice
Δt	Length of time-period
Δx^F and Δx^{C-D}	Length of freeway mainline segment and separated connecting C-D road segment, respectively
$k(n)$ and $k_{C-D}(n)$	Traffic density on freeway mainline and separated connecting C-D road at time n
k_d	Desired density of freeway mainline
$q_R(n)$	Ramp entrance traffic rates at time n, vehicles per hour
$q_L(n)$	Loop-ramp entrance traffic rates at time n, vehicles per hour
$r_R(n)$	Ramp metering rates at time n, vehicles per hour
$d_R(n)$	Queue of waiting vehicles on ramp at time n

$d_L(n)$	Queue of waiting vehicles on loop-ramp at time n
c_R	Capacity of ramp
c_L	Capacity of loop-ramp
c_{C-D}	Capacity of separated connecting C-D roadway
$c_{Freeway}$	Capacity of freeway
$\theta(n)$	The proportion of the ramp metering rates
$g_L(n)$ and $g_R(n)$	The green time of ramp metering control at time n for loop-ramp and ramp, respectively
$C_L(n)$ and $C_R(n)$	The cycle time of ramp metering control at time n for loop-ramp and ramp, respectively
L_{lost}	The total lost time in the cycle, assume 2 seconds with a 3 seconds amber period