ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

EVALUATION OF INTELLIGENT SYSTEMS: STRATEGIES IN FREEWAY TRAFFIC MANAGEMENT CASE OF RAMP CONTROL IN VARIOUS COUNTRIES

M.Sc. THESIS

Müge ÖZGENEL

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Thesis Advisor: Assoc. Prof. Dr. Hilmi Berk ÇELİKOĞLU

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

AKILLI ULAŞIM SİSTEMLERİNİN DEĞERLENDİRİLMESİ: OTOYOL TRAFİK YÖNETİMİNDEKİ STRATEJİLER, ÇEŞİTLİ ÜLKELERDEKİ KATILIM DENETİMİ DURUMLARI

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Müge-Özgenel, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID **501091459**, successfully defended the **thesis** entitled **EVALUATION OF INTELLIGENT SYSTEMS: STRATEGIES IN FREEWAY TRAFFIC MANAGEMENT CASE OF RAMP CONTROL IN VARIOUS COUNTRIES**, which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 04 May 2012
Date of Defense : 07 June 2012

To my Mom and Dad,

FOREWORD

Sometimes we thought life is a bunch of faith or coincidences. I belived that I am the luckiest person from educational side, because I have always came across with academicians who are fully equipped with marvellious scientific knowledge. There are special people in my life whom I call them my milestones in my life. First of all, I would like to thank my thesis advisor Assoc. Prof. Dr. Hilmi Berk ÇELİKOĞLU, he not only light up my way with his knowledge but also transfers me his precious methods while forming a scientific work. His valuable guidance and continous support led me to complete my thesis. Also, there is a lecturer from my Bachelor years, whom I follow steps and helps me to love transportation at first sight, I would like to extend my special thanks to Assoc. Prof. Dr. Aybike ÖNGEL.

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February 2012

Müge ÖZGENEL
Civil Engineer

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ABBREVIATIONS

RTMS	: Remote Traffic Microwave Sensor
CCTV	: Closed Circuit Television
VMS	: Variable Message Sign
DMS	: Dynamic Message Sign
HAR	: Highway Advisory Radio
ALINEA	: Asservissement LInéaire d'Entré Autoroutière
CALTRANS	: California Transportation
FHWA	: Federal Highway Administration
MDOT	: Michigan Department of Transportation
SCANDI	: Surveillance Control and Driver Information
INFORM	: Information for Motorists
LIE	: Long Island Expressway
WISDOT	: Washington State Department of Transportation
METRO	: King Country Department of Metropolitan Services
HA	: Highway Agency
ITM	: Integrated Traffic Management
ATM	: Active Traffic Management
NHC	: National Exhibition Centre
RMPS	: Ramp Metering Pilot Scheme
NADICS	: National Driver Information and Control System
SNMP	: Simple Network Management Protocol
DMRB	: Design Manual for Roads and Bridges
AHCO	: Ayalon Highway Company
LDO	: Loop Detectors Outstation
LCS	: Lane Control Signs
VTS	: Variable Text Signs
INRETS	: Internal Reports
SIER	: Service Inrodépartemental d'Exploitation de la Route
DRIEF	: Direction Régional d'Equipment d'lle de France
SIRIUS	: Service d'Information pour un Réseau Intelligible aux usagers
CRICR	: Centre Régional d'Information et de Coordination Routiére
ADT	: Average Daily Traffic
WATTS	: Wide Area Traffic Telematics Server
VIP	: Video Image Processing
ITS	: Intelligent Transportation Systems
HEROINE	: Hanshin Expressway Real-time Observation based Integrated Evaluator
DUT	: Regional Directorate Utrecht
NWR	: Nordhein - Westfalen

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EVALUATION OF INTELLIGENT SYSTEMS: STRATEGIES IN FREEWAY TRAFFIC MANAGEMENT CASE OF RAMP CONTROL IN VARIOUS COUNTRIES

SUMMARY

Ramp metering is one of the intelligent transportation system used to prevent recurrent congestion. Most of ramp metering implementations resulted in, increased travel speed with a reduced travel time, increased traffic safety, increase in Level of Service, energy and environmental efficiency increase and increase in user satisfaction. At first, the ramp metering implementation is offered for freeways and following this, it was started to be deployed on the ring roads having a higher demand level and short interval ramp seperation.

This dissertation is made to make an evaluation and comparison of ramp metering deployment in various countries.

The fundamentals of road traffic is explained in section two, briefly including measures of traffic flow and traffic flow variables. After explaning the measures of traffic flow and traffic flow variables, their relationships are presented with graphs. And following this, traffic flow modelling approaches are explained. For traffic flow modelling approaches, macroscopic, microscopic and mesoscopic traffic flow models are explained briefly. Geometrical design, pre-timed signalization and other methods are explained under the context of conventional methods.

In section three, the freeway traffic management along with intelligent transportation system is explained. Data collection methods such as; Inductive Loop Systems, Remote Traffic Microwave Sensors, Magnetic Sensors, Acoustic Array Sensors, Infrared Sensors and Closed Circuit Television Video Camera Systems are explained along with their capabilities. Following these subsections, information dissemination systems in freeway traffic management is explained. Intelligent System Applications; Ramp management, lane management and special event transportation management are explained afterwards. In ramp management, ramp control, ramp closure, ramp metering and geometric properties of ramp metering is explained along with main elements of ramp metering. And in lane management, High Occupancy Vehicles Lanes, High Occupancy Toll Lanes, bus only lanes, managed lanes and congestion pricing are explained together with their objectives. The final subsection explained within section three is special event transportation management.

Strategies for ramp metering, types of ramp control and algorithms are explained in section four. Types of ramp control is explained briefly under existing strategies subtitle. And under types of ramp control, classification of ramp control according to geometry and time based approaches are explained. For ramp geometry based classification, brief explanations of isolated and coordinated ramp control are given. And for time based classification, pre-timed, semi-actuated and real-time ramp control is explained and a comparison between these approaches are presented. In the following subsections within section four, under approaches to ramp control subtitle,

algorithms of proactive and reactive strategies explained along with their positive or else negative effects.

In section five, deployments in various countries explained with implementations, algorithms and their effects. These countries are selected from different geographies. The selected countries are; U.S, England, Scotland, Israel, France, Germany, Japan, Netherlands, Belgium, Sweden, New Zeland, Switzerland and South Africa. After detail explanation of ramp metering implementations in different countries, their comparative analysis are made according to specified criteria. First implementations system architecture, enforcement, algorithm and cycle times are presented and than the effects of ramp metering under criteria such as; travel time, speed, capacity, accident, environmental impacts and user satisfaction is evaluated. Additionally, a suggestion for Turkey, Istanbul is suggested in section five.

In the final section; section six, a conclusion is drawn with respect to ramp metering implementations, following this suggestions and future directions are explained.

AKILLI ULAŞIM SİSTEMLERİNİN DEĞERLENDİRİLMESİ: OTOYOL TRAFİK YÖNETİMİNDEKİ STRATEJİLER, ÇEŞİTLİ ÜLKELERDEKİ KATILIM DENETİMİ DURUMLARI

ÖZET

Katılım denetimi sürekli tıkanıklığı önlemeye yarayan akıllı ulaşım sistemlerinden biridir. Literatürde yer alan hemen hemen bütün katılım denetim uygulamalarının sonuçlarında, yolculuk hızlarında artış yaşandığı, bunu ile birlikte yolculuk sürelerinin azaldığı, trafik güvenliği ve Hizmet Düzeylerinde artışlar yaşandığı, enerji kullanımı ve çevreci kullanım açısından olumlu yönlerde artış yaşandığı, müşteri memnuniyetinin mevcut bulunduğu sistemler olarak görülmektedir. Katılım denetimi ilk olarak otoyollarda uygulanılmaya başlanmış, daha sonra talebin fazla olduğu ve kısa aralıklar ile katılımların bulunduğu çevre yollarında da uygulanmaya başlanmıştır.

Bu bilimsel çalışmada, çeşitli ülkelerdeki katılım denetimi durumlarının değerlendirilmesi ve karşılaştırılması yapılmıştır. Tezin ikinci bölümünde, trafik akımının asal ve türetilmiş değişkenleri anlatılmıştır.

Trafik akımının asal ve türetilmiş değişkenleri ilerleyen bölümlerde grafikler ile gösterilmiştir. Buna ek olarak, ikinci bölüm içerisinde trafik akım modellemesindeki temel yaklaşımları yer almaktadır. Bu temel yaklaşımların içerisinde; kaba-boyut modelleme yaklaşımı, ince-boyut modelleme yaklaşımı, karma-boyut modelleme yaklaşımı açıklanmıştır.

Yine bu bölüm içerisinde yer alan, trafik yönetimindeki geleneksel yöntemler içerisinde, geometrik tasarım, sabit zaman ayarlı sinyalizasyon ve diğer yöntemler anlatılmıştır. Geleneksel yöntemler içerisinde, kanallama yöntemi, tasarım ölçütleri, kanallama yönteminin nasıl uygulanması gerektiği ve son olarak da kanallama yöntemi ile sağlananlar faydalar açıklanmıştır.

Üçüncü bölümde, otoyol trafik yönetimi akıllı ulaşım sistemleri ile birlikte açıklanmıştır. Akıllı ulaşım sistemlerindeki veri toplama yöntemleri olan, indüksiyon halkası, mikrodalga algılayıcıları, manyetik algılayıcılar, akustik algılayıcılar, kızılötesi algılayıcılar, kapalı devre kamera sistemleri faydaları, kullanımları, ölçüm kapasiteleri ve çalışma sistemleri ile birlikte açıklanmıştır.

Üçüncü bölüm içerisinde otoyol trafik yönetiminde bilgi iletim sistemleri açıklanmıştır. Son olarak üçüncü bölüm içerisinde, akıllı sistem uygulamaları olan; katılım denetimi, şerit yönetimi ve özel olaylar için düzenlenen ulaşım yönetim sistemleri açıklanmıştır.

Katılım denetimi içerisinde, katılım yönetimi, katılım kapatımı, katılım denetimi ve katılım denetiminin geometrik özellikleri ile katılım denetiminin temel elemanları anlatılmıştır.

Şerit yönetiminde ise, yüksek doluluk oranına sahip taşıt şeritleri, yüksek doluluk oranına sahip ücretli şeritler, otobüs şeritleri, gözetimli şeritler ve tıkanıklık

fiyatlandırması gibi uygulamalar, öncelikle yöntemler açıklanmak üzere, amaçları ile birlikte anlatılmıştır. Bu bölümün son kısmında ise, özel olay ulaşım yönetimi açıklanmıştır.

Katılım denetim stratejileri, katılım denetim tür ve algoritmaları tezin dördüncü bölümünde açıklanmıştır. Katılım denetim türleri, mevcut stratejiler altında kısaca açıklanmıştır.

Katılım denetim türleri altında, katılım denetimi sistem zekasına ve uygulama ölçeğine göre sınıflandırılmıştır. Sistem zekasına göre yapılan katılım denetimi sınıflandırmasında, önceden zaman ayarlı, yarı uyarmalı ve trafiğe duyarlı olmak üzere üç alt başlık yer almaktadır. Uygulama ölçeğine göre yapılan katılım denetimi sınıflandırmasında ise, izole ve eşgüdümlü olmak üzere iki türlü yöntem yer almaktadır.

Dördüncü bölümün son bölümlerinde, tedbirsel ve tepkisel algoritmalar, olumlu ve olumsuz etkileri de gözönünde bulundurularak anlatılmıştır.

Tezin beşinci bölümünde, Amerika'daki mevcut ve planlanan katılım denetimi uygulamaları detaylıca açıklanmış, bu projelerde kullanılan algoritmalar dördüncü bölümde açıklanmış olduğu için, algoritmalara atıflarda bulunarak kısaca açıklamalar yapılmıştır. Son olarak, Amerika'daki proje uygulamalarının, ulaşım performans ölçütleri altında yer alan sonuçları irdelenmiştir.

İngiltere'de yer alan katılım denetim uygulamalarının irdelenmesi de, Amerika'daki uygulamalara benzer şekilde yapılmıştır. Öncelikle, İngiltere'de mevcut katılım denetimi projeleri anlatılmış, bu projeler içerisinde kullanılan algoritmalar, dördüncü bölüm ile ilişkilendirilerek kısaca bahsedilmiştir. Ve son olarak, katılım denetim uygulamalarının, ulaşım performans ölçütleri açısından değerlendirmesi yapılmış, olumlu ve olumsuz yönleri tespit edilmiştir.

İskoçya için de, katılım denetim uygulamaları anlatılmış, sonrasında bu denetimlerde kullanılan algoritmalar açıklanmıştır. Son olarak, İskoçya'daki uygulamanın sonuçları, ulaşım performans ölçütleri çerçevesinde değerlendirilmiştir.

İsrail için planlanan katılım denetimi uygulaması da yine bölüm beş içerisinde açıklanmıştır. İsrail Ayalon Otoyolu için planlanan katılım denetimi uygulamasında kullanabilecek algoritma kısaca anlatılmıştır.

Yukarıda bahsedilen ülkelere ek olarak, Fransa, Almanya, Japonya, Hollanda, Belçika, İsveç, Yeni Zellanda, İsviçre, Güney Afrika'da, katılım denetim uygulamaları, detaylı olarak incelendikten sonra, karşılaştırmalı analizleri önceden seçilmiş belirli değerlendirme ölçütlerine göre yapılmıştır.

Öncelikli olarak, sistem mimarisi, yaptırımlar, algoritmalar ve devre süreleri herbir uygulama için açıklanmış, bunu takiben katılım denetiminin etkileri, seyahat süresi, hız, kapasite, kaza, çevresel etkileri ve kullanıcı memnuniyeti gibi ölçütler ışığında değerlendirilmiştir.

Dünya'daki çeşitli uygulamaların gözlemlenmesi önceki bölümlerde yapılmış, katılım denetimi sisteminin olumlu ve az da olsa olumsuz yönleri incelenmiştir. Yapılmış olan bu karşılaştırmalar sonucunda, bir takım ölçümler ve elde edilen verilerle birtakım çalışmalar yapıldıktan sonra, bu uygulamanın Türkiye'de de uygulanabilirliğinin araştırılabileceği ve eğer tıkanıklığa uzun soluklu, uzun dönemde etki edecek bir planlama getirmek istiyorsak, katılım denetimi gibi bir akıllı ulaşım sistemi uygulanmasının getirebileceği önerisine yer vverilmiştir.

Türkiye için düşünülmüş olan bu katılım denetimi önerisi, bölüm beşin içerisinde yer almaktadır.

Tezin son bölümü olan altıncı bölümde, çeşitli ülkelerdeki katılım denetimi ve bu denetim sonucunda elde edilen faydalar verilmiştir, bu değerlendiremeler ışığında, öneriler ve gelecekte yapılabilecek açıklanmıştır.

1. INTRODUCTION

Traffic engineering deals with everyday problems faced within freeways, connection roads, generally road networks. In large metropolitan areas the existence of peak hours are in extreme levels resulting in chaotic situations. Traffic problems, recurrent and non-recurrent congestion stemming from traffic can be easily solved by using technological methods. Within the technological frame, real-time traffic management by intelligent transportation systems plays a major role. Thesis scope covers one branch of intelligent road traffic management system which is ramp control. Ramp control is explained in detail, and deployments of the system throughout the world are given, and in the final stage the adaptation of this particular system for Istanbul case is considered.

1.1 Motivation

Ramp control plays a major role while solving traffic problems. In the absence of a ramp metering, both mainstream and ramp is congested by platoon of vehicles while in the presence of a ramp metering implementation, the traffic in the mainstream relieves and only on ramp congestion is present. This system results in reduction on delays, emissions and many positive effects are present.

1.2 Scope of the Thesis

This thesis aims to make a comparison of different deployment examples throughout the world, for one of the intelligent transportation system; ramp control. As a whole, intelligent transportation systems have a key role while trying to solve traffic flow, such as maintaining free flow traffic in a freeway. The action of relieving a congested traffic flow can be made easily by using ramp metering with small touches even in large metropolitan areas. Although some difficulties (implementation & maintenance costs, society acceptance) might be present during the implementation period, successful deployment samples can be seen throughout the world. From Europe; England, Scotland, Germany, Netherlands, Belgium, Sweden, Switzerland from the other parts of the world; US, Israel, New Zeland, Japan, South Africa are the leading successful deployments as well as improvements in the overall network. The deployments in the exemplified countries above can be a role model for a developing country like Turkey. In Turkey especially big metropolitan areas face every day, daily congestion. One way of solving traffic flow problems, while relieving congestion is to spread ITS applications on a wider area.

1.3 Thesis Contributions

Istanbul is a crowded metropolitan having high transportation demand. Compensating this demand is difficult mostly all the time. Engineers specialized in transportation sector, concentrated on congestion issues even face complications stemming from high demand levels at peak hours, aggressive behavior of drivers and mainly inefficient usage of insufficient road infrastructure. At this point, rational methods and intelligent transportation systems assist to solve problems. In this dissertation, ramp metering implementation in various countries are explained first and these deployments are compared according to performance criteria.

1.4 Thesis Organization

This thesis prepared to make an evaluation of intelligent systems observing particularly, the strategies in freeway traffic management case of ramp metering in various countries. In section two, the fundamentals of road traffic and road traffic management is explained. Measures of traffic flow, modelling traffic flow and conventional methods of road traffic management are explained in section two. In section three, freeway traffic management and intelligent systems are explained covering the following subsections; data collection and information dissemination, intelligent system applications in freeway traffic management, lane management and special event transportation management. In section four, strategies for ramp metering consisting; overview of existing strategies, types of ramp control, approaches to ramp control is explained with types, algorithms and methods. In section five, deployments of ramp metering in various countries considering implementations, design concepts, algorithms and effects are explained. Moreover, implementation suggestion for Istanbul case is given. And the final section includes, conclusions and future directions.

2. FUNDAMENTALS OF ROAD TRAFFIC AND ROAD TRAFFIC MANAGEMENT

2.1 Traffic Flow Measurements

Traffic flow is examining the vehicles interacting with other vehicles on a road section moving from an origin to a destination point. For planning, design and operational purposes, the measures of traffic flow is used to make analysis. measures of traffic flow are taken from the field observations. These measures are; “Traffic Unit”, N (Vehicle, veh), “Distance”, X (km, m, mile, ft) and “Time”, T (h, min, sec). The aim of using the measures of traffic flow is to acquire the traffic flow variables The traffic flow variables are; flow (q, veh/h), density (k, veh/km) and speed (u, km/h). The fundamental relationships of these traffic flow variables are shown by specific graphs in the following sections.

In literature these characteristics named as traffic flow variables and cannot be easily obtained. For better and detailed understanding of traffic flow, some major units are; “Headway” (h), “Gap” (g), “Clearance” (c). Headway is measured as the time interval between two consecutive vehicles in a traffic flow. It can be measured by using a chronograph, by recording the seconds when the initial vehicles bumper passess through the specified point followed by the consecutive vehicles bumper. Gap differs from the headway in one point, when measuring headway the front bumpers of each vehicle taking into consideration whereas while measuring gap, the rear bumper of the initial vehicle and the front bumper of the consecutive vehicle considered. Clearance is the distance in kilometers or meters between the rear bumper of the initial vehicle and the front bumper (Todey et al., 2000).

2.1.1 Measures of traffic flow

In a particular traffic flow, the data obtained from the field observations are named as measures of traffic flow. The measures of traffic flow briefly explained in the previous section are explained in detail within this section.

“Traffic Unit” (N), is the vehicle travelling along a route on a particular road section, “Distance” (X) is the distance that vehicle covers to arrive to its destination and the “Time” (T) is the time elapsed for a vehicle to travel along a route.

Measures of traffic flow can be easily obtained by site observations, even with traditional methods like counting with naked eye, and recording the data with a pen and a paper. Their real function is to allow us to derive the traffic flow unit we needed to use in our researches, implementations, etc. In the subsequent section the aforementioned variables of traffic flow are explained.

2.1.2 Variables of traffic flow

In the previous section, measures of traffic flow have been explained, within this section the variables derived from that measures of traffic flow are explained briefly. The variables of traffic flow cannot be obtained from direct observations, as a result measures of traffic flow obtained from site observations used to derive those variables. While analyzing the traffic flow, a comparison is made among the variables of traffic flow; flow (q), speed (u), density (k) and occupancy (ч). The comparison which was made by sketched graphs is explained in the following sections.

Flow; can be obtained by counting the vehicles on a specified road section at a unit time interval, generally assumed as one hour. The traffic flow measured within one hour period is also named as, traffic capacity. The maximum traffic flow value, the capacity flow is shown by q_m. This value is the maximum number of vehicles that passes through a road section in one hour period. And the service volume, is the maximum number of vehicles that pass through a road section in one hour period, providing the required Level of Service, LOS (May, 1990). The required LOS is a relative concept that presents the flow conditions quantitatively on a particular road section. LOS is the combination of the following components; speed, comfort, travel time, the allowance for passing a vehicle and lane changing movement. In Table 2.1, LOS starting from A level and ending with F level is presented. For this particular LOS evaluation table, the conditions effecting LOS are; density, time elapsed occupancy of road and flow conditions. From A level to E level, it is accepted as tolerable as the flow condition in E is the capacity flow. When the LOS is at level F; the flow is a forced flow and the level is undesirable for the motorists.

Table 2.1: LOS Criteria for Multilane Highways (HCM, 2000).

LOS Criteria for Multilane Highways						
		LOS				
Free-Flow Speed	Criteria	A	B	C	D	E
60 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	40
	Average speed (mi/h)	60.0	60.0	59.4	56.7	55.0
	Maximum volume to	0.30	0.49	0.70	0.90	1.00
	Maximum service flow rate	660	1080	1550	1980	2200
55 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	41
	Average speed (mi/h)	55.0	55.0	54.9	52.9	51.2
	Maximum volume to	0.29	0.47	0.68	0.88	1.00
	Maximum service flow rate	600	990	1430	1850	2100
50 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	43
	Average speed (mi/h)	50.0	50.0	50.0	48.9	47.5
	Maximum volume to	0.28	0.45	0.65	0.86	1.00
	Maximum service flow rate	550	900	1300	1710	2000
45 mi/h	Maximum density (pc/mi/ln)	11	18	26	35	45
	Average speed (mi/h)	45.0	45.0	45.0	44.4	42.2
	Maximum volume to	0.26	0.43	0.62	0.82	1.00
	Maximum service flow rate	490	810	1170	1550	1900

Speed; is the distance travelled on a particular road section at a time instant. There are two seminal speed values; free flow speed v_f and optimum speed v_{opt}. Free flow speed, v_f is the speed value, when traffic flow is approaching to zero and which is obtained within the free flow conditions. The optimum speed value v_{opt}; is the speed obtained in maximum traffic flow conditions (May, 1990). Mainly in normal conditions, the distance based average speed is smaller than the time based average speed. When the speeds of each vehicle within the traffic flow is equal, this is when the variance of distance based average speed is zero (Huber, 1982).

Density (k) is the number of vehicles captured on a unit length of a road; generally 1 kilometer at any time. The unit of density is; vehicle / km-lane. There are two specific density; jam density (k_j) and optimum density (k_{opt}). Jam density, is the density formed when the traffic flow speed converges to zero and the optimum density is obtained when the maximum flow conditions are reached (May, 1990).

2.1.3 Fundamental relationships of flow variables

The fundamental relationships of traffic flow can be analyzed with both macroscopic and microscopic models. Macroscopic models show how each parameter affects the whole traffic flow. A comparison should be made in order to analyze the traffic flow. The free flow speed is the speed in which a vehicle passes through the a particular road without any interruption present.

It is shown as v_f in the following Speed, v (km/h) versus Density, k (veh/km) graph. If the graph was linear, then the mid point of the graph represents the point where maximum number of vehicles pass.

Our second analysis is made by using the Speed Density relation. The q_n and k_n values in the graph represents the optimum values for flow rate and density respectively. The data passing beyond these threshold values are called as forced flow and the data lie within the range of 0 to q_n (for our case 2300 veh/h) is named as free flow.

Speed value can be obtained from this graph by simply drawing a tangent to any point of the graph. The tangent drawn from the origin give s the free flow speed. Moreover, if a tangent to the point within the forced flow range is drawn, then the force flow speed can be obtained.

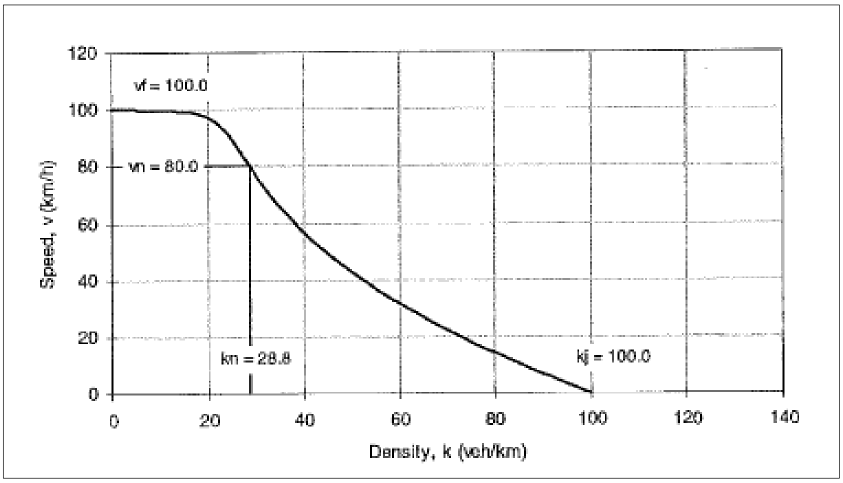


Figure 2.1: Speed versus Density Graph adapted from (Akcelik et al., 1999).

From Speed, v (km/h) versus Flow rate, q (veh/h) graph, the LOS can be determined with respect to the flow conditions present. The LOS determines and explains the flow conditions. In general, LOS depends on the volume and the speed.

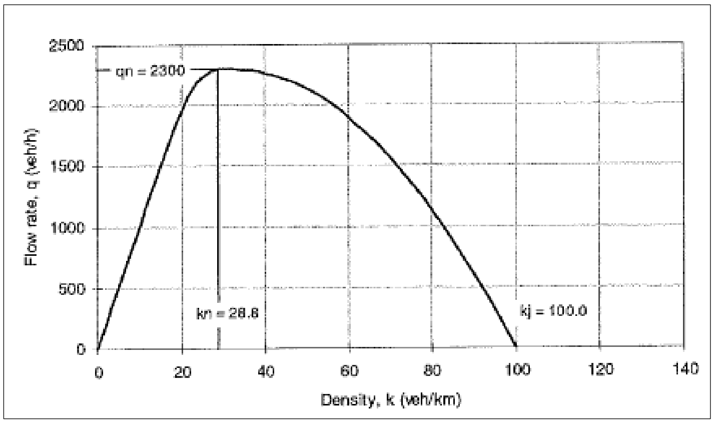


Figure 2.2: Flow versus Density Graph adapted from (Akcelik et al., 1999).

The LOS determines and explains the flow conditions. In general, LOS depends on the volume and the speed. LOS is divide into 4 class (A, B, C, D) and two more classes (E, F) in which the flow conditions are at the capacity and in the congested flow conditions. When the flow passes the 5th class (E; capacity flow) than the flow is inaccesible while providing service.

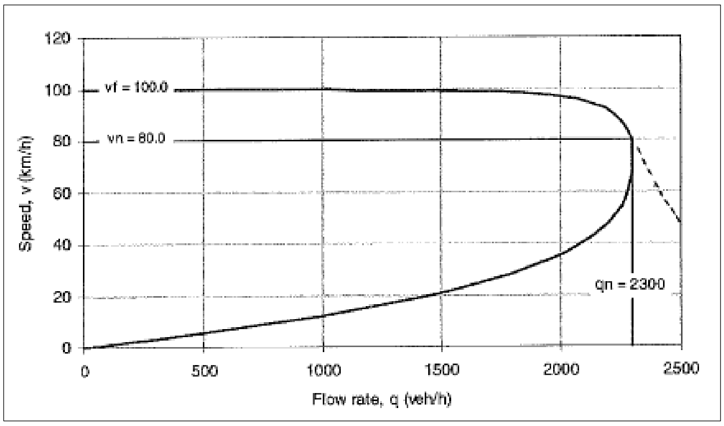


Figure 2.3: Speed versus Flow Graph adapted from (Akcelik et al., 1999).

2.1.4 Measuring variables of traffic flow

The detailed description of measures and variables of traffic flow are explained in the previous sections. In this section the methods for obtaining these variables are explained. There are traditional and innovative ways for obtaining these variables. The traditional methods for measuring the traffic flow variables are; counting the variables by hand, by counters and recording equipment. Moreover, innovative methods can be assumed as countings made by electronic equipments.

2.2 Modelling Traffic Flow

Traffic flow modelling approaches are explained within this section in the following paragraphs.

2.2.1 Approaches on traffic flow modelling

Starting from the year 1950, scientists have developed various methods concerning traffic flow modelling. In 1950, the macroscopic model (fluid dynamic model similitude) was used, in which the shock wave propagations were scrutinized by kinematic wave theory, and the traffic flow is presumed as compressible fluid along a duct. In 1960's microscopic models are used which scrutinizes the behavior of each vehicle following the consecutive front vehicle. In 1970's different variations of the microscopic models are derived; which scrutinizes the alteration of speed in accordance with the position; this model is called gas kinetic models.

In 1980's, scientist worked on especially macroscopic flow dynamic models which are used to determine link dynamics and can be practically implemented on assignment problems.

From 1990's up to date; a real time mix structured simulation model is used for traffic flow modelling and dynamic modelling solutions (which are offered in the previous years).

Today, though on network scale and real time, the existence of models making real, efficient and consistent models, there are various approaches concerning real-time network success calculations. In the following sub-sections, main traffic flow model approaches are briefly explained.

2.2.2 Macroscopic traffic flow modelling

Macroscopic model are visualized as a traffic along a reasonably crowded road, with no appreciable gaps between individual vehicles. Traffic as a continuum and characteristics correspond to the physical characteristics of the imaging fluid.

In macroscopic flow modelling, traffic flow is assumed as continuous fluid like in fluid dynamic models and aggregated vehicle dynamics are defined as; density, flow and speed. There are various macroscopic models for analyzing vehicle platoons and low density flows.

In macroscopic approach, vehicles are modelled similar to fluid flow, flow and density variables under time and distance are modelled as piecewise continuous function.

Finite difference method can be used to solve, this mathematic based instantaneous one-dimensional fluid dynamics, differential equations found within distance and time dimensions (Lebacque, 1996; Messmer and Papageorgiou, 1990; Daganzo, 1994 and 1995a).

Lightill and Whitham, Richard have proposed the first kinematic wave theory which is developed under the assumption conservation laws and flow density relation at balance state (Lighthill and Whitham, 1955; Richards 1956). This theory is also known as LWR theory and formed from an unrealistic assumption like instantaneous adaptation of equilibrium speed so it is unsuccessful when defining complex traffic flows. Though this model uses flow-density relation providing lots of calculation to be solved, it produces results close to real conditions. Basic macroscopic models are formed with respect to traffic found in a certain point within distance-time dimension and its influence from neighboring local traffic only for this point (Daganzo, 1995b and c). The flow-density which is the base of this model, is obtained by correlation of basic measurements related with flow and density. As the numerical solutions of this model are complex, the implementations of these models are restricted.

2.2.3 Microscopic traffic flow modelling

Microscopic traffic flow modelling approach, analyze the movement and their dynamics of interaction on a vehicle-based approach. Approaches developed within this model makes vehicle-based analysis and extract a conclusion. In general, microscopic traffic flow modelling is named as “vehicle-tracking”, “leader-tracking” models (Gazis et al., 1959 and 1961). Despite it is hard to calibrate microscopic traffic flow models, for the evaluation of effects of traffic management or predictions of possible traffic flow development scenarios, it is beneficiary. With this particular model, parking, passing, lane departure and similar behavioral activities for only one driver behavior within traffic is observed (Barcelo, 1996; Rillet et al., 1994; Van Aerde et al., 1987). For implementation purposes, various microscopic traffic flow model unit softwares are developed for conditions requiring special traffic management; interchanges and corridors.

2.2.4 Mesosopic traffic flow modelling

In mesosopic traffic flow modelling, the vehicle dynamics determined by microscopic traffic flow approach is defined as a function of macroscopic traffic flow modelling. Vehicle movements are solved under microscopic approach and the performance criteria; travel time, traffic flow, speed and occupancy which are obtained as a result of traffic generated by these vehicles are solved with macroscopic traffic flow modelling. In the related literature, there are various methods for the assumptions and solutions made, and various models are present that are developed with mesosopic traffic flow modelling (Leonard et al., 1978; Cascetta et al., 1991; Jayakrishnan et al., 1994; Ben-Akiva et al., 1998; Celikoglu et al., 2009).

2.2.5 Traffic engineering problems require incorporation of traffic flow modelling

In traffic mainly faced problems can be assembled into two topics; recurrent and non-recurrent congestion and their subsidiary effects. When explaining these two sources of problem their subcases are explained briefly.

Recurrent congestion is a type of congestion that occurs on a daily, hourly basis, when a high demand exist exceeding the optimum capacity level of a freeways density.

Non-recurrent congestion occurs as a result of some special events occurring on a particular road section. These special events can be summarized as; accidents, special events, sport events etc.

Daily, monthly or yearly based congestions can be solved by using daily interferences, but this method will result in only temporary solutions. A logic based traffic flow modeling approach will lead to permanent, long term solutions.

2.3 Conventional Methods of Road Traffic Management

The design and traffic control scheme should optimize the operational quality of traffic flow through the intersection. The intersection should be designed to maximize capacity utilization and their adverse consequences.

In the following subsections conventional methods of road traffic management is explained briefly.

2.3.1 Geometrical design

Designing a particular road section requires several stages, simply it can be divided into two; preliminary design and detailed design.

In the preliminary design stage, the collected data analyzed and in accordance with the obtained data, a basic design is performed.

Following the preliminary design, for the detailed design stage, more specific and detailed information is required. Mainly designing and managing traffic should maintain the traffic flow at optimum levels, and the channelization should be done to prevent and minimize accidents and it's subsidiary effects.

When managing traffic in a particular road section, geometrical design is the leading aspect. Traffic management is made through the use of channelization, and the channelization mostly depends upon the inputs for the design process. The main inputs considered while performing the detailed design are; human factor, vehicle characteristics, environmental factors, type of highway, area type with land usage and climatic conditions.

Before and during the design stage it should be born in mind that, vehicle characteristics are the leading aspects affecting the design elements used for the intersection.

The vehicle characteristics are observed under two subtitles; physical characteristics and operational characteristics. The interference of vehicle characteristics and intersection design elements are explained briefly in Table 2.2.

2.3.1.1 Design principles of channelization

While designing an intersection there are two main objectives that should be maintained. One of these objectives is the operational quality of the traffic flow made with designing an intersection which should be in optimum levels with the help of the design and the traffic control scheme. And second objective is the minimization of accidents and their drawbacks (Neuman, 1985).

In ramp metering implementations, one of the main objective is to reduce accident rates while providing continues regulation of traffic flow. Thus, traffic lights are the leading actors in providing the safety standards, channelization should be in the auxillary role.

Table 2.2: Vehicle Characteristics Applicable to Design of Channelized Intersections (Neuman, 1985).

VEHICLE CHARACTERISTICS	INTERSECTION DESIGN ELEMENTS AFFECTED
Physical Characteristics	
Length	• Length of storage lanes
Width	• Width of lanes • Width of turning roadways
Height	• Placement of overhead signals and signs
Operational Characteristics	
Wheelbase	• Nose placement • Corner radius • Width of turning roadway
Acceleration capability	• Acceleration tapers and lane lengths
Deceleration and braking capability	• Length of deceleration lanes and tapers • Stopping sight distance

2.3.1.2 The objectives of maintaining an ideal channelization

The objective of maintaining an ideal channelization for obtaining a free flow should be achieved by following the stages. An efficient operation can only be maintained by solving the potential conflict points which can end up with chaotic results for drivers not familiar with that particular road section. And complexities of conflict areas are mandatory for safety and time saving issues. In case of urgent intervention to solve the conflict areas, a limit can be maintained by determining the areas of conflict. The severity of conflicts that occur should be limited. In most intersections, the operational activities and as a consequence their problems are concentrated over a limited, small area. Within this section, drivers are have imperative tendency to make rapid and multiple decisions.

As traffic, is the movement of vehicle and mainly interaction of vehicles with respect to driver behaviors, the actions such as; sudden braking, erratic driving / maneuvers, influence other drivers within the traffic and the situation gets worse.

The speed adjustments are generally made for intersections to maintain safety at operation levels. Most of the drivers need to decelerate and apply braking for speed reduction purposes, to eliminate conflicts or turn effects while entering a particular intersection. The adjustments made over the speed results in driver error and conflict arising from requirements of other drivers perception and reactions.

Drivers behavior and attitudes of driving within the traffic significantly affect the intersection operations. The sudden lane changes or braking and inappropriate approach speeds caused by inattantive, unfamiliar or less capable drivers will lead to some serious safety problems. Additionally, the increased number of route opportunities increase the driver to make an inappropriate and unsafe maneuver (Neuman, 1985).

2.3.1.3 Principles of channelization

The general principles of channelization lead us to a controlled manner for ideal implementation. By channelization, the wrong diverted movement of traffic should be proscribed in an efficient manner. The travel paths for the road users should be clearly marked with supportive elements for the particular areas of intersection. A channelization implementation, should maintain vehicle speeds that lies within the safe region. The conflict points leading drivers to get confused and can even cause accidents that should be solved with the help of channelization. The traffic flow should be allowed to cross at near-right angles and the margining flow should be allowed at flat angles. While making the design of a particular intersection the precedence traffic flow movements should not be restricted besides assistance should be provided, parallel to assistance of traffic control. The intersection should act as a separator, keeping slow moving, stopped vehicles from high speed vehicles by using traffic lanes. When designing an intersection not only vehicles should be considered but also pedestrians, handicapped and other passengers safety should also be the first priority. For this particular reason safe refuge implementations are mandatory.

Under the design operational elements used, the system architecture can be listed as; traffic lanes, traffic islands, median dividers, corner radii, approach geometry, pavement tapers and transitions, traffic control devices such as signs, signals (Neuman, 1985). Prohibitions of movements are maintained by traffic islands, median dividers, corner radius, approach geometry and traffic control devices.

The second principle of channelization is the definition of vehicle parts, provided by traffic islands, median dividers, corner radius, approach geometry and paper tapers or transitions.

For safe traffic operations, promotion to safe speeds is of vital importance and to stay within the safety range, corner radius, approach geometry and paper taper and transitions are used.

Separation of conflict is an important channelization principle, traffic islands, median dividers, approach geometry and traffic control devices are used to eliminate conflict faced by the road users.

It is shown in Table 2.3 which of the basic design elements are applicable in addressing the nine principles of channelization.

Table 2.3: Basic Design Elements which are Applicable in Addressing the Nine Principles of Channelization (Neuman, 1985).

	1)Prohibition of Movements	2)Definition of Vehicle Parts	3) Promotion of Safe Speeds	4)Seperation of Conflict	5) Angles of Cross & Merge	6) Facilitation of High Priority Movements	7) Facilitation of Traffic Control	8) Accommodation of Slow/Decelerating Vehicles	9) Safe Refuge for Pedestrians
Traffic Lanes						*	*	*	
Traffic Islands	*	*		*	*		*		*
Median Dividers	*	*		*	*		*		*
Corner Radius	*	*	*			*			*
Approach Geometry	*	*	*	*	*	*			
Pavement Tapers / Transitions		*	*						
Traffic Control Devices	*			*	*	*	*		*

2.3.2 Pre-timed signalization

Management of traffic is generally a complex issue in which controlling the flow should be made by external interventions. One of the methods used for external intervention of the system is signalization. Signalization is divided into three main groups; pre-timed, partially actuated, and fully actuated.

In pre-timed signalization, the phase of the signal and the traffic flow is operated by the pre-set values. A fixed time of traffic cycle time is applied without any alterations with respect to the current conditions.

The partially actuated signalization, requires supplementary devices to allow vehicle flow or pedestrian movements. The devices used for actuation are; vehicle detection devices (e.g. loop detectors) and pedestrian push buttons.

Fully actuated signalization; within this system vehicle detectors and pedestrian push buttons are used, the signal phases have preset minimum and maximum green cycles which are activated in case of demand present. And for the pedestrians a simple press to the button is directed to the center and the pedestrian light goes green **(**Halifax Regional Municipality, 2012).

2.3.3 Others

Other methods can be briefly named as; intersection management with traffic signs, with a police officer or without control. The last case is especially specific to Turkey conditions. Intersection management with traffic signs are made with signs located on the freeway to inform drivers that a ramp is present ahead. And for the second case, a police officer direct drivers according to current situations present on the freeway mainline and on the on-ramp.

3. FREEWAY TRAFFIC MANAGEMENT AND INTELLIGENT SYSTEMS

Traffic Management especially on a freeway section is always considered in a complex level when compared to secondary roads.

On a particular freeway, free flow has to be obtained and within this frame, management issues gain a vital importance.

In addition to the traditional ways of traffic management, nowadays together with the development of the technology, there is a tendency for using intelligent transportation systems, ITS.

ITS have many sub branches changing according in accordance with situation based approaches. In the following sections each are explained in detail.

3.1 Data Collection and Information Dissemination

The place of surveillance systems in freeway traffic management is explained within Section 3.1. For a start we should emphasize the importance of surveillance systems in freeway traffic management. Compared to other road types, freeway traffic has to be considered in a unique manner.

In order to handle the complex situations occurred on site, an assistance should be provided by ITS. These systems will not only provide observation of the site situations on real time but also allow collection of traffic information. For security reasons, critical transportation infrastructure can also be monitored.

Surveillance systems are mainly divided into three subcategories; roadside detection, transportation management center, roadside telecommunication.

Roadside detection generally consists of inductive loops, Remote Traffic Microwave Sensors, RTMS and Closed Circuit Television Video Camera, CCTV.

Transportation management center subsystem only comprises of hardware and software for traffic surveillance. Roadside telecommunication subsystem includes conduit design and installation of fiber optic cable.

3.1.1 Roadside detection subsystem

Roadside detection subsystem plays a major role in ITS, it not only provides data but also support the system fully to obtain results in an efficient utmost behavior. Under the frame of this section, various roadside detection subsystems are explained in detail.

3.1.1.1 Inductive loop system

Roadside detection plays a major role in collecting freeway data and regulating traffic, in order to provide traffic data, one of the method used is inductive loops implemented on a corridor section. The implementation of inductive loops consists of one or more loops of wire embedded under a pavement close to traffic lights.

The wire loops are connected to a control box which is called “pull box” and it directs signals to a cabinet & controller, for both collecting data and providing regulation of traffic.

In case of vehicle passing over that particular wire loop, the electrically induced energy reduces which states the presence of a vehicle. After the system realizes the presence of a vehicle, a signal is excited by the control box having frequency ranging from 10 KHz to 200 KHz. The collected data includes vehicle passage, vehicle presence, counting and occupancy (Çelikoğlu, 2011).

These valuable data are used to measure density on a particular road section and assist authorities to take essential precautions. From our observations in Turkey, it is clearly seen that Inductive Loop Implementation in required sections of Istanbul will only reduce queues on traffic lights, but also it can result in an increase of travel time savings.

Inductive Loop systems consist of three main components; underground electrical wire, system computer, electrical meter. These components work in coordination with each other to obtain effective field results. The electromagnetic field produced by the underground electrical wire, disappears in the presence of a vehicle and the electrical meter recording this data simply transfers it to the system computer.

The system computer records the data and queue formation detected whether by computer programs or an engineer, accordingly precautions required to be taken are implemented. Inductive Loop System configuration is presented in Figure 3.1.

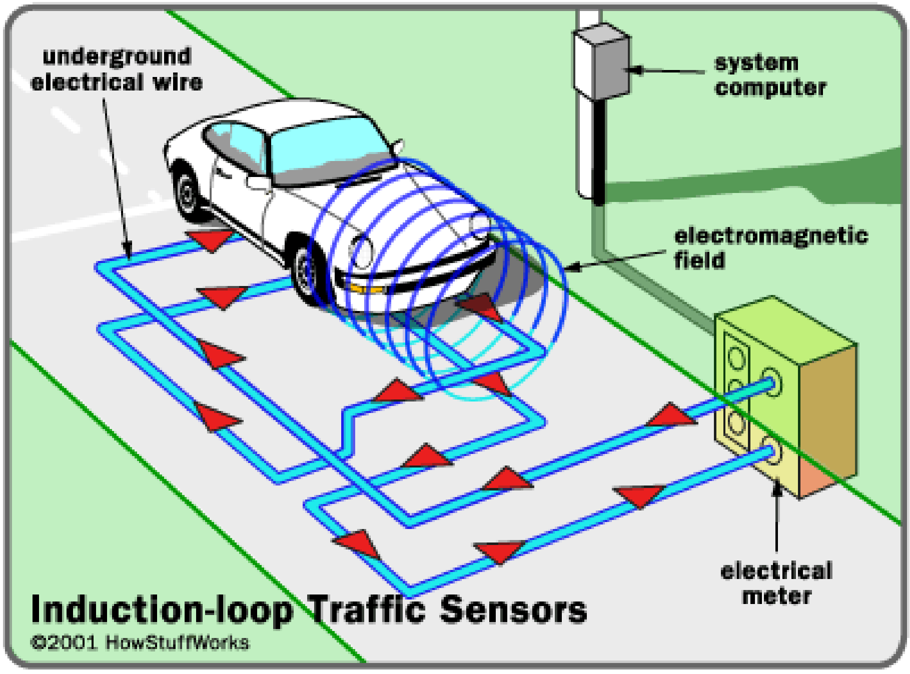


Figure 3.1: Inductive-Loop Traffic Sensors Implementation adapted from (Harris, 2012).

From implementation point of view it should be noted that, although Inductive loop systems can easily be implemented, it should be born in mind that in order to obtain precise data while constructing the system, high attention should be maintained.

Inductive Loop System has both positive and negative feedbacks. The beneficiary sides of this system are that, it works efficiently in all weather conditions as well as detecting vehicle counts accurately. It can ideally be used while dealing with high and low volume traffic. Moreover, it can deal even with most subtle errors arising from vehicle flows.

The negative feedbacks of a inductive loop detection system occurs when improper connections made in the pull boxes additionally application of sealant over the saw cut causes unreliable solutions. These problems specified increases and can be seen more frequently as directly proportional with the interference of pavement for some implementations and maintenance activities increases. Data obtained can be inaccurate in cases when loop malfunction exists.

The last negative feedback can be addressed as it doesn't directly measures speed, if speed is required, two-loop speed trap should be implemented as well as a single loop having an algorithm including loop length, average vehicle length, time that a vehicle spent over the detector (Çelikoğlu,2011).

3.1.1.2 Remote traffic microwave sensors

The second roadside component is Remote Traffic Microwave Sensors, RTMS which uses microwave signals for the detection of vehicles along a road corridor. It can easily detect stationary objects as it modulates the transmitted frequency.

The RTMS comprises of three main components for implementation purposes; RTMS, Power and Data Cables, Remote Traffic Control Protocol (RTCP). Additionally, solar panel to obtain energy for the system, batteries and modem are also needed. The mechanism works as follows, the data collected obtained from the microwave radar stored in the RTCP counter unit and this data stored can be easily obtained by using a direct computer connection or a modem having a serial cable.

The RTCP have two components; a clock and a location, by setting up the clock, the computer time starts to retrieve and the data copied to the RTCP with computer. The location in the system is a name given or a station code in which data are collected from, and as well as location, the time and memory information can also be collected from the RTCP. The collected data can be obtained by downloading and recorded as an ASCII file in the computer. The visual implementation of RTMS can be seen in Figure 3.2 (Çelikoğlu, 2011).

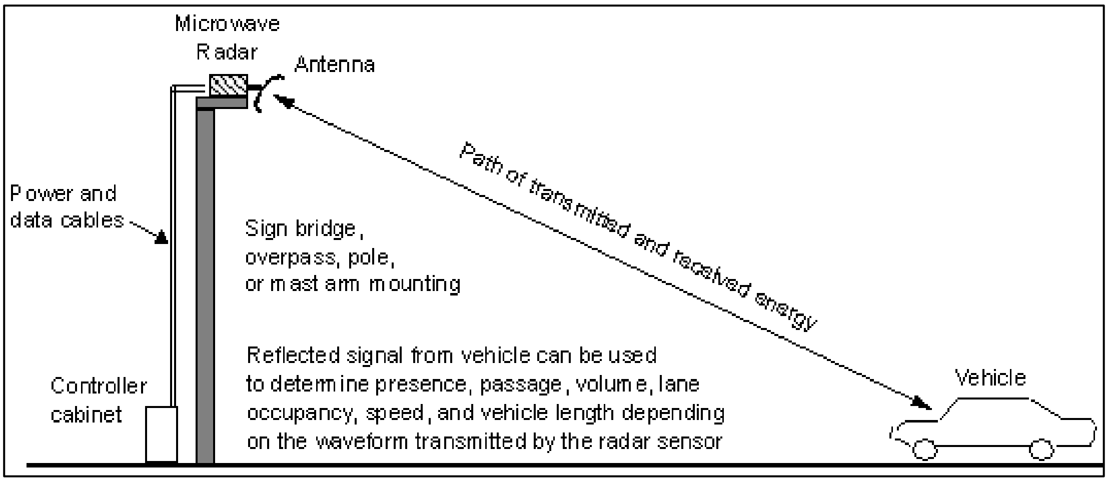


Figure 3.2: RTMS Onsite Components adapted from (Gillman, 2007).

RTMS Onsite components are generally outlined before, now a brief explanation about a typical RTMS mounting configuration is given. RTMS mounting have subcomponents like; Banding, Mounting Bracket and MS Connector that provides the stability of the camera recording the road section (Çelikoğlu, 2011).

RTMS can be set up either in a side-fired or forward looking set-up, to count vehicles and measure speeds in an efficient manner. When the RTMS set-up as a side fired position, the volume and occupancy can be obtained from one detector monitoring maximum eight lanes.

In forward looking set up, there are three detection zones lining up in one lane which are forming a speed trap. In this set-up, although RTMS per lane is required, the speed and vehicle length measurements compared to other set-ups are much more accurate.

The data recorded by RTMS set-ups are stored in the data base and by RTMS Data Analyst 2.5 or similar programs, the data obtained can be recorded on a sheet, including every detail, such as the required data (speed, volume, occupancy). The data sheet is presented in Figure 3.3.

RTMS Data Analyst 2.5 106
File Path: C:\RTMS\DataAnalyst\Asc\december1.asc
File Date: 12 20 2001 12:10:54
Speed In: Mph
Location: Hawaii

Station ID	Active Zones	Messages	Time Period(sec)	LVeh Used?	Fwd Speed	Date Start	Date End	Filtered Sli
1	11000000	2264	290	True	No	12/18/01	12/19/01 12:15:00 AM	900

	Time Slice Ending	Volume	Occup.	Speed	LongVeh	Fwd_Speed	Messages
1	12 18 2001 00:15:00	8	0.8	36.6	0.0		6
2	12 18 2001 00:30:00	3	0.5	49.0	0.0		6
3	12 18 2001 00:45:00	19	1.0	38.7	0.0		6
4	12 18 2001 01:00:00	9	1.0	37.5	0.0		6
5	12 18 2001 01:15:00	4	0.5	47.0	0.0		6
6	12 18 2001 01:30:00	5	0.5	31.3	0.0		6
7	12 18 2001 01:45:00	4	0.5	36.0	0.0		6
8	12 18 2001 02:00:00	11	0.7	32.8	0.0		6
9	12 18 2001 02:15:00	18	0.8	33.2	0.0		6
10	12 18 2001 02:30:00	11	0.7	36.8	0.0		6
11	12 18 2001 02:45:00	5	0.5	32.7	0.0		6
12	12 18 2001 03:00:00	12	0.8	30.4	0.0		6
13	12 18 2001 03:15:00	2	0.3	37.0	0.0		6
14	12 18 2001 03:30:00	4	0.5	33.7	0.0		6
15	12 18 2001 03:45:00	1	0.2	25.0	0.0		6
16	12 18 2001 04:00:00	10	0.8	40.2	0.0		6
17	12 18 2001 04:15:00	14	0.8	30.8	0.0		6
18	12 18 2001 04:30:00	17	1.0	36.5	1.0		6
19	12 18 2001 04:45:00	55	1.0	32.8	0.0		6
20	12 18 2001 05:00:00	67	1.2	32.2	2.0		6

Figure 3.3: Data Collected as ASCII Files from RTMS Database, Report Generation from RTMS are as above adapted from (Çelikoğlu, 2011).

RTMS applications are used in wide range for multi purposes. These purposes can be listed as follows; “Multi lane intersection control, stop-bar, and mid-block detection, Freeway Traffic Management and Incident Detection Systems, Travel Time Predictions, Ramp Metering, Off-Ramp Queue Control and Signal Control Actuation, Work Zone and Temporary Intersection Control, Permanent and Mobile Traffic Counting Stations, Enforcement of Speed and Red-Light Violation.”

There are other sensors which have beneficiary effects on surveillance surveys. We can list them as follows; Magnetic Sensors, Acoustic Sensors, Ultrasonic Sensors, Infrared Sensors. The sensors listed are presented in the following figures; Figure 3.4., Figure 3.5, Figure 3.6 (Çelikoğlu, 2011).

3.1.1.3 Magnetic sensors

The magnetic sensors are passive devices, which are activated, in case the presence of a ferrous metal object; in our case vehicles. The activation of the system results in the perturbation, a magnetic inconsistency that takes place in the Earth’s magnetic field. A vehicle propagates energy fields once it enters the magnetometers detection zone. In Figure 3.4, the magnetic inconsistency that a particular vehicle generate is presented (Klein et al., 2006a).

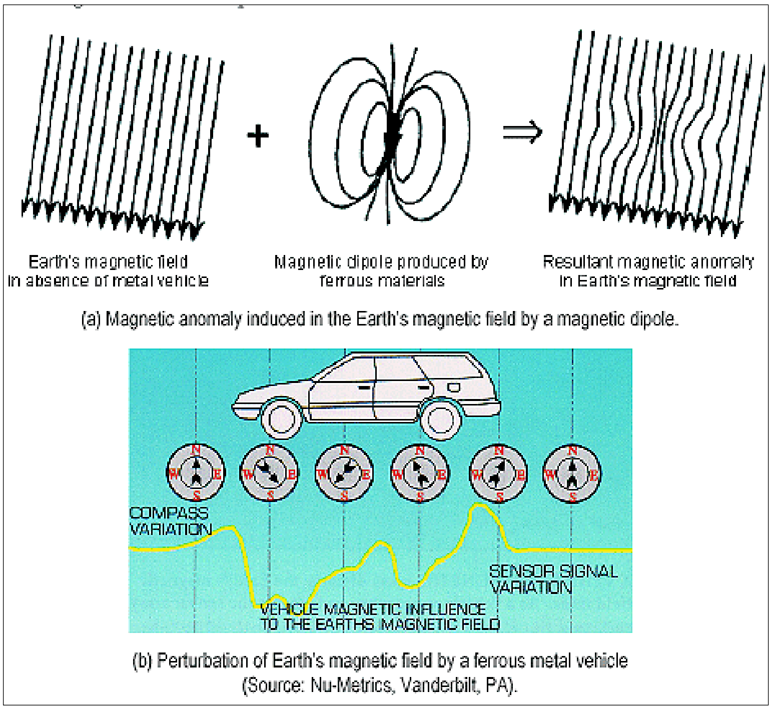


Figure 3.4: Magnetic Sensor Configuration adapted from (Klein et al., 2006a).

3.1.1.4 Acoustic array sensors

Acoustic sensors are used to measure data such as; vehicle passage, presence and speed. The values are obtained by the detection of acoustic energy or audible sounds as a result of a vehicular traffic.

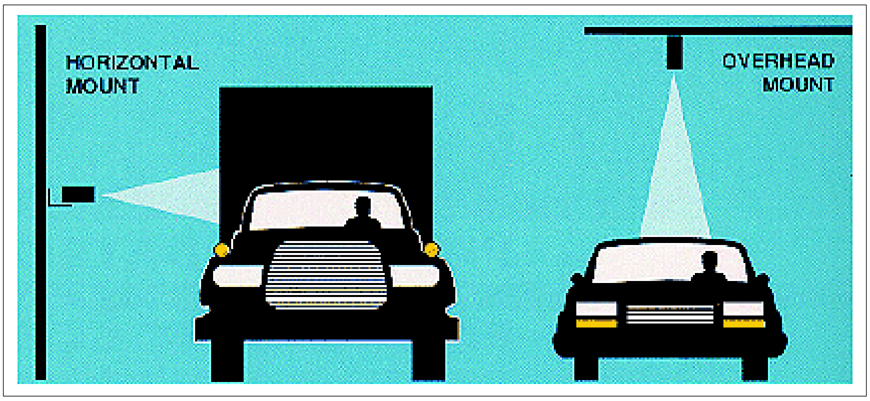
For each vehicle, the interaction of vehicle tires with and any road surface and any other sounds which are exceeding the detection threshold is recorded. This recorded signal processed by algorithm recognizes the increase in sound energy when a vehicle passes through that particular detection zone and a signal concerning this presence is generated. When the vehicle departs from that particular road section, the level of sound drops below the threshold level and the signal stating the vehicle presence is terminated. The sounds originated from other sources are attenuated for prevention of errors. Single lane and multiple lane models of acoustic sensors are marketed. Both use a two-dimensional array of microphones for detection of sounds produced by approaching vehicles (Klein et al., 2006b).

Figure 3.5: Acoustic Array Sensors adapted from (Klein et al., 2006b).

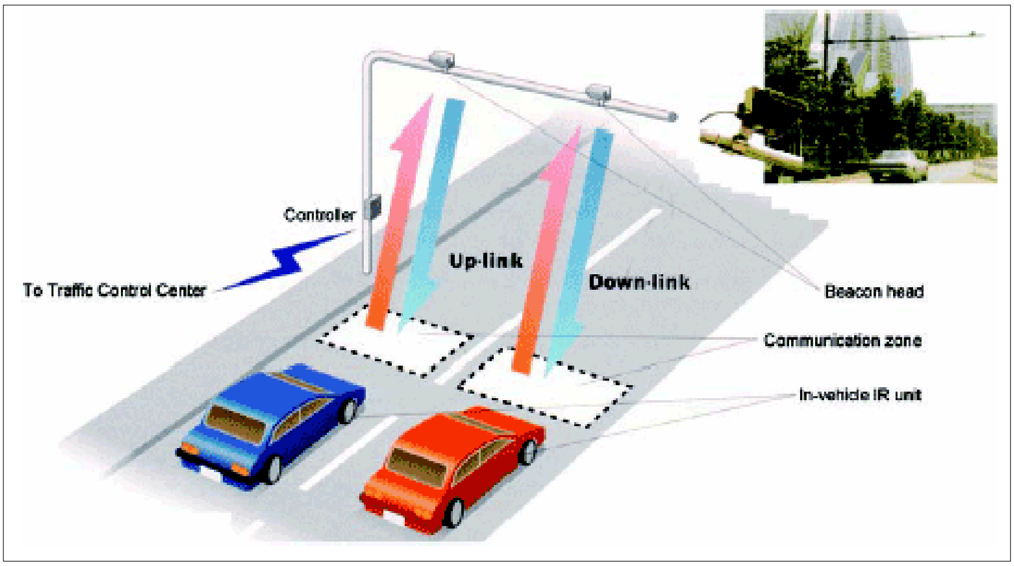
3.1.1.5 Infrared sensors

The mechanism of passive sensors operates in such a way that the system transmit no energy within itself. It is programmed to detect the energy from outer sources such as; energy emitted from vehicles, road surfaces and other objects found in their field of view and the energy emitted by the atmosphere and that are reflected by vehicles, road surfaces, or any other objects into the sensor aperture.

The infrared sensors which are focused by an optial system onto a material sensitive to infrared captures energy at the focal plane of optics. Infrared sensors can convert the reflected and emitted energy into electrical signals and the real time signal processing use these signals for analyzing the determined vehicle presence. Infrared sensors can either be mounted overhead or in a side-looking configuration. Main measurements obtained from a particular infrared sensor are; volume, speed and class measurement, pedestrian (passing the crosswalks) detection, transferring the traffic information to drivers (Klein et al., 2006b).



(a)



(b)

Figure 3.6 (a) (b): Active Infrared Sensor Installed for Transmitting Traffic Conditions to Motorists adapted from (Klein et al., 2006b).

3.1.1.6 Closed circuit television video camera system, CCTV

CCTV is one of the major components of roadside detection systems in the world. This versatile tool have capability of tilting, zooming action and it provides monitoring roadway conditions, identify incidents, made verifications of the reported or detected vehicles. It organizes response action to be taken concerning incidents, verification of the dynamic message sign information, reporting congestion and enumerate the sources it arise from and the consequences it will bring along.

Despite the main beneficiary aspects listed above, the range of observation is limited with the camera installation. The main reason for this obstruction is stemming from the following freeway design characteristics; vertical alignment, cross-street bridges and interchange ramps, horizontal alignment, the obstruction as a result of roadside signaling, billboards, tall trees and buildings, freeway guide signing and camera stability (Gerald, 1996).

3.1.2 Information dissemination systems in freeway traffic management

One way of managing freeway traffic is by using information dissemination systems. Information concerning traffic conditions, reporting density value of that particular road section whether heavily congested, congestion at medium levels or at free flow conditions are vital information for drivers. This information is provided to the drivers in several ways; Dynamic Message Signs (DMSs), Highway Advisory Radio (HAR), in-vehicle displays, specialized information transmitted to individual vehicles.

The detailed version of DMS also shows the status of the road sections such as closure of road/lanes, accidents occurred, maintenance or construction activities, travel times, speed limits, amber alerts, and weather conditions. This particular DMS only shows warning signs in case of accidents, construction activities or incidents related with the weather conditions (Çelikoğlu, 2011).

Highway Advisory Radios, HAR are provided by Department of Transportation within the country. HAR are commonly near highways and airports and in tourism zones, extending necessary information to drivers. Main objective of HAR, is to provide information for the drivers regarding the traffic conditions, traffic, and delays.

For a last word we can say that, in-vehicle systems or, specialized information transmitted to individual vehicles are different ways of information dissemination on freeway traffic management (Çelikoğlu, 2011).

The summary information of sensors used for roadside detection including; operational properties, measurement capacities and explanations for each of them are given in Table 3.1.

Table 3.1 : Sensors Used for Roadside Detection.

Technology Used	Operation	Measurement Capacity	Explanation
Ultrasonic Sensors	Propagation of sound waves below the perception of human sense	Flow, Occupancy, Presence and Queue Length	Point Measurements, depends upon weather conditions
Active Infrared Sensors	Propagation of high frequency laser beam signal	Flow, Occupancy, Classification, Spot Speed, Presence	Point Measurements, depends upon weather conditions
Passive Infrared Sensors	Measurement of infrared energy that are propagated from objects	Flow, Occupancy, Presence	Point Measurements, depends upon weather conditions
Remote Traffic Microwave Sensors	Propagation of a lower signal similar to active infrared sensor	Flow, Presence, Spot Speed	Point Measurements, related with human health
Acoustic Array Sensors	Detects traffic sounds generated by vehicle	Flow, Presence, Vehicle Classification	Point Measurements, depends upon surrounding sounds
Video-Image Processing	Direct connection analysis of video images with equipments and softwares	Flow, Occupancy, Speed, Queue Length, Presence	Detailed computer work, limited observation area
Aerial Video Image Processing	Aerial video image analysis	Flow, Density, Queue Length	Wide observation area, depends upon the weather conditions
Induction Loop	Detection of change in induction and determination of vehicle passage or presence	Flow, Occupancy, Presence, Spot Speed	Point measurements, used widely, cause infrastructure problems
GPS	The duration of the signal taken and transmitted from minimum four satellites, travel time	Travel Time, Distance based speed	Presenting the track of a vehicle in a wider area
Automatic Vehicle Detection	Communication of vehicle unit and road section	Flow, distance based average speed, travel time, vehicle classification	Fee collection, related with private life

3.2 Intelligent Systems Applications in Freeway Traffic Management

Intelligent systems applications in freeway traffic management is divided into following sections; surveillance (traffic, infrastructure), ramp control (ramp metering, ramp closures, priority access), lane management (high-occupancy vehicle facilities, reversible flow lanes, pricing, lane control, variable speed limits, emergency evacuation, enforcement including; speed enforcement, high-occupancy vehicle facilities and ramp meter enforcement), special event transportation management (occasional events, frequent events, other events, temporary traffic management center), information dissemination (dynamic message signs, ,in-vehicle systems, highway advisory radio).

3.2.1 Ramp management

A ramp management includes; ramp control, ramp closure and ramp metering implementations. Their descriptions are given in this section.

3.2.1.1 Ramp control

Ramp Control is a system developed to improve freeway traffic conditions in a wise manner. This system mainly consists of three components; ramp geometry, flow measures and performance measures.

To start with we can briefly explain the ramp geometry. In this system the ramp section is controlled by regulatory traffic lights. The on-ramp section is where vehicles are merging to the freeway traffic and off-ramp section is where vehicles are diverging out from the traffic flow. The on-ramp is controlled by traffic lights that follows this particular rule; one car per lane per green light or two car per lane per green light depending upon determined and applied strategy.

Second components are flow measures, mainstream flow, merging flow and occupancy. When ramp control is applied, a queue is present on the on- ramp while the freeway relieve from congestion, and a free flow traffic is maintained. In this case, the mainstream present on the freeway has a free flow traffic and the merging flow is delayed for a short period of time.

The third and the last component of the ramp control system is the performance measures; queue length, travel time and travel time delays (Çelikoğlu, 2011).

3.2.1.2 Ramp closure

Ramp closure is a rarely implemented long-term strategy having major influence over the current traffic flow. A ramp closure where the access to a ramp is not available made via full or permanent ramp closures. These kind of closures divert drivers to other routes or transportation modes. In full ramp closure the ramp road is removed physically, in order not to recall the drivers that the ramp is planned to be re-opened again.

There are other ramp closures such as, temporary and scheduled ramp closures. Road closure site components that unable access to ramp is mainly consist of gates operating automatically or barriers placed manually. This type of freeway management are rarely used and chosen as the last option to be selected and implemented. The main intention for a ramp closure is to reduce conflicts faced by drivers stemming from construction activities, incidents, emergency cases or special event conditions (Jacobson et al., 2006).

3.2.1.3 Ramp metering

Ramp metering is an application of dynamic signalization. For this application the aim is to control and regulate the freeway traffic, ramp traffic by the help of sensors.

The main components of ramp metering system are; mainline sensors placed on freeway mainline, advanced signs to warn drivers about ramp metering application presence, queue sensor to detect vehicles, demand sensor, ramp metering signals, a stop line, passenger sensor and a controller.

The driver aiming to enter from a frontage road, surface street first faces with the advanced sign on the enterance of an on-ramp, which informs that there is a ramp metering implementation present ahead. After the drivers enter the on ramp, queue sensor detects the presence of a vehicle, secondly demand sensor analyses the presence when the vehicle stops on the ramp metering signal before the stopline. The traffic light allows only one vehicle per lane to enter the freeway mainline, though in some cases it can increase up to two vehicle per lane. As a result of this implementation, the congestion levels on the freeway mainline relieves but on the other hand queue formation is present on the on-ramp. Considering overall benefits of the system, this small negative feedback can be eliminated. In Figure 3.7, the ramp metering implementation is presented.

When a vehicle enters the on-ramp from a frontage road, it is detected by queue sensor first and the signal input is sent to controller which is connected with the other sensor within the road network and directly connected to the control center where cycle lengths are determined. As vehicle continue moving along its route on the on-ramp, it is detected by Check in Sensor and Demand Sensor respectively, before it reaches the stop line. Depending on the traffic flow conditions, the signal turns red or green, the vehicle stops or go, when it crosses the stopline it is detected by the Output Sensor and further by the Merge Sensor. All this time, each sensor is connected with each other inside the road network via direct connection or with the help of the controller, so that cycle times can change with respect to the changing flow conditions in a dynamic manner.

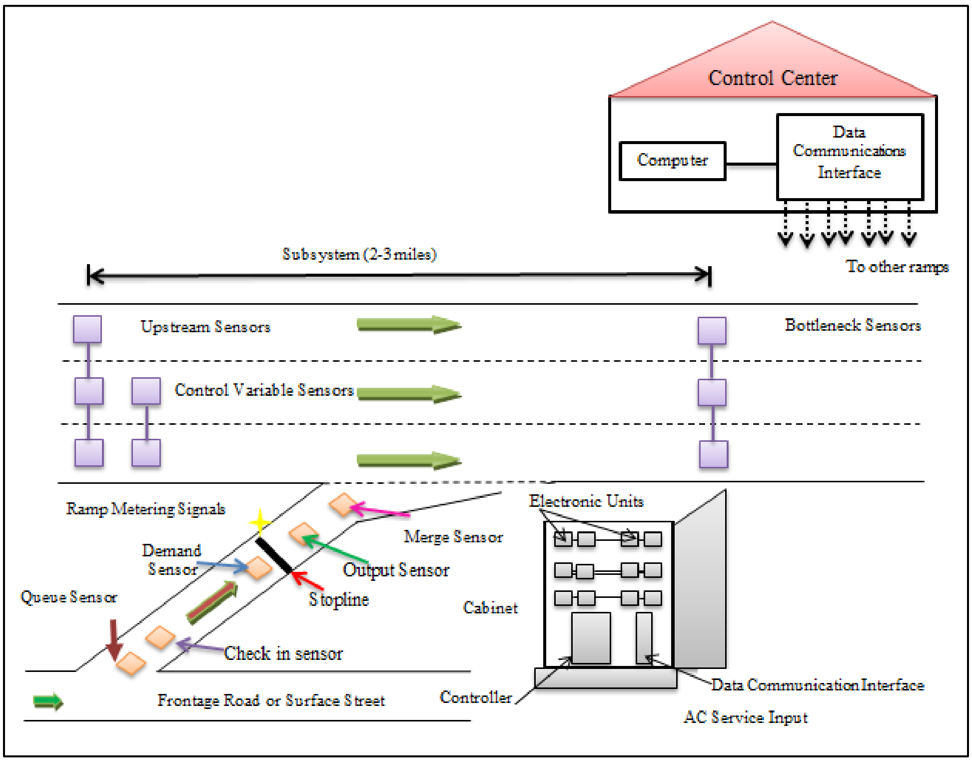


Figure 3.7: Ramp Metering System Architecture Configuration.

3.2.1.4 Geometric properties of ramp metering

The geometric properties effecting the operational quality are briefly explained in this section. A particular road is designed for a period of 20 years, this is also same for ramp metering implementations. A ramp metering implementation is designed to last for 20 years and the evaluation should be made periodically for the sustainability of the system and for the whole road network.

One lane ramp metering

Federal Highway Administration; FHWA advises this type of ramp metering when the on-ramp has a flow of 240-900 veh/h, it should be noted that the maximum capacity, 900 veh/h can change depending upon driver behaviors and capacities.

For one lane ramp metering the advised cycle length for on-ramp is; 4-4.5 seconds.When the flow present on the on-ramp is 240-1200 veh/h, having a maximum capacity 1100- 1200 veh/h, multiple vehicle per green strategy is applied, with a cycle length of 6 – 6,5 seconds.

For single lane ramp design between the stop line and the entrance of the freeway, a minimum width and distance should be maintained. The recommended pavement width is 3.6 meter and width of inside shoulder is 1.2 meter and outside shoulder width; 2.4 meter is sufficient for a single lane ramp metering (Wilbur, 2006).

Multiple lane ramp metering

This type of ramp metering implementation is advised for on-ramps having 400 - 1700 veh/h, with a maximum capacity of 1600 – 1700 veh/h. This strategy allows vehicles to consecutively enter the freeway.

The number of lanes needed for a ramp metering implementation depends on, ramp volume, required queue storage, meter release rate (one vehicle per green or two vehicle per green) and available ramp width.

Generally, the maximum discharge rate for a one lane metered strategy is, 900 veh/h and the minimum cycle length for this strategy is; red cycle time of 2.5 sec and green cycle time of 1,5 sec. And the lowest discharge rate is, 240 veh/h, having a cycle length of 15 sec.

For multi-lane ramp metering design, an important thing that one has to take into consideration is that an adequate distance from the stop bar to the freeway entrance for acceleration purposes should be maintained. The operation for each lane can act independently, each can have different metering rate (Wilbur, 2006).

As stated before, the number of metered lanes and the release rate of a particular ramp highly depend on the volume present on the on-ramp. In Table 3.2, the design considerations according to ramp volumes are given. Following this, the suggested design speeds for both freeway mainline and ramp is given Table 3.3.

Table 3.2: Ramp Metering Design Considerations with respect to Ramp Volume adapted from (Wilbur, 2006).

Ramp Volume	Metered Lanes	Release Rate (N)
<1000 veh/h	One Lane	Single
900-1200 veh/h	One Lane	Dual
1200-1600 veh/h	Two Lanes	Single
1600-1800 veh/h	Two Lanes	Dual

Table 3.3: Ramp Design Speed Suggestions adapted from (Wilbur, 2006).

Freeway Mainline Design Speed (km/h)	64.4	80.5	96.6	112.7	128.8
Ramp Design Speed (km/h)	56.4	72.5	80.5	96.6	112.7

Freeway to freeway ramp metering

Freeway to freeway ramp metering can be implemented in case of necessity. In this type of ramp metering, a freeway mainline is connected to the other freeway mainline as an on-ramp. Standard design for lane and the shoulder width are recommended for implementation and minimum 80 km/h speed is considered.

Storage yard

One important condition that should be provided in order to efficiently operate and maintain a ramp metering implementation is the adequateness of the storage yard capacity. There is a flow restriction present; minimum 240 veh/h/lane and maximum 900 veh/h/lane for the ramps which is planned to be metered.

Ramp metering does not works efficiently outside this value range. Additionally, when peak hour flow values are between 500 veh/h and 900 veh/h, two lane ramp metering can be implemented, to create for secondary storage creating purposes.

The length and number of lanes depend upon the characteristics of the ramp. Additional congestion can be present, in case of queue length reaching the neighboring lane (Davis et al., 2000).

Stop line location

Stop line should be located on the point starting from where freeway and ramp is 7 m distant and minimum 23 m distant to upstream flow. 300 mm thick opaque white line is drawn on the lanes where metering is present.

3.2.1.5 Main elements of ramp metering

In this section main element of ramp metering is explained briefly with specific relevant information.

Detectors

Detectors are dependent upon several factors like; ramp metering type; isolated or coordinated, algorithm used, planned cost for maintenance and implementation, and geographical restrictions. These factors help us to determine what kind of detector we can use and where should we locate it. Detectors can be listed as; Freeway Detectors, Demand Detectors, Ramp Queue Detectors, Ramp Entrance Detectors and Corridor Detectors. Some of these detectors are mandatory, and some are used optionally.

Freeway detectors

Freeway detectors should be used in ramp metering as it provides occupancy, speed or flow data which are obligatory to be used in algorithms as input value. Moreover, freeway detectors can provide data for accident-incident algorithms, and can give assistance to incident management. According to American specifications, if loop detector is used as the freeway detector, the dimensions suggested are; 1.8 m edge, location centered on the lane and 6.1 m distant for implementation (Davis et al., 2000).

Demand and corridor detectors

Demand detectors are used only in special implementations, located in front of the stop line. Corridor detectors are counting number of vehicles data entering from on-ramp to freeway mainline. Corridor detectors are located downstream the flow prior to stop line (Jacobson et al., 2006). The width of demand and corridor detector is suggested to be more than 3.6 m in American specifications (Davis et al., 2000).

Ramp queue detectors

Ramp queue detectors are used to monitor and analyze the upstream flow of the on-ramp. The main objective of this sensor is to prevent the values obtained from the upstream flow to exceed the storage yard capacity. In order to prevent the probability of queue formation affecting the surface roads, data obtained from the detectors, directly used as an input into the algorithm.

Ramp enterance detectors

Ramp entrance detector is a tool used in coordinated real time networks. These detectors are used in every ramp metering implementation regardless of which type is used (Jacobson et al., 2006).

3.2.2 Lane Management

This freeway management system aims to use the capacity on freeways in an efficient manner while encouraging road users to prefer public transportation or any other transportation modes having higher occupancy ratios.

Lane management also subcategorized within itself as; High Occupancy Vehicle (HOV) Lanes, High Occupancy Toll (HOT) Lanes, Bus Only Lanes, Managed Lanes, Congestion Pricing. In freeway management, enforcement plays a major role for the sustainability of continuous operation.

In most ITS, system enforcement implementation is obligatory for the sustainability of the system. There are several enforcements used for this kind of purpose; speed enforcement, HOV facilities and enforcement used for ramp metering. In speed enforcement, the vehicles passing a pre specified limit is fined to pay a fee, and the detection of this disobey behavior of drivers are detected by video cameras located on the freeway.

The positive feedback of the system revealed out as reduction on accident levels, and injured pedestrians, road users.

3.2.2.3 High occupancy vehicle (HOV) lanes

Since 1970, HOV lanes are used to encourage carpooling and transit usage. The system allow, vehicle having 2-3 occupants to travel in an HOV lane.

The main objective of an HOV lane is to increase the total number of people moving from a congested corridor to their arrival point. The system provides the road users; travel time savings in addition to reliable and predictable travel time (Çelikoğlu, 2011).

3.2.2.4 High occupancy toll (HOT) lanes

When single occupancy vehicles pay to use a HOV lane, it is called an HOT lane. The HOT lane is implemented when HOV lane is not used efficiently. It provides attraction from non-HOV lanes resulting in a reduction on congestion levels. With this implementation, not only revenue collection is made, but also the congestion present on the non-HOV lane is reduced (Çelikoğlu, 2011).

3.2.2.5 Bus only lanes

High occupancy vehicles like busses and vanpools use a separate lane to avoid congestion. With this physically separated lane, they have the priority to freely travel along the road. With bus only lanes, passengers move quickly arising from the shortened travel times and more passenger attracted to busses (Çelikoğlu, 2011).

3.2.2.6 Managed lanes

Managed lanes can either be highway facilities or a set of lanes in which strategies on operational basis are implemented proactively and management is made with respect to changed conditions. Contra flow lanes can be an example of the managed lanes (Çelikoğlu, 2011).

3.2.2.7 Congestion pricing

Congestion Pricing is one of the control methods used for regulation of traffic. Its main objective is to regulate peak demand, resulting in a reduction of congestion levels. Under this implementation, the drivers were made to pay predetermined charges when passing through an area, corridor etc. The fee paid by the other road users, is a price for each driver to eliminate the negative effects they exert on other road users. There are mainly four types of congestion pricing implementation in operation, depending upon the local conditions of that particular area. Charging a cordon located around a city center is the first type of congestion pricing. In this type, the drivers passing through that cordon line are made to pay a pre specified fee.

Second type is, congestion pricing on an area wide base which is used to change drivers using the area having high demand levels.

The fee obtained from toll collection surrounding the city is the third type of congestion pricing. And the last type of congestion pricing is implemented for a corridor or a single facility which can be exemplified as drivers pay to have access to a lane or a facility.

3.2.3 Special Event Transportation Management

In special event transportation management, the congestion on freeways near to shopping malls, stadiums, conference halls and other places attracting high level of traffic can be controlled with on-site components. These on-site components are; DMS, software and labor for information dissemination of traffic conditions, cables and a controller.

4. STRATEGIES FOR RAMP METERING

Ramp metering strategies can be diversified like it's benefits. These benefits have been explained in detail in the previous section within ITS. There are several ramp metering strategies varying according to choice based approaches. In this chapter, ramp management strategies and algorithms are explained case by case. Ramp metering strategies have been divided into two main groups; Strategies classified according to system intelligence and strategies classified according to implementation scale. The strategies classified according to system intelligence divided into two categories; pre-timed ramp metering and traffic responsive or reactive strategy.

4.1 Overview of Existing Strategies with Specific Reference to Relevant Literature

In this section overview of existing strategies with specific reference to relevant literature are given. Ramp metering algorithms are used to calculate control ratios that determine cycle lengths. Determined control ratio is transformed into cycle length by the controller and used within ramp metering implementation.

4.2 Types of Ramp Control

Reactive strategies are divided into two main groups; local or coordinated. In local reactive strategy, each individual ramp's value is calculated in accordance with the traffic measurements obtained from the vicinity of that particular ramp. While in coordinated reactive strategy traffic measurements over a specified area of a freeway network is used.

4.2.1 Ramp Geometry Based Classification

Ramp geometry based approaches are categorized as; isolated and coordinated ramp controls. In the following subsections brief explanations of these ramp controls are explained.

4.2.1.1 Isolated, local ramp control

Controlling a single ramp individually is named as isolated ramp control. Though the ease of implementation of designing and implementing an isolated ramp control is an undeniable fact, under recurrent traffic congestion conditions it can be inadequate.

4.2.1.2 Coordinated ramp control

In coordinated ramp control, various ramp meters are in coordination with each other and their evaluation is made as a whole for determination of the ramp metering rates in algorithms.

4.2.2 Time Based Classification

Time based classification of ramp metering is under proactive strategies, which are classified according to system intelligence and the intelligence of system while evaluating data.

There are three types of time based approaches of ramp control; pre-timed, semi-actuated, traffic responsive control.

4.2.2.1 Pre-timed

In pre-timed control strategy, control ratios are determined by using the traffic counts from the database, and the cycle length calculations are made accordingly. Calculated cycle lengths are implemented under pre-timed control strategy.

For pre-timed isolated ramp control, system is updated with respect to changing traffic demands, so there is no need for sensors hereunder.

The continuous updating takes places for time periods of; 3 months, 6 months, 1 year or 3 years. This type of ramp control is inactive on incident management and congestion costs are far more higher compared to traffic responsive systems.

Pre-timed coordinated ramp controls are systems which are used infrequently. For both cases; pre-timed isolated and pre-timed coordinated ramp control, implementation of sensors are not necessary but in case of an intention present, on-ramp sensors can be used and these sensors have the ability to activate the signalization in the presence of a vehicle.

4.2.2.2 Semi-actuated

In semi-actuated control strategy, freeway is always have the green cycle and some of the roads connected with freeway can have green cycle for a period of time in case of necessity. Requirement can be observed from data obtained from the detectors located on site. This type of control strategy is used in isolated intersections, on-ramps accessing to freeways where stop sign is present but found insufficient for efficient control (Kutlu, 1993).

4.2.2.3 Real-time

The current traffic conditions form the basis of real-time control strategy. Ramp control ratio is determined for traffic conditions in that particular time slot. And finally, cycle length calculated in compliance with the predetermined ramp control ratio. In real-time isolated ramp control the sensors should be implemented on the site. Implementation and maintenance costs are higher compared to pre-timed ramp control systems. When we consider congestion cost of the system, as it is reactive to traffic conditions, this cost is lowered accordingly. The systems operating mechanism is as follows; the data obtained from the sensors (freeway mainline and other) transmitted to the controller, this data are input value for algorithms, the algorithm produces a metering rate, and with dynamic cycle times the control mechanism works.

Real-time coordinated ramp control is widely used and pronounced as the most efficient control type. Sensor implementation is necessary, each ramp has a sensor. These sensors are connected to a center controller. Data transmitted from sensors are sent from controllers to the center controller and ramp control ratios periodically determined for each ramp, these ramp control ratios are transformed into cycle length for implementation. Although the cost of implementation and maintenance is ultra-high, the system provides beneficiary aspects in an utmost level. With the increasing number of sensors located on the freeway and on the on-ramp, the system cope with non-recurrent congestion more efficiently, with this respect downstream sensors on the freeway mainline and bottleneck sensors can be used.

The Table 4.1, a comparison of different approaches and types of ramp control; including positive effects and negative effects of the system is given.

Table 4.1: Comparison of Different Approaches and Types of Ramp Control.

<table>
<tr><th rowspan="2">Approaches to Ramp Control</th><th rowspan="2">Types of Ramp Control</th><th rowspan="2">Ramp Control Type</th><th colspan="4">Implementation</th><th rowspan="2">Positive Effects</th><th rowspan="2">Negative Effects</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td rowspan="3">Proactive</td><td rowspan="3">Time Based</td><td>Pre-Timed</td><td>X</td><td>X</td><td></td><td></td><td rowspan="5">Scenario 1 :

*Freeway Sensors are not mandatory.
*Connection with the traffic Control center is not needed.
*Has basic equipment implementation compared to other scenarios.
*Provides safety by seperating platoons vehicles entering the freeway.
*Is efficient when recurrent congestion has a similar nature.

Scenario 2:
*Freeway and some of the connected roads have green cycle.
*Detectors used on-site for data collection.

Scenario 3:
*Manage traffic in the utmost efficiency compared to pre-timed local control type, especially when there is non recurrent congestion present.
*Congestion cost is less compared to pre-timed local control type, as a result it can compensate it's implementation costs over time.

Scenario 4:
*Optimum control is maintained according to real-time data observed from that route or corridor.
*With this implementation, it is possible to work with different algorithms on multi-purposes. (congestion, queue formation)</td><td rowspan="5">Scenario 1:
*As control ratio is calibrated according to traffic conditions, frequent observation of conditions needed.
* Insensitive to extra ordinary conditions like non-recurrent conditions.
* Very restrictive control ratios which results in queue formation and delays in traffic.

Scenario 2:
*Found insufficient for efficient control.

Scenario 3:
*Implementation and maintenance costs are much more compared to pre-timed control.
*Maintenance cost increase is as a result of detectors implemented.
*It is a reactive control, improvements are made not before but after the incident.
*Surface roads in the hinterland of freeway is not taken into consideration (before and after section).

Scenario 4:
*Freeway detectors are required. (located on the upstream and downstream of the flow).
*For connection purposes, central computer is required.
*For system calibration and improvement technical support is required.
*Compared to traffic responsive isolated control, the implementation cost is much more higher.</td></tr>
<tr><td>Semi-Actuated</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Traffic Responsive</td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td rowspan="2">Reactive</td><td rowspan="2">Geometry Based</td><td>Local</td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>Coordinated</td><td></td><td>X</td><td></td><td>X</td></tr>
</table>

4.3 Approaches to Ramp Control

Approaches to ramp control are given in this section. Ramp metering has been classified into two categories according to Papageorgiou and Kotsialos (2002). The categorized approaches are; proactive strategies and reactive strategies.

4.3.1 Algorithms of proactive strategies

Proactive strategies can be mainly named as strategic approach over a freeway network. Within this strategy, the main objective is to obtain optimal conditions for a particular freeway or a freeway network depending upon the modelling approaches and demand levels. An important thing that should be taken into consideration is that the optimal traffic conditions are obtained over a long time period.

The examples of proactive strategies are; “Coordinated metering using ANN”, “Dynamic modelling control”, “Metering model for non-recurrent congestion”, “Sperry ramp metering algorithm”, “Fuzzy logic method”, “Linear programming method”, “METALINE”, “Ball aerospace / FHWA algorithm”, “Advanced real-time metering system”.

The sperry, fuzzy logic, linear programming, METALINE, FHWA ARMS are coordinated algorithms or methods and the remaining algorithms may not be coordinated.

The sperry ramp metering algorithm is developed by Virginia Department of Transportation and used to control 26 ramp along I-395 in northern Virginia. According to predefined values, this algorithm operates in two modes; restrictive and non-restrictive (Zhang, et al., 2001).

In fuzzy logic algorithm, the traffic flows and ramp controls empirical data are converted into fuzzy rules. The finite categories are determined for traffic condition values; occupancy, flow rate, speed and ramp queue and classified as; small, medium and big. Accordingly the metering rates are related with traffic conditions with the developed rules. An example of a rule can be given as; “if the local occupancy is small, and ramp queue is small, then metering rate is high.” As a final step related with the membership functions, the values categorized as small, medium and big are converted into crisp numbers.

When right rules are applied this particular method is very powerful and robust. For local control strategies few rules are needed but on the other hand in system-wide control, more complex rules are required in order to establish the system accurately. Despite the dominating advantages of the system, extra effort is required to calibrate the parameters, which may result in a poor functioning of the system with respect to changing traffic conditions (Zhang, et al., 2001). The schematic explanation of a fuzzy logic operation is given in Figure 4.1.

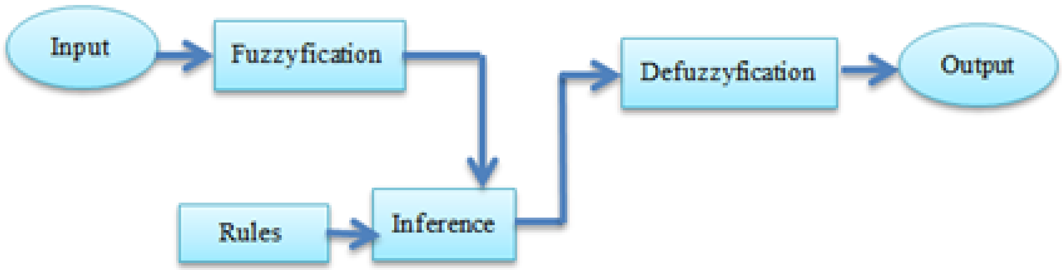


Figure 4.1: Fuzzy Logic Operation for Seattle adapted from (May et al., 1999).

The ramp control algorithm based on linear programming can be classified as one of the oldest algorithms. Before the introduction of automatic control based dynamic algorithms, linear programming method is widely used to develop ramp metering rates which are named as time-of-day. In this method, user selects the weights in accordance with his/her thought while categorizing the importance of ramps and the ramp flows are maximized by the weighted sums. Following this step, each road segment is assigned to real-time capacity, as a consequence this method can even work under congested road conditions.

The change in measured occupancy for each freeway part is used to calculate metering rate for each ramp under METALINE algorithm control and metering rate for the deviation of occupancy from critical occupancy for each part having a controlled ramp is calculated (Zhang, et al., 2001).

Ball aerospace, FHWA algorithm is developed by Federal Highway Administration, which is a corridor control system having system-wide ramp metering as one of its components. Though this algorithm seem to have a complex logic base, very limited information and no information regarding the algorithm details are present (Zhang, et al., 2001).

4.3.2 Algorithms of reactive strategies

Another approach to ramp control is the reactive strategy, which has also named as a tactical approach over a freeway network. In reactive strategy, real-time measurements obtained is used to keep freeway traffic conditions close to pre-specified set values. Reactive strategies are divided into two main groups; isolated and coordinated.

4.3.2.1 Reactive isolated algorithms

A ramp metering rate for an isolated ramp metering algorithm is determined in accordance with local conditions of that particular ramp, these local conditions are ranging from; flow, occupancy, travel speed, and sometimes queue overflow on that particular ramp is also included. The main algorithms for reactive isolated strategy are; feed forward strategies; demand capacity (DC) strategy, Masher et al. (1991), feedback mechanisms like; ALINEA, Papageorgiou et al. (1997), Neural network and controls, Zhang and Ritchie (1997), Zone algorithm (Stephanedes, 1994).

Isolated (local) ramp metering strategies; DC demand capacity strategy, Masher el al. (1975), OCC occupancy strategy, Masher et al. (1975) and ALINEA (Papageorgiou et al., 1991). DC and OCC are feed forward disturbance rejection schemes in which the system obtains measurements from upstream of the ramp.

ALINEA uses measurements of occupancy for a particular ramp to regulate and give a feedback to the system by using downstream data. Though ALINEA has led to successful results in field implementation, there are several issues needed to be developed in order to improve the defects of the system. ALINEA uses downstream measurements, changing this aspect and making the system to use upstream measurements will affect the results in a positive way.

Secondly, ALINEA strategy uses occupancy-based set values and measurements. The use of flow-based set values and measurements instead of occupancy-based values, directly affects the system (Zhang, et al., 2001). ALINEA feedback algorithm by Markos Papageorgiou explained briefly in this section. The problem faced in this study is recurrent congestion and the solution for this kind of problem is on-ramp coordinated traffic responsive strategies which are defined as “optimal control problem".

“There are basically three main components; mathematical process model, physical constraints and performance index needed to be minimized subject to model equation and the constraints” (Papageorgiou, 1998). With the help of ALINEA algorithm equations ramp metering and freeway traffic volume does not exceed threshold values additionally upstream on ramp traffic volume reduction is present.

With neural network algorithm, desired level of occupancy or target occupancy is achieved by feedback regulation. The target occupancy is usually chosen as the critical occupancy. The core traffic model is presented as locally calibrated fundamental diagram (see section 2) and the kinetic wave theory is applied with respect to these diagrams. When the existing congestion is at moderate levels, neural network algorithm is effective, flexible and robust; moreover it can be easily implemented arising from working only with control gain and target occupancy parameters.

One negative aspect of neural network algorithm is that, it does not consider queue spill back in a direct manner. But this can be eliminated by overriding restrictive metering rates approach. Another disadvantage is that under heavily congested traffic conditions, it faces difficulty in balancing freeway congestion and ramp queues (Zhang et al., 2001).

In Zone algorithm, it is assumed that the mainline freeway is divided into several zones and each entry ramp is associated with a zone. The main objective of this particular algorithm is to, balance traffic flow on zonal basis and to maintain a targeted traffic flow in each zone. This target traffic flow inside each zone is achieved by, traffic conservation, in which the metering rate for each on-ramp is used to balance the traffic volumes entering and leaving each zone. Additional adjustments to the system under consideration of environmental factors and other factors can be made in case of necessity. The main factors which help us to outline the system are; zones divided equally, accurate bottleneck capacity estimation, measuring traffic flows in and out of zone. Although, the system is adaptable in most cases and flexibility of the system is possible depending upon different cases, while considering the local traffic and freeway characteristics, the adjustments on the aforementioned parameters should be done carefully. Hence, the control parameters and control objective’s relation is not clear.

As zone algorithm does not consider traffic flow dynamically, under incident conditions or quick changes happened in traffic flow, it cannot perform in an efficient manner. The example of zone algorithm can be seen in Section 5 (Zhang et al., 2001).

The metering rates are ranging from non-metering case to cases having 24 seconds cycle length. Green and yellow cycle time is 1.3 seconds, 0.7 seconds consequently. Zone algorithm also provide output values such as; occupancy detection along the roadway for each zone, to determine localized congestion and queue arise from incidents, weather conditions, special events, etc. Adjustments of metering rates for zones are made with respect to measured occupancy considering local traffic conditions (May et al., 1999).

4.3.2.2 Reactive coordinated algorithms

In reactive coordinated algorithms, the control ratio is calculated by obtained and calibrated data according to system conditions. Reactive coordinated algorithms are divided into four groups as; cooperative, competitive, coordinated ALINEA and layered zone algorithm. The cooperative algorithms are; “Helper ramp algorithm”, “Linked ramp algorithm” and the competitive algorithms are; “Compass algorithm”, “Bottleneck algorithm”, “SWARM algorithm”.

In cooperative algorithm, first the ramp metering rate is calculated for each ramp and the adjustments in the following steps made accordingly to obtain system-wide information. The system-wide adjustment aims to avoid congestion at bottleneck section as well as to prevent spillback for critical ramps. These algorithms can be entitled as improvement on isolated ramp metering strategies, they are reactive to critical conditions and the adjustments are made in an ad hoc manner (Zhang et al., 2001).

Helper algorithm divide freeway corridor into six groups, each group having one to seven ramps. Based on localized upstream freeway mainline occupancy, each meter selects one available metering rate out of six. The system is in coordination and when a ramp faces queue formation and classified by the system at critical level, than the load assigned by metering to that particular ramp is distributed to upstream ramps in sequence. This algorithm experience the local traffic patterns and implements trial-error method to benefit fully from it’s potential system.

So, it is ideal for heavily congested situations, modifications for bus bypasses and HOV lanes can easily be adapted. Helper algorithm is very useful when the controller is inaccessible to accurate traffic models and origin-destination information (Zhang, et al., 2001).

The main basis of linked ramp algorithm is demand-capacity; metering rate on local basis is calculated with upstream flow measurement made for each location. The metering rate is equal to subtraction of target flow rate and upstream flow rate. The same coordination component is also valid for this algorithm, when a ramp is determined as critical; having a low metering rate, than the upstream ramp is courage to meter in the same rate or with a lower rate, in case of necessity other upstream ramps are also included.

Although it has similar positive and negative aspects as the Helper algorithm, this algorithm is not convenient for traffic in congestion conditions. In case of a congested traffic, as congestion level increases, the upstream flow rate reduces and the metering rate becomes higher. Thus, this is an undesirable case, conflicting with the objectives of the algorithm (Zhang et al., 2001).

Within competitive algorithm, two sets of metering rates are calculated with respect to local and global traffic conditions. The rate to be implemented is chosen among these two metering rates depending upon which metering rate is the most restrictive one. Considering spillback and any other constraints, adjustments on the selected metering rate is made when required (Zhang, et al, 2001).

The metering rates are determined by the Compass algorithm from an ad-hoc table in which each ramp includes seventeen levels. The included seventeen levels are determined by the local mainline occupancy, downstream mainline occupancy, upstream mainline volume, some pre-defined parameters. These pre-defined parameters include; thresholds for local and downstream occupancies and upstream volume. Off-line optimization is used for coordinated control and for calculation of metering rates system-wide information is used.

In case when the occupancy value exceeds the threshold value for a ramp queue detector, the metering rate is increased one by one (each time on rate) until the occupancy level determined by the detector turns back to its normal value under threshold level. The spillback is prevented by overriding restrictive rates.

All in all, though the compass algorithm is flexible, easily implemented and consider many constraints; it does not robust as the metering rates are determined in accordance with ad-hoc tables (Zhang et al., 2001).

In bottleneck algorithm, local ramp metering rate is determined by a comparison made with a control strategy on the upstream demand and between the downstream supply; real time capacity and take the difference of these values.

At global level, bottlenecks are identified by a coordinated control strategy as an initial step, predicating on the flow conservation, volume reduction for bottlenecks are decided, and the volume reduced is distributed to upstream ramps with respect to preset weight values. As a final step, the more restrictive metering rate among the local and global level is selected as the metering rate to be implemented (Zhang et al., 2001).

In system wide adaptive ramp metering SWARM algorithm, the ramp metering rates are calculated in both local and global basis. The local control determines the metering rate based on the local density and in global control, the overall volume reduction from ramps located in the upstream of a critical bottleneck is decided by the global control, and in accordance with the pre specified fractions the reduced volume are distributed among upstream ramps, and as a result ramp metering rate is found.

Implementation of metering rates are based on the selection made for each ramp, by choosing the most restrictive metering rate.

The input data obtained by the detectors and entered to the system can be deleted by a module in the SWARM algorithm; this failure management module cleans the data which causes error. For queue spill-back, adjustments within the system is made to overcome the situation.

The SWARM algorithm identifies bottlenecks based on predicted traffic conditions, not with the measured traffic conditions; as a result it can prevent the congestion formation by the intervention taking place at the beginning.

On the contrary, in case of poor predictions presence, the results found are poor and inefficient. To conclude all, a successfully implemented SWARM should include the following input values; good prediction models and accurate Origin Destination, O-D information (Zhang et al., 2001).

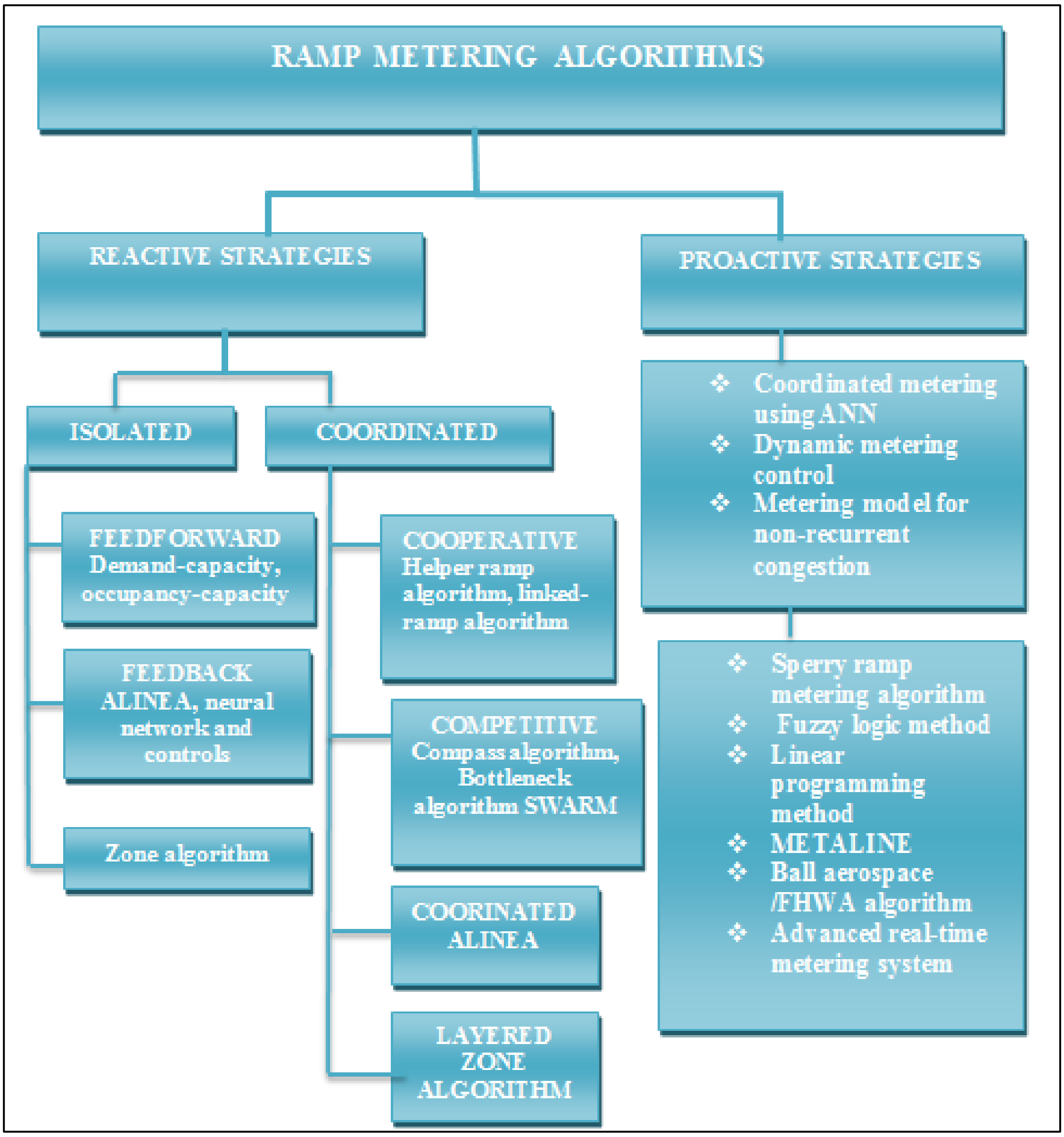


Figure 4.2: Ramp Metering Algorithm Classification adapted from (Zhang et al., 2001).

5. DEPLOYMENT OF RAMP MANAGEMENT STRATEGIES IN VARIOUS COUNTRIES

Traffic management principles and systems have international standards throughout the world, but for instance some developments and improvement levels are changeable according to transportation strategies parallel to political issue that varies with each country's implementation procedures. In this chapter the deployment of ramp management strategies in various countries particularly in United States and Europe is scrutinized and commentary explanations are made afterwards.

5.1 Sample Deployments of Ramp Management Strategies

Various ramp management strategies are present throughout the world. In this section, implementations including their history are explained briefly. The design concept and algorithms used to operate the system for each implementation within the specified country is given. And in the final subsection, the effects for that particular implementations is explained.

5.1.1 Deployments in US

The first ramp metering implementations are deployed in US, this dissertation starts with one of the rooted ramp metering implementation examples. In the interior of this section, first the implementation examples is given for Detroit, Michigan; Long Island, New York; Portland, Oregon; Minneapolis, St Paul, Minnesota; Seattle, Washington; Denver, Colorado; Austin, Texas; San Diego, California and following this section, design concepts under the light of system necessities, algorithms and effects of each implementation is explained briefly.

5.1.1.1 Implementations

In early 1960's the foundations of ramp metering applications in US have been established. Detroit, St. Louis and New York are the first places where sample ramp metering applications have been deployed.

A specific case can be given as Eisenhower Expressway in Chicago, where traffic responsive metering application has been deployed since 1963. In the following paragraphs, implementations throughout US is explained in detail.

Figure 5.1: Existing and Planned Ramp Metering Deployments in US adapted from (Copp et al., 2011).

Detroit, Michigan

The ramp metering implementation within Detroit, Michigan is performed by Michigan Department of Transportation (MDOT) Surveillance Control and Driver Information (SCANDI) System.

In November 1982, on the eastbound Ford Freeway I-94, SCANDI has started implementation of six ramps.

In January 1984, an additional nineteen ramps were added and in November 1985 three more were implemented (May et al., 1999).

Long Island, New York

The Information For Motorists (INFORM) on Long Island consists of a 40 mile long section and a 5 mile long section at the center of Long Island Expressway (LIE). Within 129 miles of roadways, there are 70 metered ramp on the LIE and in the Northern State / Grand Central Parkway (May et al., 1999).

Portland, Oregon

In January 1982, the first ramp metering implementation was installed along a 6 mile section of I-5 in Pacific Northwest in Portland. Within the implementation, 16^{th} ramps have been metered between downtown Portland and the Washington state. In the northbound direction during afternoon peak, nine ramps within the 16^{th} ramps were in operation and the rest seven ramps which are situated in the southbound entrances were operated in the morning peak (May et al., 1999).

Minneapolis, St. Paul, Minnesota

In 1970, on southbound I 35 E north of downtown St. Paul, the first two fixed time meters were installed. In November 1971, these meters go under improvement and transformed into traffic responsive system, plus an additional 4 meters were put into operation. By the year 1974, a second ramp metering implementation was installed on I-35 West, about a 27 km section. From 1988 to 1995, over 300 additional ramp meters have been deployed and the current values of ramp meter presence is 400 in Minneapolis, St Paul (May et al., 1999).

In Figure 5.2, on the figure left the existing ramp metering system is highlighted with green color and on the right figure the red colored ramps are presenting the planned ramp metering implementation along with their years. As this study is made in 1999, the years presented on the map are 1999 or 7 years after this base year. The I-35W consists of 39 ramp meters, 16 CCTV cameras, 5 VMS (DMS), a HAR zone, 380 vehicle detectors and a computer control monitor which is located at the Traffic Management Center in Minneapolis (MNDOT).

Additionally, extensive bus service and 11 ramp meter bypass lanes for HOV is also included (May et al., 1999).

Seattle, Washington

In September 1981, a metering was implemented on I-5 north of Seattle Central Business District by Washington State Department of Transportation (WISDOT).

Totally 22 ramps are metered in the system called FLOW, 17 southbound ramps which are metered during morning peak period and 5 northbound ramps which were metered during afternoon peak period. On I-5, I-90 and SR 520, there are now 54 ramps metered within the system.

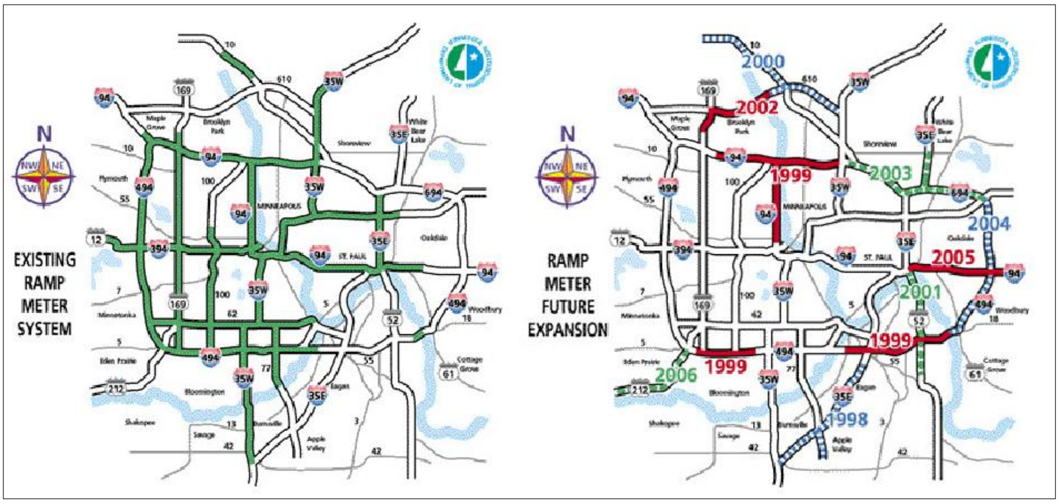


Figure 5.2: Ramp Metering Deployment in the Twin Cities Area adapted from (May et al., 1999).

In 1986, on SR-520 in Seattle a different implementation has been adapted. On SR-520 between I-5 and Lake Washington, two eastbound ramps are implemented. One ramp meter that has been installed in Lake Washington Blvd. is the last entry onto the mainline (SR-520) before Evergreen Point Floating Bridge.

As a result of no bottleneck formation on the downstream of that particular ramp, the traffic flows freely on the bridge and after passing through. The road users mainly choosing Lake Washington Boulevard on ramp in order to avoid congestion present on SR-520. And this leads with an increase in levels of congestion as high volumes of vehicles access is not limited to enter SR-520. With the implementation of metering on Lake Washington Blvd. on ramp, it is assumed that the road users will prefer to use Montlake Boulevard on ramp which is also metered. In the implementation on Montlake Boulevard on ramp, an HOV bypass lane has been installed aiming to encourage transit usage and carpooling.

In 1993, a ramp metering has been implemented just for weekends. On southbound I-5 in the north of Seattle three ramps are metered for several hours to restrict heavy weekend volumes. As a result of this implementation leading to success, in March 1995, this implementation is expanded to four southbound ramps. In April 1995, weekend ramp metering is implemented in the evening period. There is a different strategy applied for this implementation, the metering is operated in the morning period southbound which is inbound toward Seattle and in the evening on the northbound which is the outbound (May et al., 1999).

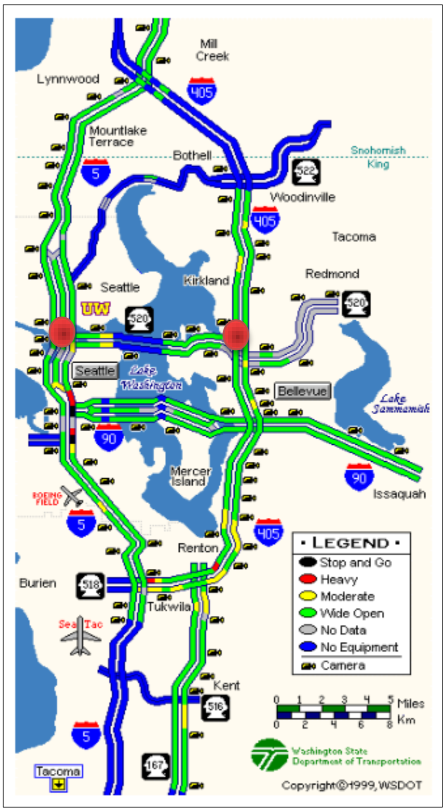


Figure 5.3: Ramp Metering Deployment in Seattle Freeway Network adapted from (May et al., 1999).

Denver, Colorado

In March 1981 on a section of northbound I-25, the Colorado Department of Transportation has implemented a pilot project which consists of five local traffic responsive metered ramps. The ramp metering is present on a 3 mile section of I-25 on the morning peak period.

In 1984, a System Coordination Plan is implemented which use to control all metering in operation and provides monitoring from the center by a central computer system. Starting from the year 1984, various metering implementations have been made, reaching to a number up to 28. In 1988 and 1989 evaluation on the metered sections and various changes are made. With the completion of the new freeway C-470, a more direct access from the southwest area is allowed to I-25, resulting in a higher demand.

In 1987 spring, a self-evaluation of the system is occurred by the central computer, which made the metering started one hour later and the traffic conditions became worse, this self-assessment has led to a positive feedback, since this incident, the media has supported metering implementation in a stronger way.

In 1988, a study conducted by Colorado Department of Transportation for the evaluation of different levels of ramp metering. The main objective of this study is to make a general comparison between the local responsive ramp metering and centralized computer control. It shows that, if the freeway speeds are above 56 mph and this level can be maintained by local traffic responsive metering, than the central computer control has slight beneficiary effects over the system. But when freeway speeds are not close to posted speed limit which is 56 mph, then the effects of centralized computer system is significantly higher. By the year 1998, 31 ramp metering system is in operation within Denver Metropolitan Area (May et al., 1999).

Figure 5.4: Ramp Metering Deployment in Denver Metropolitan Area adapted from (May et al., 1999).

Austin, Texas

In late 1970's, Texas Department of Transportation has implemented traffic responsive metering system on northbound of I-35 along a 2.6 mile section during morning peak period. The need for ramp metering implementation, arise from the formation of two bottlenecks within freeway section in I-35 (May et al, 1999).

San Diego, California

In 1968, a system is installed by California Department of Transportation CALTRANS, 134 metered ramps are present on 68 miles of freeway section. Eight metered ramps are providing freeway to freeway connection. Currently, approximately 240 ramp meters are in operation, along 200 miles network of interstate and state highways (May et al., 1999).

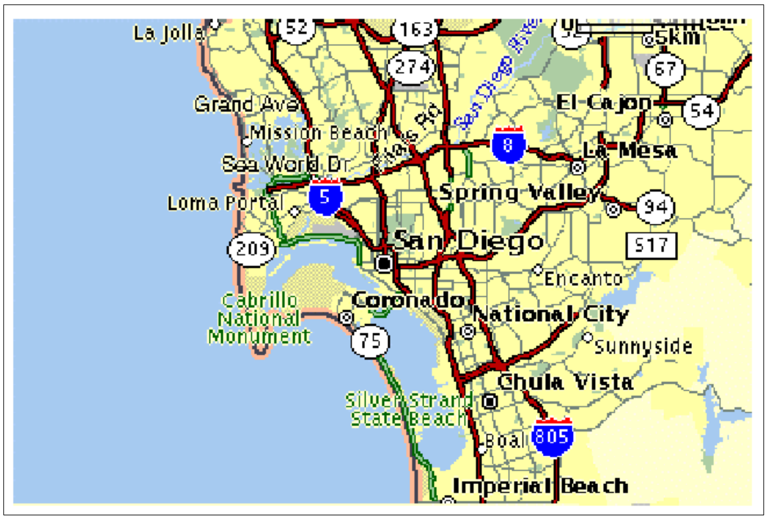


Figure 5.5: Ramp Metering Deployment in Caltrans District 11, San Diego Area Freeway Network adapted from (May et al., 1999).

5.1.1.2 Algorithms

In this section ramp metering algorithms in US is explained briefly.

Minneapolis, St. Paul, Minnesota

Zone algorithm is used for the ramp metering deployment in Minneapolis, St. Paul. (May et al., 1999).

Seattle, Washington

Bottleneck algorithm is used for ramp metering deployment in Seattle, Washington. One of the most sophisticated algorithms throughout US is bottleneck metering algorithm used in Seattle. The sophistication is, as a result of several internal adjustments including downstream bottleneck volume reduction and localized adjustments like; queue override. Local metering rate and a bottleneck metering rate is determined by the system with local responsive detector data, upstream occupancy obtained from each ramp and additionally bottleneck data is used. The implementation of these two rates local metering & bottleneck metering depend upon which rate is the most restrictive one (May et al., 1999).

In early 1999, the fuzzy logic algorithm is installed by WSDOT, the system controls 15 metered ramps along I-405. The improved results compared to traditional Seattle Bottleneck algorithm, made authorities to change the algorithm into fuzzy logic algorithm for the entire I-405; total converted ramps sum up to 55 (May et al., 1999).

Denver, Colorado

Helper algorithm is used for ramp metering deployment in Denver, Colorado. This particular algorithm includes a local traffic responsive metering algorithm which is integrated with a centralized coordinated operation override feature. Ramps under control are branch into six zones of each group assigned ramp meters changing in the range of one to seven. The system is in operation during week days and particularly in the peak hours, besides freeway traffic conditions are being monitored by computer located in the center for adjustment of start and end of ramp metering operation in accordance with the requirements. In local responsive algorithm, localized upstream mainline occupancy based available metering rates are selected by each meter; one among the six. Waiting vehicle detection and clearing of ramp signals are determined using ramp presence and passage detectors (May et al., 1999). In section 4, Helper algorithm is explained in detail.

San Diego, California

Linked-ramp algorithm is used for ramp metering deployment in San-Diego. (May et al., 1999).

5.1.1.3 Effects of ramp metering

Overall effects of ramp metering throughout US are given within this section.

Detroit, Michigan

The Michigan State University has performed an evaluation for MDOT and as a result, the increase of volume with ramp metering is 8 %. The peak hour volume on I-94, three eastbound lanes are increased from a value of 5,600 veh/h to 6,400 veh/h.

Additonally, there is a reduction present in the total number of accidents by 50 % and within the accidents resulted in injuries, reduction present is 71 % (May et al., 1999).

Long Island, New York

In 1989 after 2 months from implementation of the metering system, an evaluation study is conducted. The results of that particular study shows that, in the peak hour period, in the mainline, there is a decrease present in the travel time by 20 %, the reduction is from 26 minutes to 21 minutes and an increase in average speed by 13.1 %, from 23 to 28 mph.

Within this study, also vehicle emission measurements are made. The reduction present in fuel consumption is 6.7 %, 17.4 % reduction in carbon monoxide emission levels, 13.1 % reduction in hydrocarbon levels and an increase about 2.4 % in nitrous oxide emissions. A final conclusion can be obtained as implementations on a wider road network leads to greater beneficiary effects. In 1991, a more comprehensive study for INFORM project has been conducted and within the study, the shutting off of a ramp metering system due to heavy ramp volumes are also taken into account.

Results of this evaluation have showed that, the average mainline speed is increased by 9 %, from 40 to 44 mph. When the results obtained from two bottleneck sections are observed, the speed increase is from 33 to 52 mph and 33 to 55 mph consecutively; gain in percent is 36 % and 40 % respectively. Also, "congestion index" is also calculated. This congestion index is determined by the proportion of detector zones in which speeds are less than 30 mph. According to "congestion index", the study shows no positive feedback during evening peak period and 25 % improvement in morning peak period (May et al., 1999).

Portland, Oregon

In Portland, on five different freeways, there are 58 ramp meters in operation currently. Fuel consumption is reduced by 540 gallons of gasoline per weekday. And a final positive effect of ramp metering implementation is the peak period traffic accident reduction at about 43 %. In northbound direction during afternoon peak period, the average speed is measured as 16 mph before the implementation of a ramp metering system. After the implementation, approximately 14 months later, speed measured increased and 41 mph is obtained from the field observations. Additionally, travel time along that route is decreased from 23 minutes to 9 minutes, which is considerably an effective positive feedback of the system. In southbound direction, during morning peak hour, the average speed increased slightly from 40 to 43 mph with respect to less severity of the situation before implementation (May et al., 1999).

Minneapolis, St. Paul, Minnesota

I35 E's 5th mile section which goes under improvement, and is periodically observed from the beginning of the installations of ramp metering. The observations time period is; 14 years and results found shows the presence of efficient improvements.

Peak hour speed is increased from 37 to 43 mph by a 16% rate. According to increase present in demand, peak period volume increased by 24%. Finally, accidents occur in peak hours is decreased by 38% (May et al., 1999).

Seattle, Washington

In 1981 and 1987, during peak hours period, mainline volumes in northbound increased by 86 % and in southbound it is increased by 62 %. Travel time improvement can be seen by a comparison made between measurements taken from a 6.8 mile section; before the implementation the travel time measured within this particular section is 22 minutes and in 1987 travel time is reduced to 11.5 minutes. According to observations made within 6 year time period, the accident rate reduction is also present with a reduction of 39%. The result for SR-520 implementation in Seattle; Lake Washington Boulevard on ramp and Montlake Boulevard on ramp is given in the following paragraphs. After four months later from the implementation for two on ramps, the peak period volume in the mainline is increased by 6.5%, at the same time, volume on Lake Washington Boulevard on ramp is decreased by 43 % and a 18% increase on Montlake Boulevard on ramp is present. According to values obtained by King Country Department of Metropolitan Services (METRO), there is a 3 minute reduction in transit travel times for buses travelling from downtown to east and 4 minutes reduction in transit travel times for buses travelling from University District to east. With the improvements present in transit travel times, there is an increase present in reliability for travel times as an indication of HOV bypass lane and improved flow on SR-520 (May et al., 1999).

Denver, Colorado

After 18 months later from the implementation on I-25 in March 1981, there is a speed increase present at about 57 % and a 37 % reduction present in travel times. Additionally, as a result of abolished stop and go traffic, rear end and sideswipe accident incidence is reduced by 5 %.On I-25, in 1981, during morning period at about two hours period, the volume is increased from 6,200 vph and in 1989 the volume is increased to 7,350 vph.

The speed measured before the implementation is 43 mph and after implementation, it is increased to 53 mph in 1981 but in 1988 the speed measurements show a value of 50 mph.

There is no reduction present in accident levels, but as a result of an increase presence in volumes, accident rate is decreased during morning peak period. Rear end and sideswipe accidents are decreased by 50% during implementation of metering. In the study conducted by Colorado Department of Transportation in 1988, the speed is increased by 35.5. %, it increases from 31 to 42 mph, additionally travel time (veh/h) is reduced by 13 % (May et al., 1999).

Austin, Texas

Results of metering implementation on freeway section of I-35 are the vehicle increase by 7.9 % and an increase present on average peak period speeds found in the mainline which is increased by 60 %. But after reconstruction of I-35, ramp metering is removed (May et al., 1999).

San Diego, California

Although there is no evaluation study conducted by Caltrans, volumes on the mainline of metered freeways are increased from 2200 vph to 2400 vph (May et al., 1999).

5.1.2 Deployments in England

In the interior of this section, first implementation examples are given for England freeways (M6, M3/M27, M42) and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.2.1 Implementation

In 1980, first trial of ramp metering implementation is conducted on two ramps of M6 southbound close to Birmingham. Between 1988 and 2002, on M27 and M6 (having five ramps and four ramps respectively), a pilot study is conducted, aiming to identify a standard for equipments and algorithms used throughout UK. M6 is the main freeway corridor located in West Midlands, continuing to north from Birmingham towards Scotland border line and passes through cities; Stoke-on-Trent, Manchester, Liverpool and Preston. On M6 freeway there are 4 ramps (J10s, J9s, J7s and J9n) having sufficient infrastructure for ramp metering implementations and Highway Agency, HA is planning to implement new infrastructures.

Discussion is made with HA and it has been decided that, within EURAMP project, two ramps; J9s and J10s on the M6 are the most suitable sites that are ideal for both objectives and timetable of EURAMP project. The separation; 2 km between J9s and J10s is suitable to demonstrate ramp metering link strategies. In 2003, a new toll freeway parallel to M6 freeway is put into operation aiming to relieve congestion levels. Traffic data are collected from inductive loops and results reveal out that only slight changes are occurred. Morning peak hour period is shortened, before the opening of new freeway it was; 05:30 to 19:30 and after the opening, it is recorded as; 06:30 to 11:00.

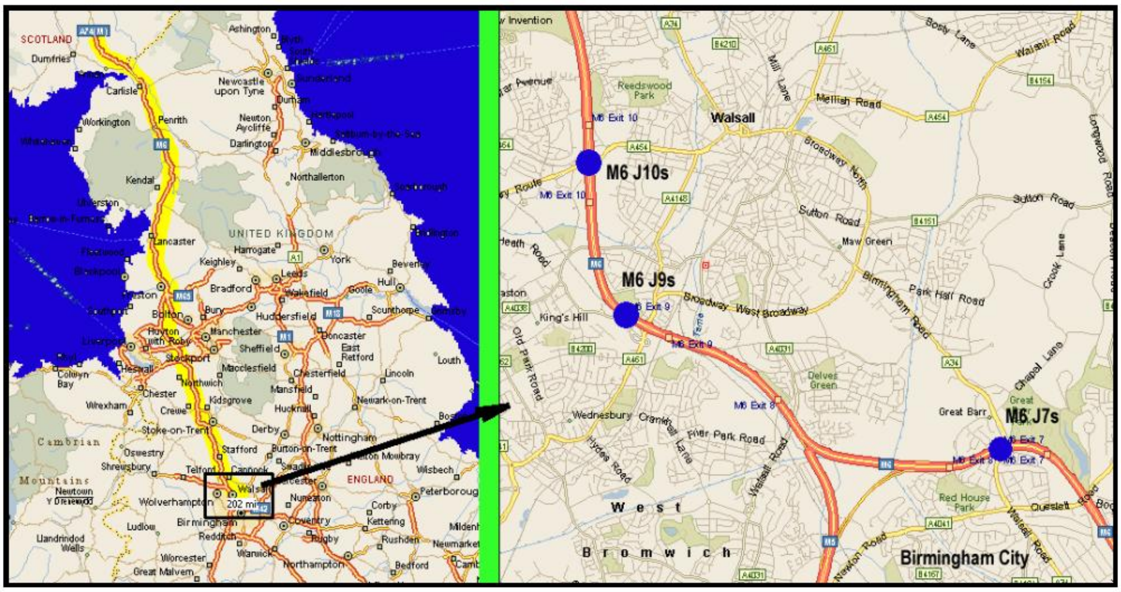


Figure 5.6: M6 Freeway and Current Ramp Metering Operated Sites adapted from (Papageorgiou et al., 2004).

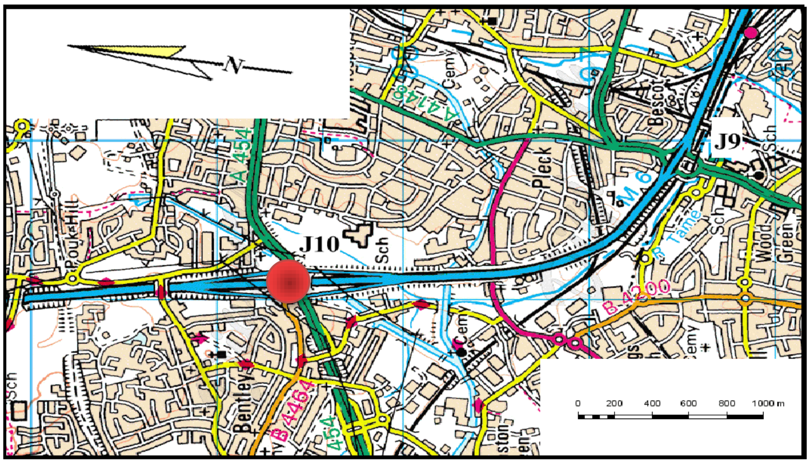


Figure 5.7: M6 Freeway and Current Ramp Metering Operated Sites adapted from (Papageorgiou et al., 2004).

Estimated peak upstream demand for J10s is 4000 veh/h on the mainline and 1450 veh/h on the on-ramp. At J9s the demand values are; 4500 veh/h on the mainline and 1100 veh/h on the on-ramp (Papageorgiou et al., 2004). In Integrated Traffic Management, ITM programme, HA aim to provide improved traffic conditions with the implementation of ramp metering on M1 Junction 33. On pre-implementation phase, HA determined 3 main objectives for evaluation of ITM within the frame of M1 freeway Junction 33. First objective is to evaluate the impact of ramp metering implementation on M1 freeway, Junction 33. Secondly, the identification of the impact of ramp metering implementation on local roads is planned to be considered and the final objective is evaluating ITM management performance with HA and local authorities (Butler et al., 2008).

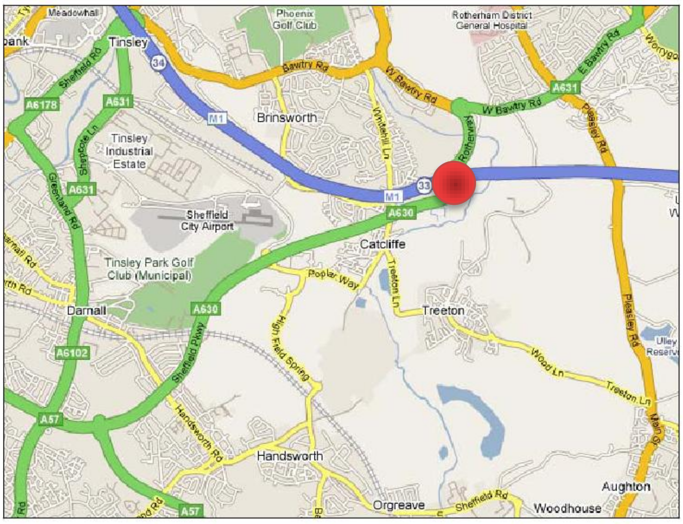


Figure 5.8: ITM Evaluation Area adapted from (Butler et al., 2008).

Government published a “Ten Year Plan” in 2000. Within this plan, an Active Traffic Management (ATM) scheme is introduced by HA in 2006, which includes M42 located between junctions 3A and 7. Beginning from the year 2008, ramp metering implementation on six sites of M42 freeway (J4, J5 and J6 in both directions) are in operation. M42 freeway is approximately 17 km see Figure 5.5. M42 freeway stretches along a wide network; it forms the east side of “Birmingham motorway box” which wraps Birmingham and its suburbs. Other sides of the box are; M6 to the north, M5 to the west and M42 between J3A and M5 to the south. The overall topography along this network is considerably flat. Within the network, there are 5 junctions in total, shaving equal intervals, except the distance between J5 and J6; which is 5.2 km.

Figure 5.9: Location Plan of ATM with Identified Link Lengths adapted from (Arlow, 2009).

Stemming from long distanced network category and local traffic attraction, M42 freeway has total daily traffic between 50,000 and 75,000 vehicles. Also M42 freeway is a strategically important route, which provides connection between south and north of England, furthermore it provides the connection between Birmingham International Airport and freeway network, also the main junction which allows access to National Exhibition Centre (NHC).

HA of England has choosen M3/M27 freeways in Southampton area, situated on south coast of England as Ramp Metering Pilot Scheme (RMPS). RMPS consists of operational sites at M3 junction 11 southbound, M27 junction 3 eastbound, M27 junctions 5&7 westbound and M27 junctions 10 & 11 eastbound, and control sites; M3 Junction 12 northbound and M27 Junction 5 eastbound.

The objective of operation sites is collecting data to control changes in traffic flows. All sites are monitored to obtain traffic flow, travel time data, vehicle number plate recognition systems, video recording by CCTV systems are also in use. From the monitored sites, information concerning weather conditions and traffic incidents can also be collected for driver notification systems.

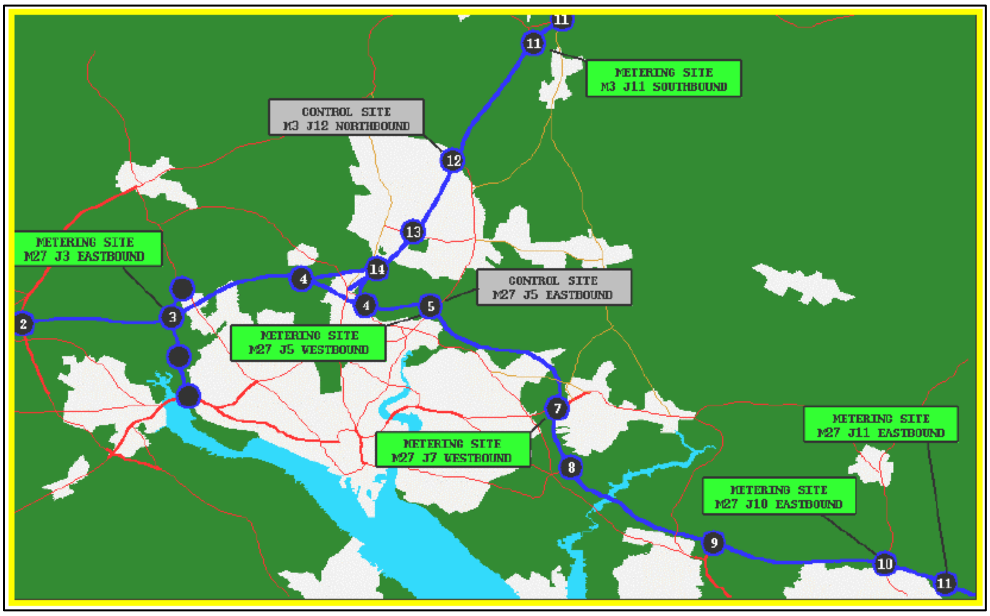


Figure 5.10: Ramp Metering Implementations throughout England, adapted from (Kenis et al., 2001).

At M6 freeway, on J9 and J10 on-sites, inductive loop detectors, local outstations and CCTV cameras are main components composes the system architecture. All outstations are connected with central station, that are assisting and providing continuation of system (Papageorgiou et al., 2004). Within M1 freeway, Junction 33, there are several queue loops present in each lane of southbound on-slip between slip road entrance and ramp metering stop line. Average occupancy obtained from loops are calculated and sent as a percentage to the controller in every 10 seconds. There are also CCTV cameras which are located on lighting columns (Butler et al., 2008). Site architecture of ramp metering system on M42 freeway comprises of the following components; fixed advanced warning signs, loop interface unit, slip road traffic sensors, signal heads, upstream and downstream detectors (MIDAS).

Loop detectors are used to support ramp metering implementation architecture. Detection of vehicle travelling on ramp to the freeway is determined by these loop detectors. The role of warning road users regarding a ramp metering implementation is provided by standard signals with a companied blue diamond backing board. For further implementation opportunities, LED signals are considered to lower the maintenance cost and to adopt a different signal for repeating operation purposes. Additionally, pre-signing for on-site implementation is provided in order to warn drivers regarding queue formations to partial traffic signal operations within the specified hours in a day.

Cycle time used in the system; for stopping duration it is two seconds and for release phase it is half a second which is equivalent to minimum amber cycle time. To obtain the desired metering rate, red and green cycle times are adjusted according to traffic situation of that particular road section. Ramp metering implementations are designed to support and work in harmony with controlling reinforcements like; red light running camera. It should be assured by professionals that the system is sustainable in compliance levels accommodated by road users. But for this case automatic enforcement is not used as high proportion of road user compliance with the red stop light existence and police officers giving feedback support to system is efficient for the sustainability of the system (Arlow, 2009).

5.1.2.2 Algorithms

For M6 freeway, algorithm used is an isolated ramp metering strategy which has neither connection nor coordination with local traffic control systems or with neighboring ramps. Cycle time for the algorithm is 1 minute and data obtained from inductive loops are; speed, flow and occupancy which are collected in 1-minute approach. This particular algorithm uses a table including occupancy and flow threshold values which are used to control on-ramp throughput. Depending from which detector (downstream, upstream of the merging section), the data is obtained, threshold values change accordingly. This algorithm does not feedback the decision making, it is just used to smooth the flow and this is where algorithm differs from ALINEA. In the case when ramp is loaded, queue-over-ride is switched on and ramp is opened to operation for 45 seconds. Both J9 and J10 have a one-lane merge but the stop line lie within a section having 2 lanes, so more than one car per green per lane is released. System only operates when the speed levels drop beyond a specified threshold value; 75 km/h, in order to avoid undesirable situations (Papageorgiou et al., 2004). For M1 freeway, Junction 33, two algorithms is used; a slip road release rate for maintaining the laminar flow on mainline is set by the primary algorithm which measures mainline congestion. On the other hand, other algorithm measures slip road queue formation and according to increase of the present release rate, compensation is performed. In other words, second algorithm results in a reduction of positive effects of the first algorithm. But, the arrival rate of traffic found on slip road is controlled by ITM and queue is reduced (Butler et al., 2008).

Algorithm of the M42 freeway has sections which are divided into four independent sub-processes, each of them providing a specific ramp release rate recommendation, changing with respect to the objectives.

“Metering Switch”; main ramp metering algorithm that provides regulation of release of ramp flow depending upon traffic conditions on the main carriageway. Release rate is calculated either with ALINEA or Demand Capacity controllers

Within ALINEA, optimization of downstream occupancy in merging section is made by an accompanying comparison of preset values; desired occupancy. Demand Capacity controller; optimize flow of merging section (downstream or upstream) by making a comparison with the desired values.

“Speed Switch”; this sub-process is preventing ramp metering to switch on even when the speed on the main carriageway upstream of merging section is higher than the pre-set value; 80 km/h.

“Override Switch”; prevents queue on the on-ramp from spilling back into adjacent roundabout or road upstream, so a cut-off threshold value for occupancy is used by the algorithm, and when initiation of spill back perceived by the system, signal on the ramp set to green continuously limited by 45 seconds.

“Queue Switch”; this sub-process manages queue length on the ramp. While setting ramp release rate, it considers traffic flow entering the ramp and estimated queue length on the ramp. Estimation of queue length on the ramp is calculated based on either weighted occupancy or proportional occupancy of loops on the ramp.

After briefly explaining of the four sub-process of ramp metering algorithm, the following conclusion can be obtained as; for an ideal ramp metering operation, running of the metering switch sub-process should be the highest within activation period, so that traffic conditions on the main carriageway can be effectively optimized.

For M3/M27 freeways, both ALINEA and demand-capacity method are used in order to compare which algorithm have the most beneficiary effects.

After utilization of both algorithms for implementation purposes, it has been concluded that using ALINEA within the system results in effective benefits.

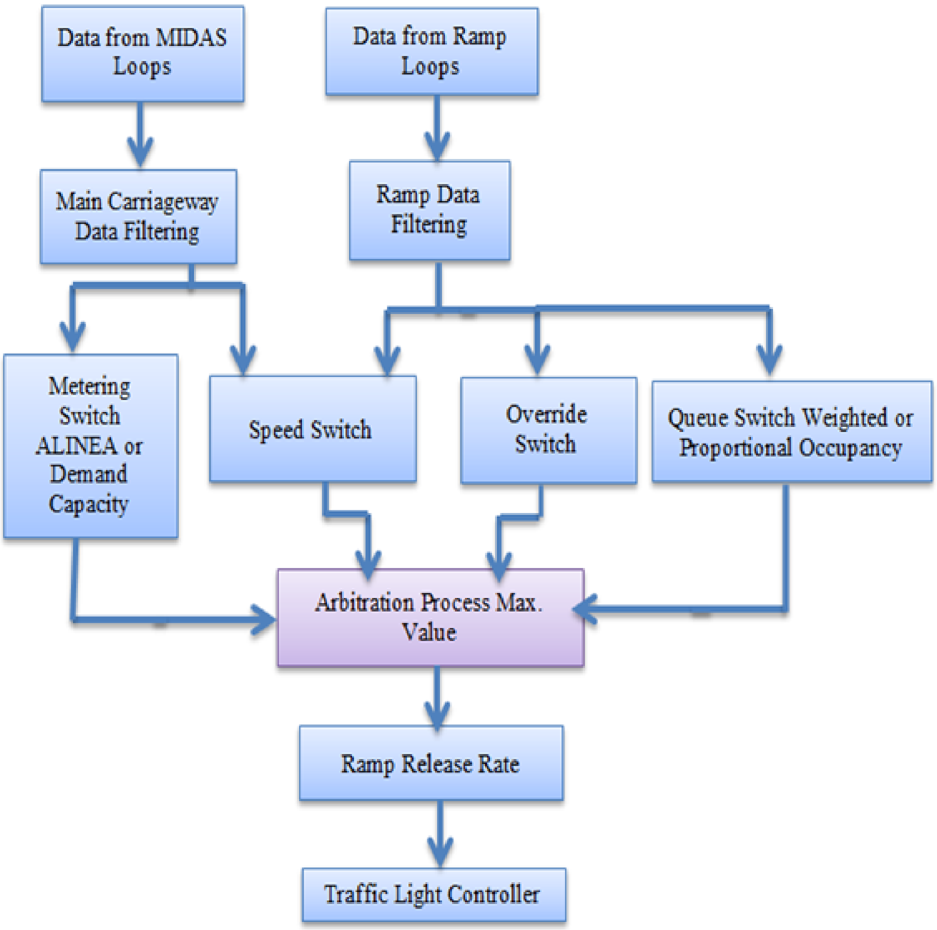


Figure 5.11: High Level Description for Ramp Metering Algorithm on M42 Freeway adapted from (Arlow A., 2009).

5.1.2.3 Effects of ramp metering

On M6 freeway, for J10 and J9, flow throughput is increased by 4% between hours; 07:15 and 09:45 when ramp metering is in operation. Travel time during peak hours has been shortened by 15 minutes, and additional 600 vehicles start using freeway in case of ramp metering open to operation. In speed levels, though the increase is 14%, on particular days, speed levels are lower and no improvements are observed (Papageorgiou et al., 2004).

For M1 freeway, Junction 33, an evaluation made in September 2007 and it revealed out that for evening peak hour, travel time savings is improved about 9.1% and by ITM, this value is increased to 14.7% on freeway carriageway.

For local road network, during evening peak hour, travel time savings are improved by 8.7 % and when ITM starts operating this value is increased up to 9.8% (Butler et al., 2008).

The evaluation reports for M42 freeway ramp metering implementation shows that, there is considerably efficient improvement in average journey times when a comparison between before and after ramp metering implementation is conducted.

Table 5.1: Average Journey Times Over Partial Periods of PM-Peak adapted from (Arlow, 2009).

	Average Journey Times (seconds)				
Cases	15:00 - 16:00	16:00 - 17:00	17:00 - 18:00	18:00 - 19:00	16:30 - 18:00
Before	400	534	560	422	560
After	357	456	553	394	534

Results shown above in the table clearly states reduction of average journey time by 26 seconds, to emphasize major improvement, sample size should also be considered (Arlow, 2009). In Table 5.2, average flow present on the downstream, upstream and on-ramp is listed along with the average flow differences and their percentages.

Table 5.2: Average Flows Around J6 M42 Northbound adapted from (Arlow, 2009).

		Before		**After**		**Average Flow Difference**	**Average Flow Difference %**
Location	**Period**	**Average Flow**	**Standard Deviation**	**Average Flow**	**Standard Deviation**		
Downstream	15:00 - 16:00	5549	85	5629	82	80	1.4%
	16:00 - 17:00	6373	102	6386	72	12	0.2%
	17:00 - 18:00	6314	73	6251	67	-63	-1.0%
	18:00 - 19:00	5258	146	5167	119	-90	-1.8%
	16:30 - 18:00	9481	88	9426	62	-55	-0.6%
Upstream	15:00 - 16:00	4106	67	4188	60	83	2.0%
	16:00 - 17:00	4434	100	4539	70	105	2.3%
	17:00 - 18:00	4408	84	4376	61	-31	-0.7%
	18:00 - 19:00	3482	110	3873	95	391	10.1%
	16:30 - 18:00	6630	94	6661	62	31	0.5%
Ramp	15:00 - 16:00	1508	50	1519	46	11	0.7%
	16:00 - 17:00	2008	43	1911	35	-97	-5.1%
	17:00 - 18:00	1911	41	1850	31	-60	-3.3%
	18:00 - 19:00	1403	52	1294	38	-109	-8.4%
	16:30 - 18:00	2893	41	2777	31	-116	-4.2%

5.1.3 Deployments in Scotland

In the interior of this section, first implementation examples are given for Scotland freeways (M8) and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.3.1 Implementations

In 1996, first ramp metering implementation is installed at Junction 16 Eastbound on M8 freeway in Glasgow. It is one of the components of National Driver Information and Control System (NADICS).

M8 Model

A model of M8 through Central Glasgow is developed and validated with a Paramics microsimulation model. Time slot chosen is between 15:00 – 19:00 and data obtained from NADICS traffic database. Traffic data obtained from M8 through Junction 16 particularly on lane usage and vehicle detector occupancy on M8. Observed data are taken with 15 minutes time interval and a comparison between the observed and the modelled data is made. The modelled and observed models are presented in Figure 5.15.

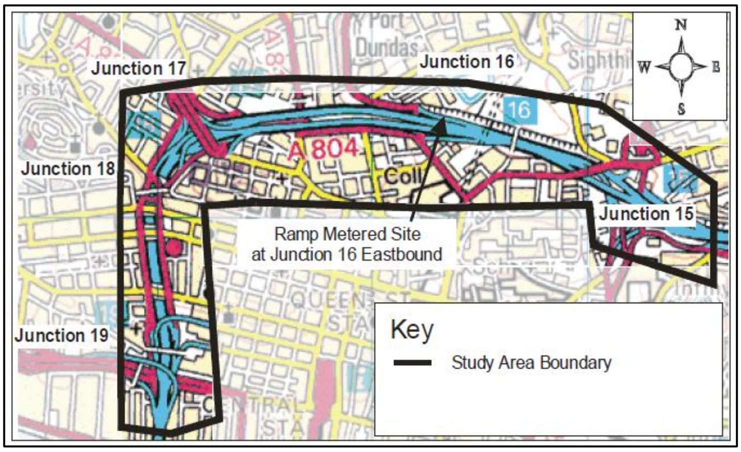


Figure 5.12: Ramp Metering Model for M8 in Scotland, adapted from (Stewart, 2003).

Graph presented on Figure 5.13 is sketched for the presentation of M8 Junction 16 implementation. Dashed line is symbolizing modelled flow and continuous line is the flow observed from site investigations. From the graph, following extraction can be obtained; modelled flow and observed flow are slightly different, as a result model has the ability to represent the actual situation efficiently.

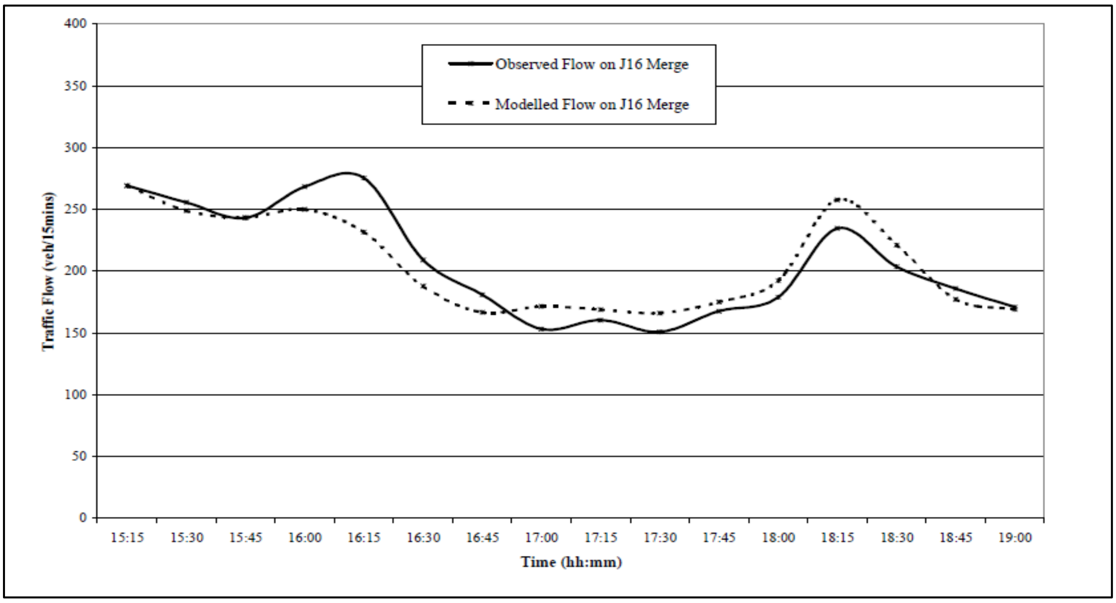


Figure 5.13: Observed and Modelled Traffic Flow (vehicle per 15 minutes) versus Time Graph for M8 at Junction 16 On-Ramp adapted from (Stewart, 2003)

A720 Model

Under the light of M8 model, a ramp metering implementation is modelled for A720, The model includes; traffic signals on the merging Dreghorn ramp and on the west of the Dreghorn merge a motorway occupancy loop detector is placed and ramp flow detectors on the ramp are placed at signal stop line.

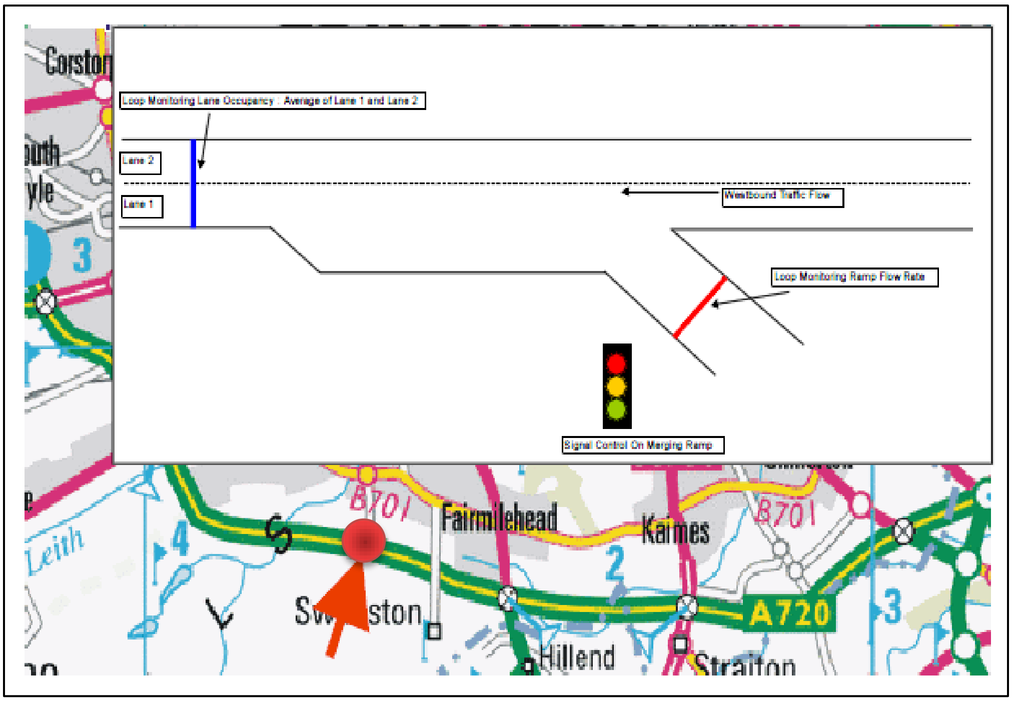


Figure 5.14: A720 Ramp Metering Infrastructure at Dreghorn adapted from (Stewart, 2003).

System aim to establish a trigger value for ALINEA at this site, so the model runs are completed and over flow breakdown period, occupancy value on the dual carriageway is monitored. Average motorway occupancy changing with time is shown above.

Breakdown of flow at Dreghorn starts at about 07:30 and with this breakdown ALINEA starts to control ramp flow by using traffic signs. ALINEA control period, operating period is between; 07:30 to 09:00. Before and after peak congestion period, as seen from Figure 5.16., ALINEA has shoulder periods of control.

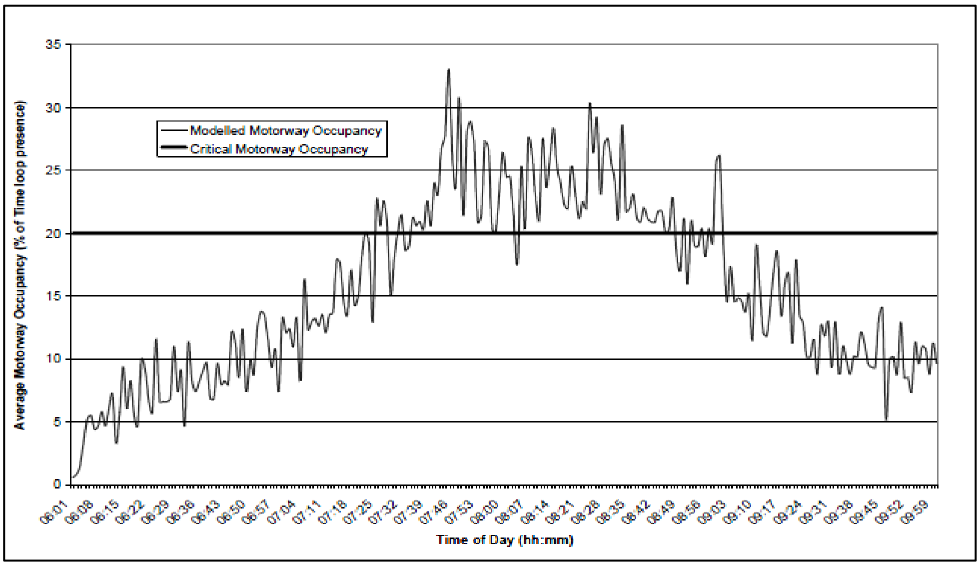


Figure 5.15: A720 Modelled Motorway Occupancy at Dreghorn adapted from (Stewart, 2003).

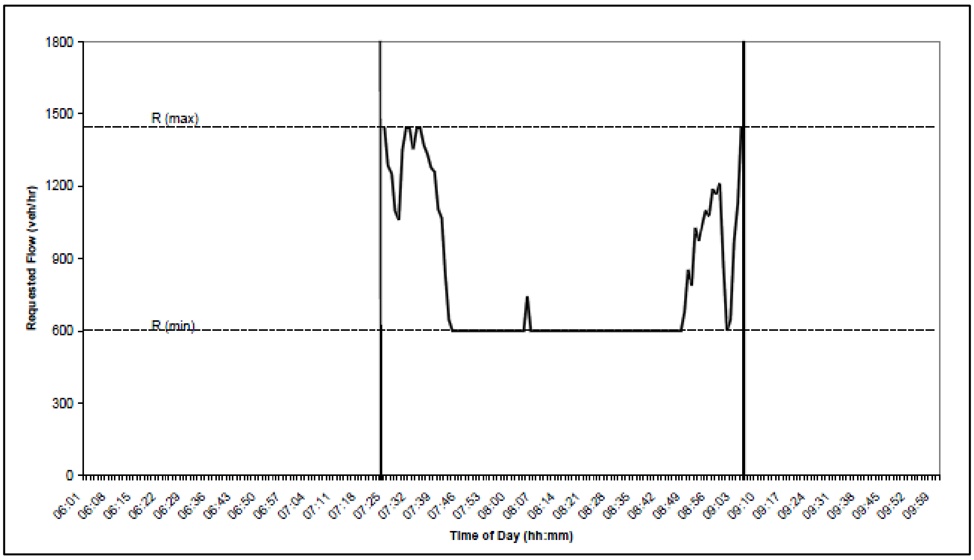


Figure 5.16: A720 Modelled Requested Flow Rate (veh/h) at Dreghorn adapted from (Stewart, 2003).

Between 07:30 and 07:50 the ramp flow rate is steadily reducing as motorway congestion increases. Likewise between 08:50 and 09:00 ALINEA begins to increase the rate of flow for the on-ramp as motorway congestion eases.

5.1.3.2 Algorithms

ALINEA algorithm is used within the implementation in Glasgow. Preference for ALINEA arises from its simplicity and as it is previously tested on other implementation sites. Within the project implementation, a software development phase takes place.

A Simple Network Management Protocol, SNMP based interface is added to the Paramics microsimulation package and it is used to develop a Ramp Metering Controller software simulator which is based on ALINEA. System architecture consist of the following components; on-site detectors; vehicle detector loops, VMS signage and signal control.

5.1.3.3 Effects of ramp metering

For M8 Model results show that this model has high accuracy levels. Additionally, a comparison made with modelled and observed value revealed out that the model sufficiently met Design Manuel for Roads and Bridges (DMRB) criteria.

As a result ALINEA / Paramics software are found suitable for ramp metering modelling.

If the outputs from Paramics are used, operational, economic and environmental assessments can be conducted in before and after implementation cases of ramp metering.

Paramics model outputs are used and operational, environmental, economic assessments are considered for the evaluation of ramp metering at A720 Dreghorn.

Beneficiary effects of the system are considered and a comparison graph for no ramp metering and ramp metering cases are compared.

From Figure 5.18, a main conclusion can be easily extracted that, with ramp metering implementation a major benefit is obtained, shaded areas are the proof for this positive impact adapted from (Stewart, 2003).

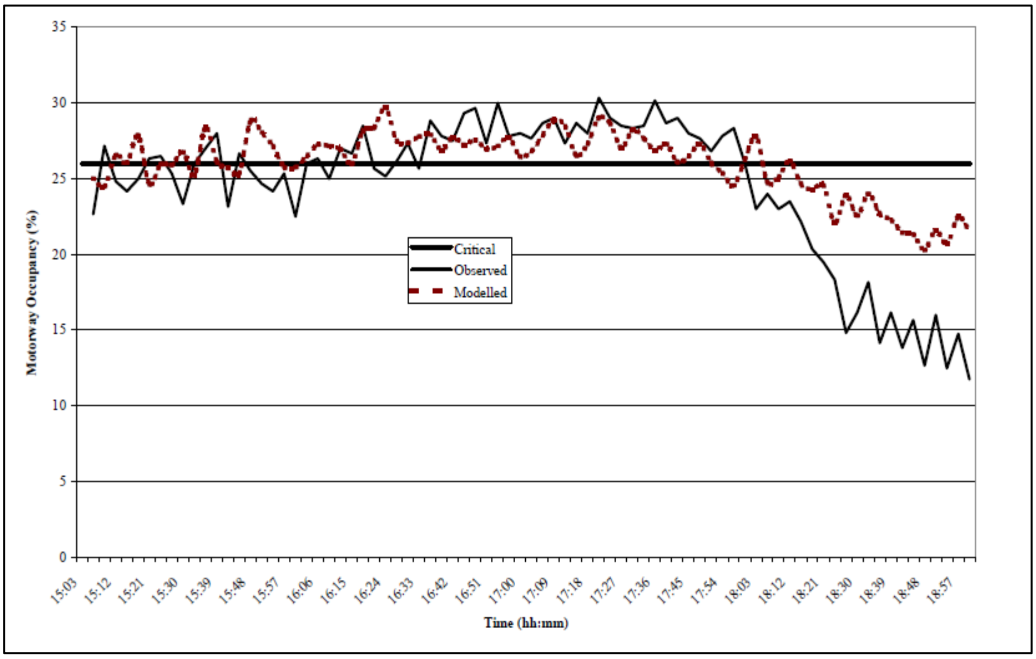


Figure 5.17: Observed and Modelled Motorway Occupancy (%) versus Time Graph for M8 at Junction 16 On Ramp adapted from (Stewart, 2003).

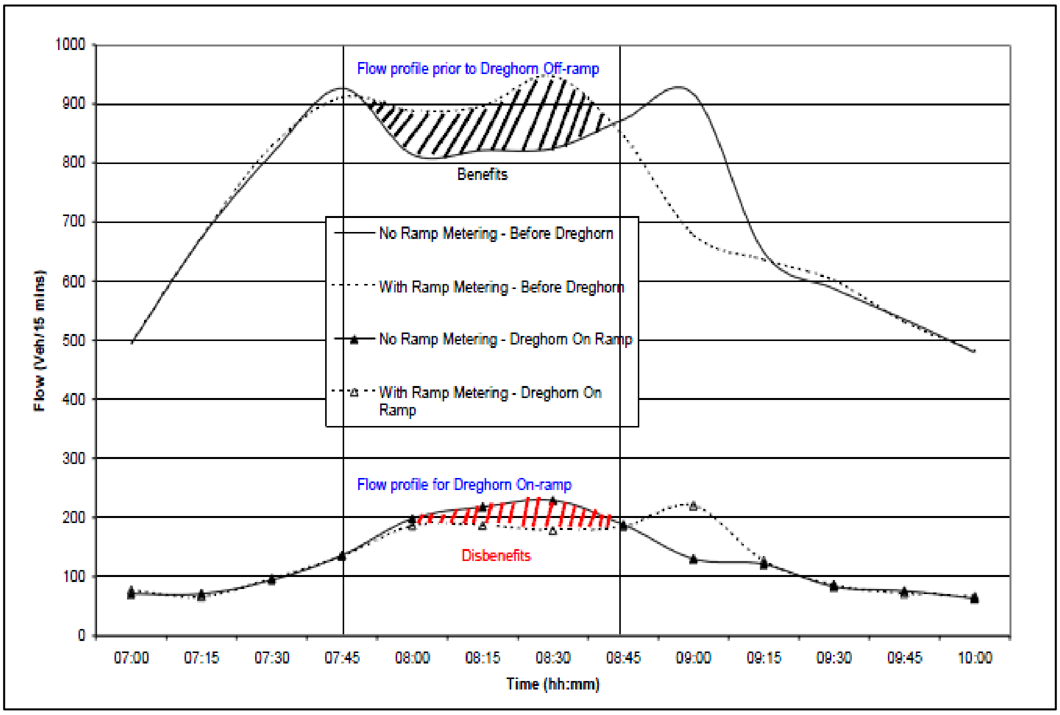


Figure 5.18 : A720 Traffic Flow Profiles at Dreghorn adapted from (Stewart, 2003).

5.1.4 Deployments in Israel

In the interior of this section, first the implementation examples are given for Israel Ayalon Highway and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.4.1 Implementations

Ayalon Highway which crosses Tel Aviv metropolitan area from North to South is where ramp metering implementation present. Ayalon Highway is the busiest highway in Israel, serving 600,000 vehicles per day and North Bound section of this particular highway having 5 lanes carrying traffic volumes of 140,000 vehicles per day.

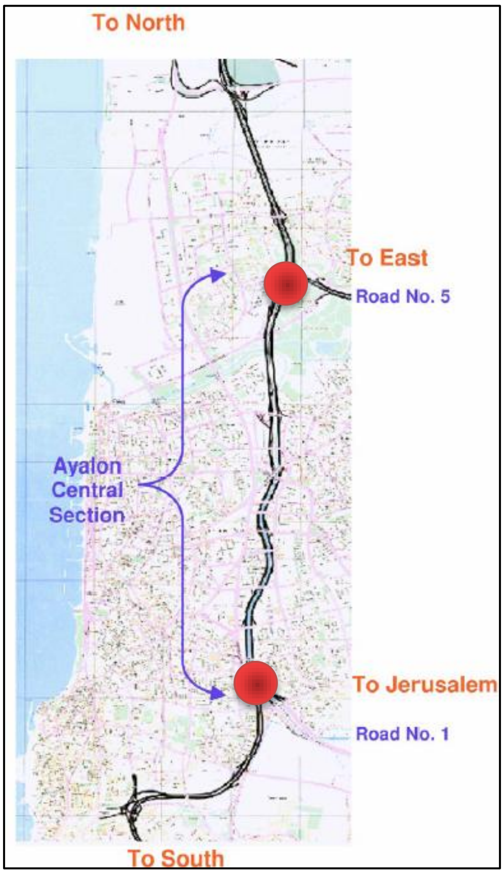


Figure 5.19: Ayalon Highway adapted from (Papageorgiou et al., 2004).

Ayalon Highway is a 17 kilometere highway which intersects with 3 Israel main interurban roads. Road number 1; towards Jerusalem and in south, road number 2 which I located in the northern part of Israel and road number 5 is towards the east part of Israel.Inside the network, daily recurrent congestion is present. In the morning, South Bound (from Gilot –Arlozorov interchanges 7 km long) from 07:30 to 20:00 and North Bound (from Kibutz Galuyot to La Guardia 3 km long) from 15:30 to 20:00. In the evening, South Bound (from Rokach to Kibutz Galuyot 7 km long) from 15:30 to 20:00 and North Bound (from Halacha to KKL 3 km long) from 15:30 to 20:00.

Ayalon Highway consists of 3 or 4 lanes. On-ramps within the highway have two lanes which are merging into one lane into the main lane. Curvature is an effective aspect for efficient traffic flow, a 2 kilometere section in the central and busiest part of the highway includes 4-1 lanes for each direction and have relatively small radius which is; 635 m. In Ayalon Highway, number of on-ramps along the central section is 16 and 17 for off-ramps. For Ayalon Highway, Ayalon Highway Company (AHCo) is responsible for maintenance and operational activities. A traffic management and control system; TSCS has been installed by AHCo consisting of the following on-site components:

- Loop Detectors Outstation (LDO); the LDO’s are located at 500 m intervals, each one controlling two loops for each lane. Totally there are 500 loop detector sites.
- CCTV; 13 cameras are located in a strategical places.
- Lane Control Signs (LCS); in the system 132 LCS are present. The LCS can display speed (20 to 90 km/h), left and right diversion arrows, red x and queue legend for incident management purposes.
- Variable Text Signs (VTS); 7 VTS are in operation, informing drivers about the traffic situation.
- Traffic Control Centre; provides connection with Tel-Aviv Urban Traffic Center, police, radio and other emergency agencies.
- Information Dissemination; information regarding traffic situation can be obtained from the website: “www. ayalonhw.co.il”.

In the freeway section sensors are located with 500 meter intervals on upstream of the off-ramp, downstream of the off-ramp, upstream of the on-ramp, downstream of the on-ramp and between interchanges. One sensor is located on off-ramp and other one on the on-ramp.

Loop detectors are installed on freeway and on-ramp and to off-ramp. For freeway and on-ramp, two loops per lane is installed to determine volume, speed, occupancy, headway (in seconds and meters) and type of the vehicle. And for the off-ramp only one loop per lane is installed, for measurement of volume and occupancy on per lane basis.

An overall data comprising; volume, speed, occupancy and headway can be obtained for the entire traffic site. Within the frame of EURAMP project; two ramps are selected for installation, implementation and demonstration of ramp metering system. First ramp chosen is KKL, northern on-ramp along Ayalon northbound section and second ramp is Kibutz Galuyiot; the southern on-ramp along the Ayalon southbound section.

5.1.4.2 Algorithms

Ramp metering system is planned to be implemented on both ramps; KKL and Kibutz Galuyiot and algorithm planned to be used is chosen as ALINEA with queue override. Ramp metering implementation is on plan phase, as building works carried out around Galuyiot result in a police restriction for the area. Though it is planned to be implemented, ramp metering system can be in operation when constructional activities within the area is finalized.

5.1.4.3 Effects of Ramp Metering

In the report of ramp metering implementation performed in Israel, there is neither information nor a study conducted concerning the effects.

5.1.5 Deployments in France

The deployments in France are not covering a wide area, despite this fact there are few implementation examples which are explained within this section.

5.1.5.1 Implementations

In the year 1970, first implementation consisting 35 ramps on Paris freeway network are in operation with traffic lights having fixed cycle times.

Fixed cycle timed traffic lights are in operation only during morning peak hours within the week and returning periods for the weekends.

A similar system to ramp metering implementation is installed in Lyon (around Fourviére Tunnel), the manual system works in case of congestion or incident presence around the tunnel and the operation was controlled with open-close barriers.

In 1980 and early 1990’s the conducted and reported implementation studies are published under the name of Internal Report, INRETS.

And the report published in 1997 includes various ramp metering implementation sites that are selected to exemplify case studies in Paris and Bordeaux.

“Ille de France” motorway network is under the responsibility area of two main authorities that are in charge of traffic management. Authorities are; the Paris City “Ville de Paris” authority which controls Paris inner urban network, additionally ring way and the other authority is; “Service Interdépartemental d'Exploitation de la Route” , SIER which operates freeway network around Paris city; from A1 to A13 freeways. “Direction Régional d'Equipement d'Ile de France”, DRIEF is the authority responsible for SIER and DRIEF which is controlled by Transport Ministry.

SIER motorway network, includes A1 to A13 freeways, covering approximately around 600 km. To easily conduct implementation and management issues, this large scaled network is divided into four sections as; North, South, East and West.

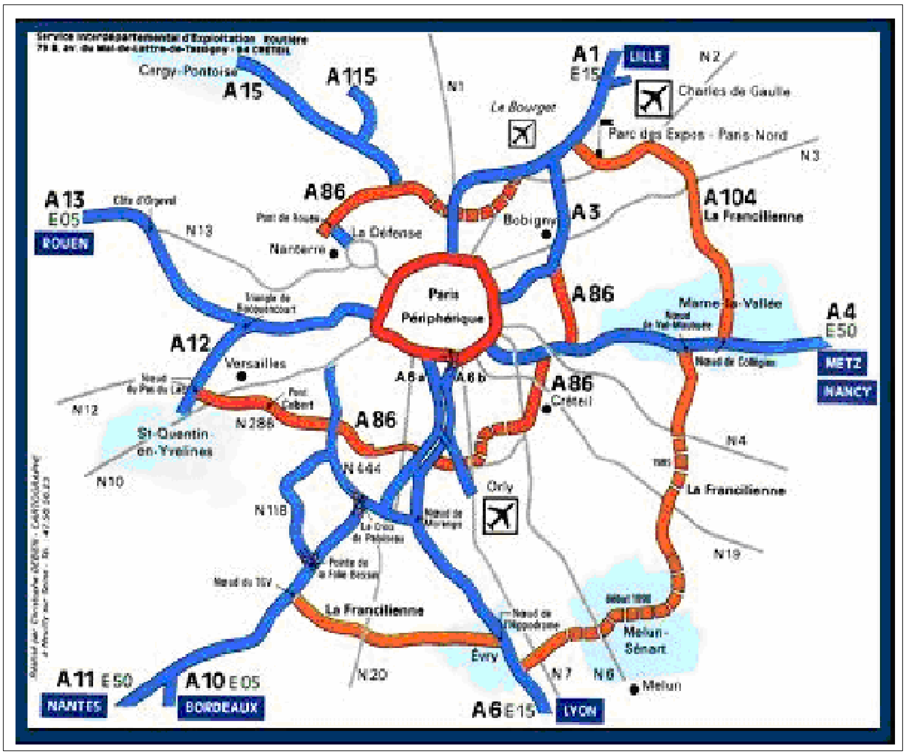


Figure 5.20: Ille de France Network adapted from (Papageorgiou et al., 2004).

In 1988, DREIF has launched a project; “(Service d'Information pour un Réseau Intelligible aux USagers), SIRIUS”, which has a main objective of optimizing the traffic flow on “Ille de France” freeway network, by traffic control systems, including ramp metering. Congestion level in “Ille de France” freeway network is 80 % of the total congestion of the overall France freeway network.

In addition to A6W freeway in which real time implementation is in operation, there is also a virtual site implementation which is in the east part of Ille de France freeway. This virtual site implementation includes the following freeways; A1, A6, A86, A3 and A4 in both directions. The mentioned freeways are located in the southern part of “Ille de France” freeway network, and the length of the site is approximately 250 km. Selection of this freeway network is particularly because its critical position and severe congestion level that this regions faces. Especially in the morning and evening peak periods, congestion extends over several hours and several kilometers, mainly for A86, A3 and A4 freeways.

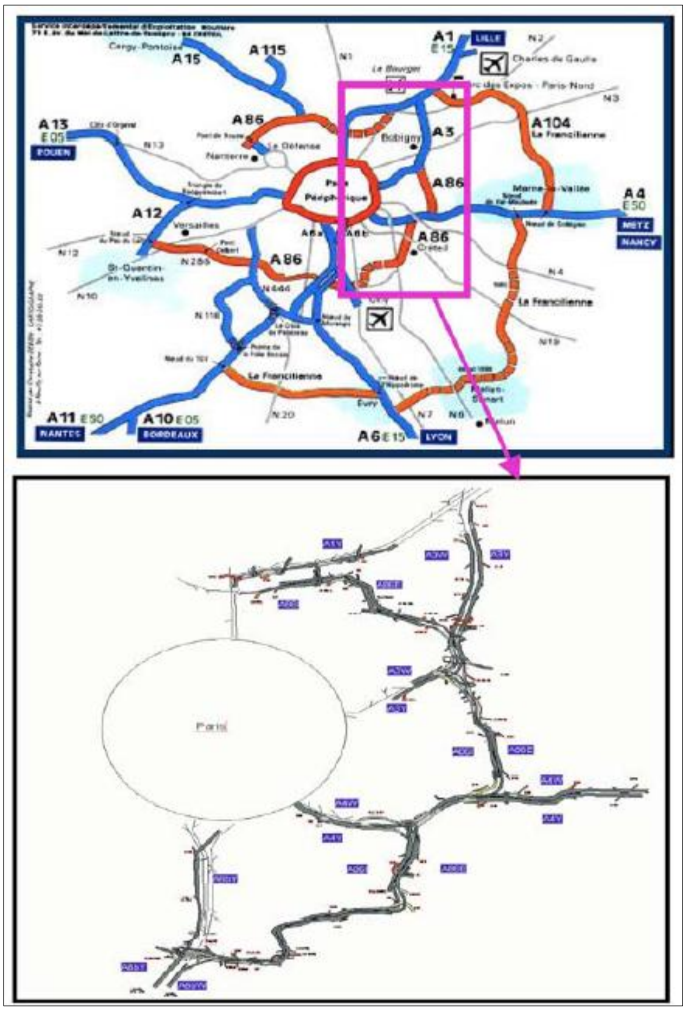


Figure 5.21: Virtual Test Site adapted from (Papageorgiou et al., 2004).

An overview of Paris freeway network is given in this section. Main detection method used for the system architecture is inductive loops, one situated on slip road to control congestion levels and prevent congestion formation on the open roads and the other one is on freeway section which is used to provide traffic flow estimation.

Traffic lights exist within ramp metering implementation site is; red, amber and flashing amber. Implementation period of ramp metering is between 06:00 AM and 10:00 AM on weekdays and considering returning drivers for weekend, it is switched on Sunday afternoons as well.

In conditions when there is too much demand present, the system switches off and warns drivers by using flashing amber.

Cycle time used for the system in Paris is; amber time, minimum 3 seconds, flashing amber time (when the system is switched off) minimum 6 seconds and minimum cycle time for red light changes according to traffic conditions.

For pre-information purposes, fixed signs and flashing amber light are situated on site. Amber light is switched on and flashes when ramp metering implementation is activated within the specified time period mentioned before.

Following implementations is considered to include Variable Message Sign, VMS systems in an experimental level and it is assumed to decrease the maintenance cost, while taking attention of the road users at high level.

SIER motorway network required site implementation equipments are found sufficient. Measurement stations are located 500 m apart. Main on-site components are; 600 loop detector; measuring traffic volumes, occupancy and speed, 400 video cameras that are used to monitor traffic, emergency phones located every 1000 meters; for incident or accident reporting purposes, mobile police; 10 police cars for on-site traffic survey purposes and 175 VMS to serve for user information service. To control whole network in an easy and efficient manner, traffic management and control centre is divided into four main control centres: North; PC St Denis, East; PC des Ratraits, West PC Boulogne, South: PC Arcueil.

Each control center is connected via ETHERNET network and all real data collection is stored in a server which is located at Creteil center Centre Régional d'Information et de Coordination Routière, CRICR for information dissemination purposes to users.

Within SIER site, for SIRIUS system, several real time applications are implemented and used. Mainly real time applications provide the following functions; real time data collection, traffic monitoring with cameras, information dissemination via VMS, ramp metering and detection of incidents or accidents.

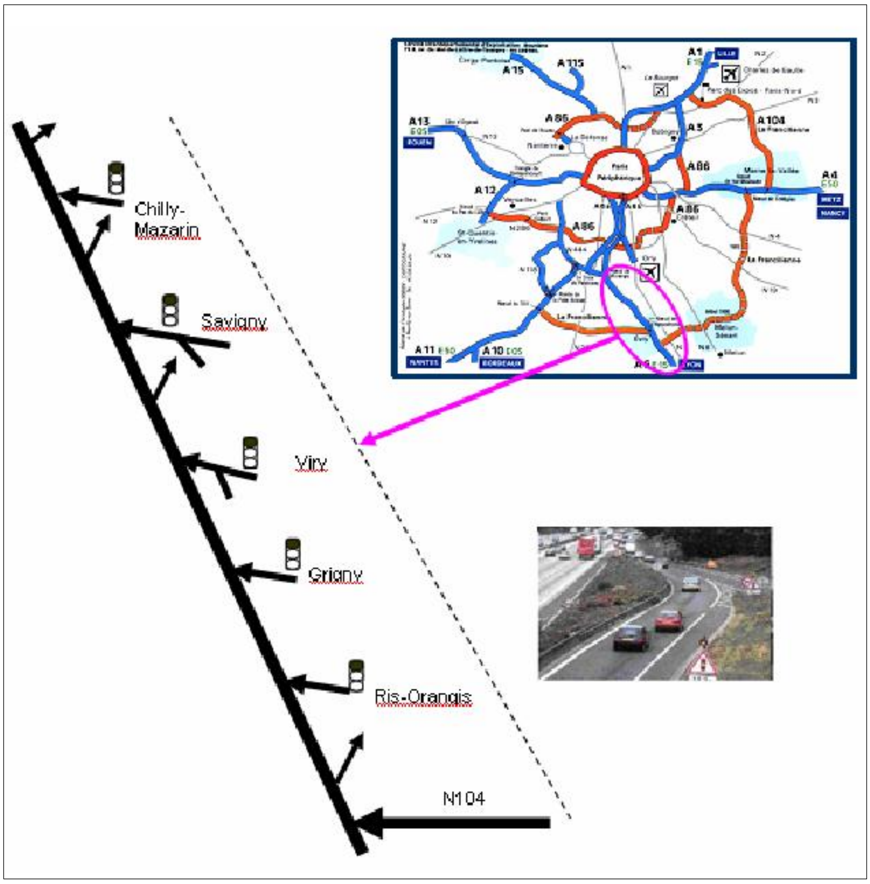


Figure 5.22: Paris Test Site A6W adapted from (Papageorgiou et al., 2004).

The virtual site implementation located in the southern part of “Ille de France” freeway network and total number of on-ramps is 70, in which 50 on-ramps are under control. On-site components of the system include; measurement stations in each 500 meters for traffic volume and occupancy measurements (Papageorgiou et al., 2004).

5.1.5.2 Algorithms

The algorithm used within Paris freeway network ramp metering implementation is ALINEA. Cycle time for ALINEA algorithm is 40 seconds, including minimum 15 seconds of flashing amber cycle time. On June 2000, a coordinated strategy is implemented on A6 freeway. Results obtained by this implementation are satisfactory, and the most positive feedback gained is the journey time, which results in a constant stability. For SIER, ALINEA strategy is implemented with accompanying simple heuristic strategies. The evaluation process is focused on the assessment of fixed time and ALINEA strategies. Evaluation reveals out benefits of traffic responsive ALINEA strategy.

Virtual site implementation is tested on simulation with the following ramp metering strategies. Isolated strategies including; ALINEA with a fixed cycle and ALINEA with variable cycle.

Coordinated strategies including; OSIS the application of nonlinear optimization technique and METALINE which is based on the linear Quadratic Approach. Concordantly, METACOR is found as the efficient dynamic macroscopic traffic flow model to be used. Main step to be followed while conducting this study are; calibration and validation of METACOR, demand and turn estimation and origins of nodes, definitions of scenarios: definitions of strategies for testing and evaluation purposes and off-line simulation and evaluation (Papageorgiou et al., 2004).

5.1.5.3 Effects of ramp metering

The objective lies behind the implementation of ramp metering contains several aspects. First, ramp metering strategy aims to reduce the extent of recurrent and non-recurrent congestion within freeway. Secondly, reduction in total travel time inclusive of waiting times on the on-ramps. And finally the last two aspects are; increasing the serviceability of the freeway by increasing amount of vehicles travelling freely and parallel to this optimizing freeway capacity utilization. For SIER site, by using ALINEA, total time spent in the system is reduced by 17%, mean speed by 3% and travel time improvement is 18% (Papageorgiou et al., 2004).

5.1.6 Deployments in Germany

In the interior of this section, first implementation examples are given for Germany; A9, A94, A40 freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.6.1 Implementations

In Germany, one of the implementation present is on A 94 at AS München-Riem junction, direction Passau (outbound). A94 is the first ramp metering implementation in Germany. Average daily traffic, ADT for A94 is 61,000 vehicles. Ramp is located in the middle between inner urban ring road which is; Mittlerer Ring having ADT of 77,000 vehicles, and is the main road for collection and distribution of urban traffic from inner parts and motorway ring road A99 which has an ADT of 110,000 vehicles.

This particular ring road connects Nuremberg, Berlin freeway; A9 to the north and Salzburg freeway; A8 to the south. Within A94 there are two ramps present; "Riem" and "Messe". Main areas that junction AS München Messe Riem provides access are; a trade fair area in which 40 national and international fairs and exhibitions take place, additionally 280 national events and 120 congresses and conferences held for each year.

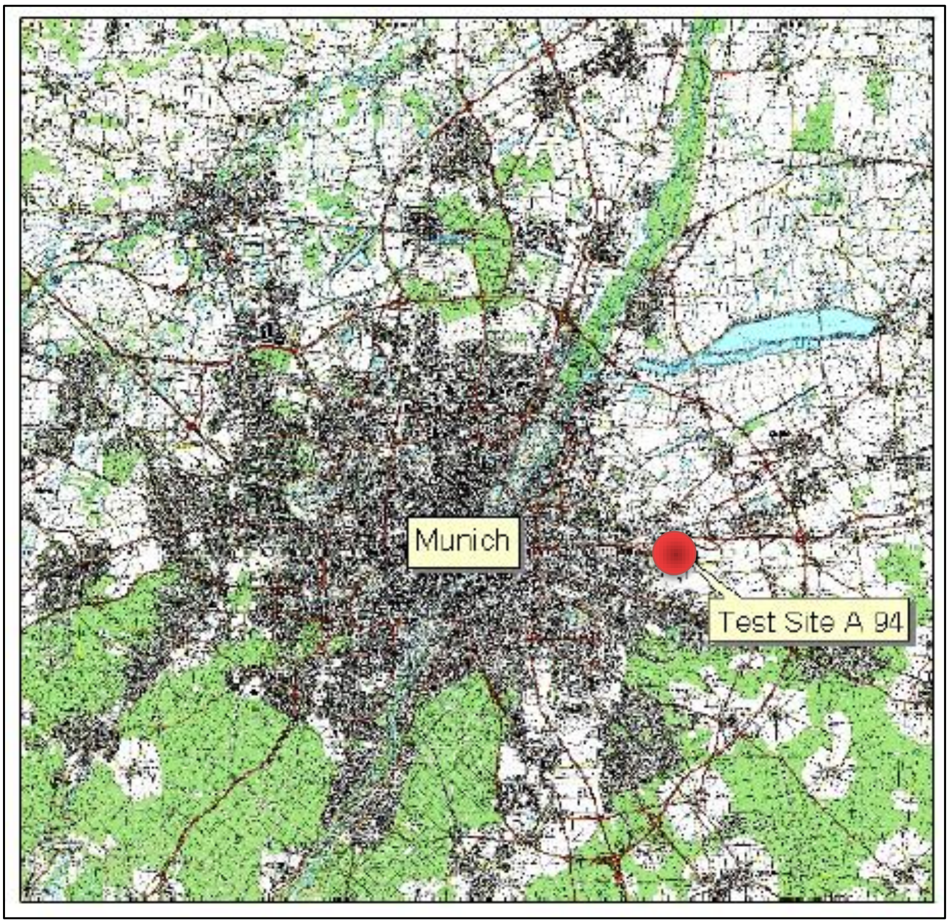


Figure 5.23: Test Site A94 in Munich adapted from (Papageorgiou et al., 2004)

Moreover, access to industrial and service areas; 13,000 person working capacity, residential area; Messestadt Riem; 7,500 apartments in which 16,000 people living in and finally a shopping mall; Riem Arcaden; having a parking lot which has a capacity of 2,700 vehicle. Test sites on A94 motorway is presented on Figure 5.23, Figure 5.24 and Figure 5.25.

Another implementation in Germany is on A9 motorway situated in north of Munich having an ADT between 64,000 (entry or exit AS Schwabig) and 146,000 vehicles (interchange AK Munich-North).

Figure 5.24: Selected Ramp, A94 from Aerial Photo adapted from (Papageorgiou et al., 2004).

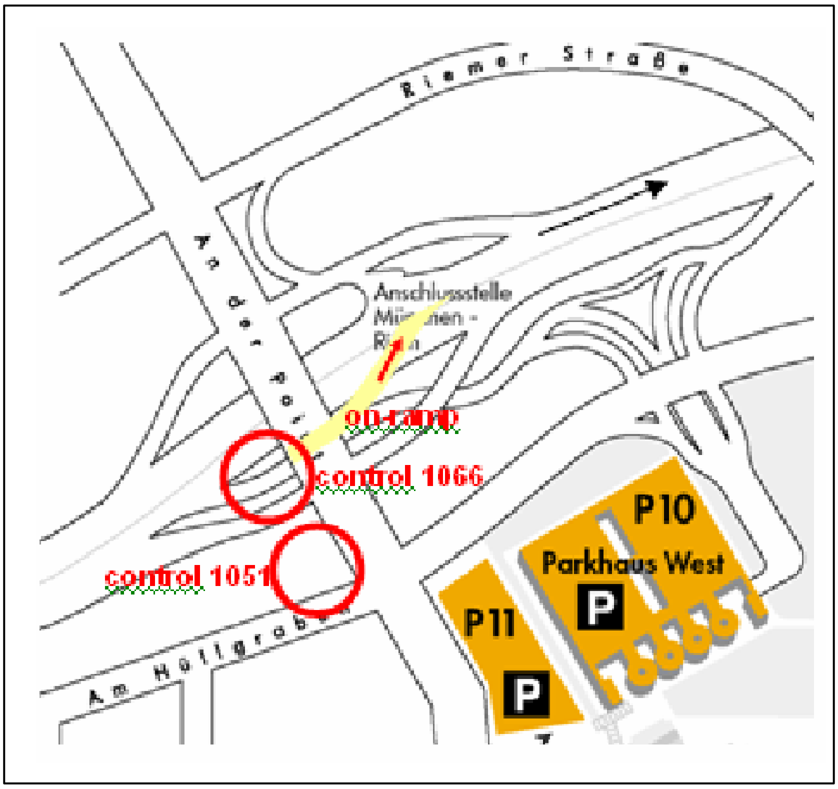


Figure 5.25: Traffic Controls Right Before On-Ramp at A94 adapted from (Papageorgiou et al., 2004).

A9 is the main road for collection and distribution of motorway traffic into inner urban areas, it provides connection to airport and the northern parts of Bavaria, Nuremberg then continues to Berlin (Papageorgiou et al., 2004). Two outbound ramps for A9 are; AS Frankfurter Ring and AS Freimann, additionally inbound ramps are; AS Allershausen, AS Garching North and AS Garching South. An alternative road for access to A9 is; Frankfurter Ring and Föhringer Ring which are parallel to Middle Ring Road. These roads are connected to big industrial areas where BMW; in the west and commercial media companies; in the east are located. The controlled junction of Frankfurter Ring and Ungerer Strasse filters the traffic coming from west side and there is a obligatory situation that, this flow has to give right to flow coming from East direction which has direct access to on-ramp (Papageorgiou et al., 2004). See Figure 5.26 for A9 motorway implementation.

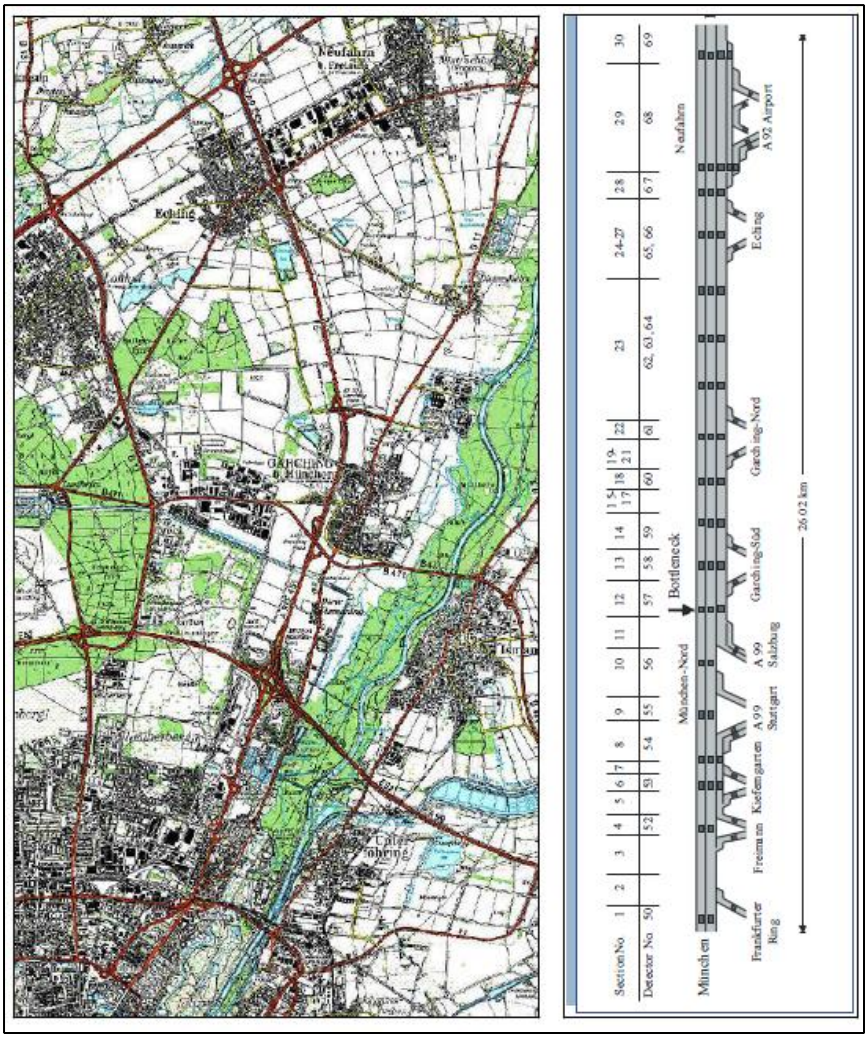


Figure 5.26: Location of the Virtual Site A9 adapted from (Papageorgiou et al., 2004).

AS Freiman; the connection between a residential area located in the East and a big industrial area including hypermarkets and an exhibition, fair center to A9 motoway is provided by Heidemannstrasse. AS Allerhausen allows entrance from several municipalities which are the areas located nearby. Junction AS Garching North provides main connection to Munich Technical University campus, the nuclear research center and other high tech companies. Ramp metering implementation made in the Nordhein-Westfalen, NWR region, the freeway network is 2,200 km long, having an intensive traffic load. Annual Daily Traffic, ADT is minimum 60,000 vehicle per day (vpd) and 180,000 vpd at maximum levels on the Cologne ring road (Papageorgiou et al., 2004).

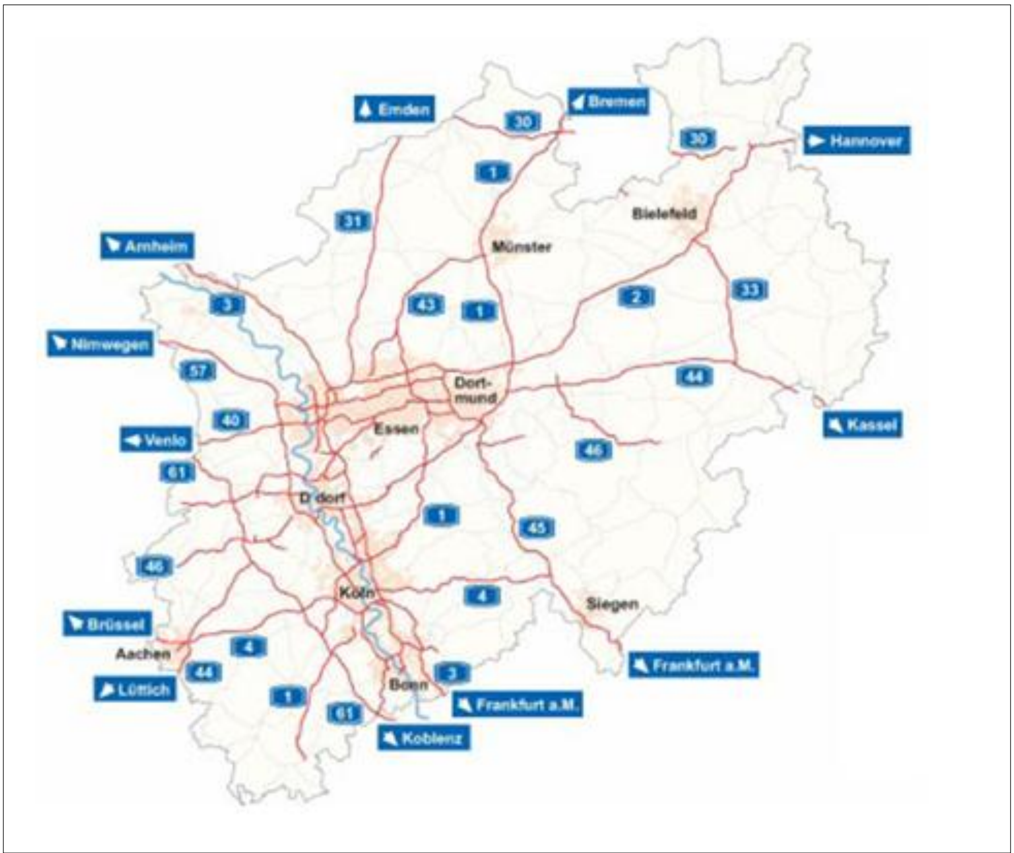


Figure 5.27: Ramp Metering Implementation in Germany adapted from (Papageorgiou et al., 2004).

Junction AS Garching South provides main connection to Garching city which is located on the east of A9 and the industrial areas (west of A9). Another connection of this particular junction is with B471; federal road which is a parallel road to the motorway ring A99 that connects several towns and industrial areas (Papageorgiou et al., 2004). For NRW region, Federal Ministry financed a Telematics Programme, which includes 100 ramp metering systems in operation until the middle of 2008.

For now 75 system is in operation, 5 of which are at double junctions where ramp and also parallel lane are metered. One of the deployment areas of ramp metering in Germany, is Nordhein-Westfalen, A40 freeway.

A40 freeway is situated between the access points of Gelsenkirchen and Bochum-Stahlhausen in the direction of Dortmund. 5 ramp metering implementations have been deployed and all implementations are independent from each other; only one lane of on ramp has been metered within the system (Kenis et al., 2001).

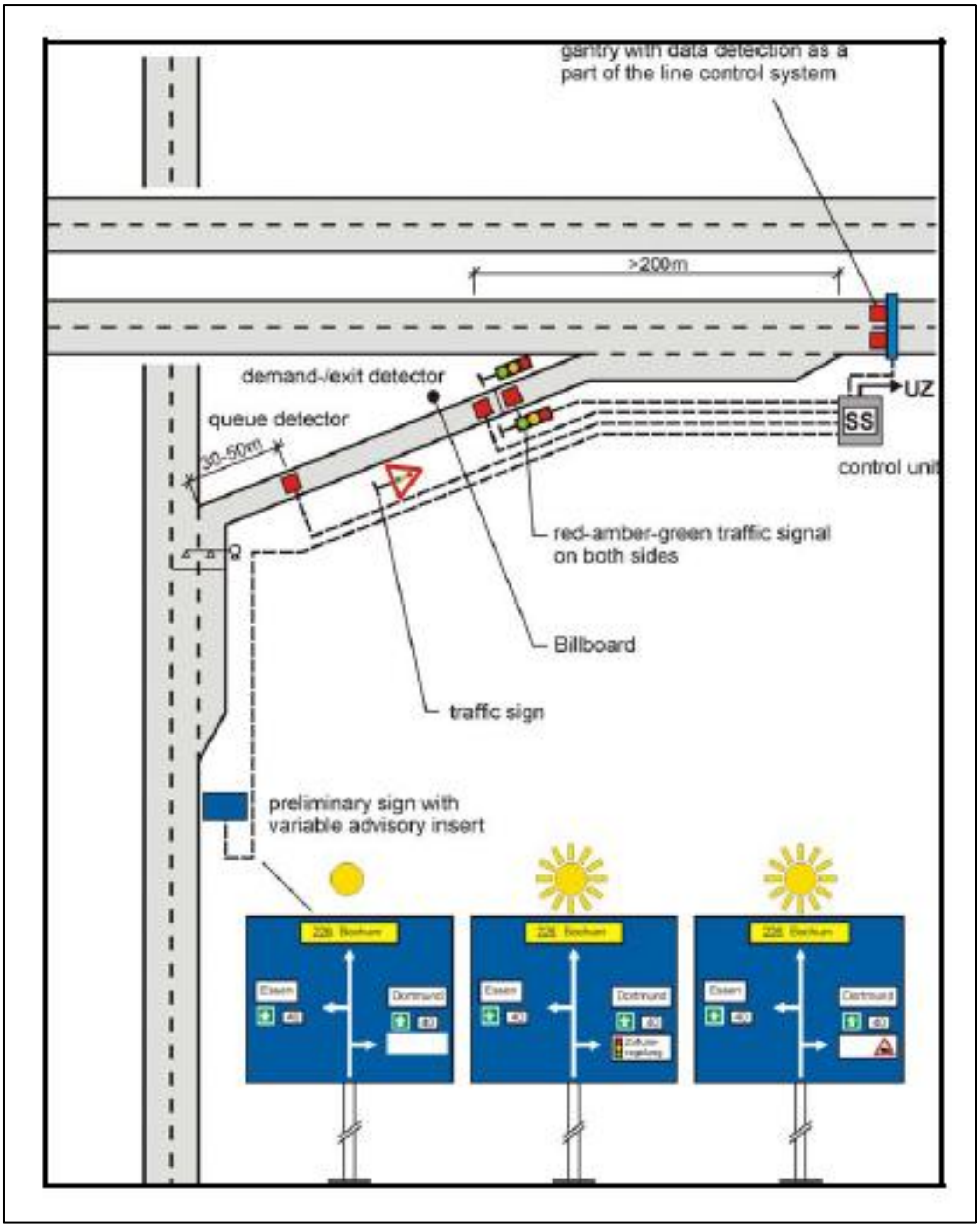


Figure 5.28: Ramp Metering System Architecture in Germany, Nordhein Westfalen, A40 Freeway, adapted from (Kenis et al., 2001).

There are several sites in which ramp metering implementation projects are also considered; 50 other sites including A40 in the area of Bochum and Essen, A1, A3 Cologne, A40, A43, A46, A47 and A 59 Duisburg-Ruhrort.

For NRW region, other newly implemented systems are also available, one of them is in Krefeld city center in which a slight rise implementation is applied with the help of a small barrier. This small barrier help to avoid blocking of the whole ramp area and provides passing of vehicles having the right of way. Cycle time for this particular implementation is, red time (3 sec), red or amber time (1 sec), green time (3 sec), yellow time (1 sec), so a cycle time duration is totally 8 seconds. The number of cars allowed to have access from on-ramp to the freeway is 900 cars per hour. Two cars per green strategy is embraced for this particular road section. The system should be operated continuously during peak periods and should not be switched off.

A similar implementation in Köln-Dellbrück, implementation of slight slope on the ramp is also in operation. Cycle time for this particular implementation is, red time (3 sec), red or amber time (1 sec), green time (2sec), yellow time (1 sec), so a cycle time duration is totally 7 seconds. The number of cars allowed to have access from the on-ramp to the freeway is 1020 cars per hour. Strategy used for Köln is also; two cars per green (Kenis et al., 2001).

Physical system architecture for A94 motorway on-ramps includes the following components; 2-field traffic light having three phases; red-yellow-off which is placed in the lower are of the ramp, 2 prism displays placed nearly at the middle of the ramp which shows that ramp meter is in operation and one vehicle per green is allowed to enter the freeway. Traffic detection is made by the help of loops which are situated before and after signal control and one if located at the beginning of ramp for queue detection. Main objective of these loops; on the on-ramp and on the freeway mainline is to provide a feedback by sending data to the algorithm. The detector obtained data is delivered every minute to roadside stations and to the control sub-center. Within the control sub-center, data process takes place and after finalizing the control decisions, results are sent to VMS. A9 motorway is using a lane control system which includes; speed reduction, overtaking restrictions, warnings etc. Dynamic video cameras are used for route A92-A9-A99. Moreover, local traffic data is obtained from loops located on site (Papageorgiou et al., 2004).

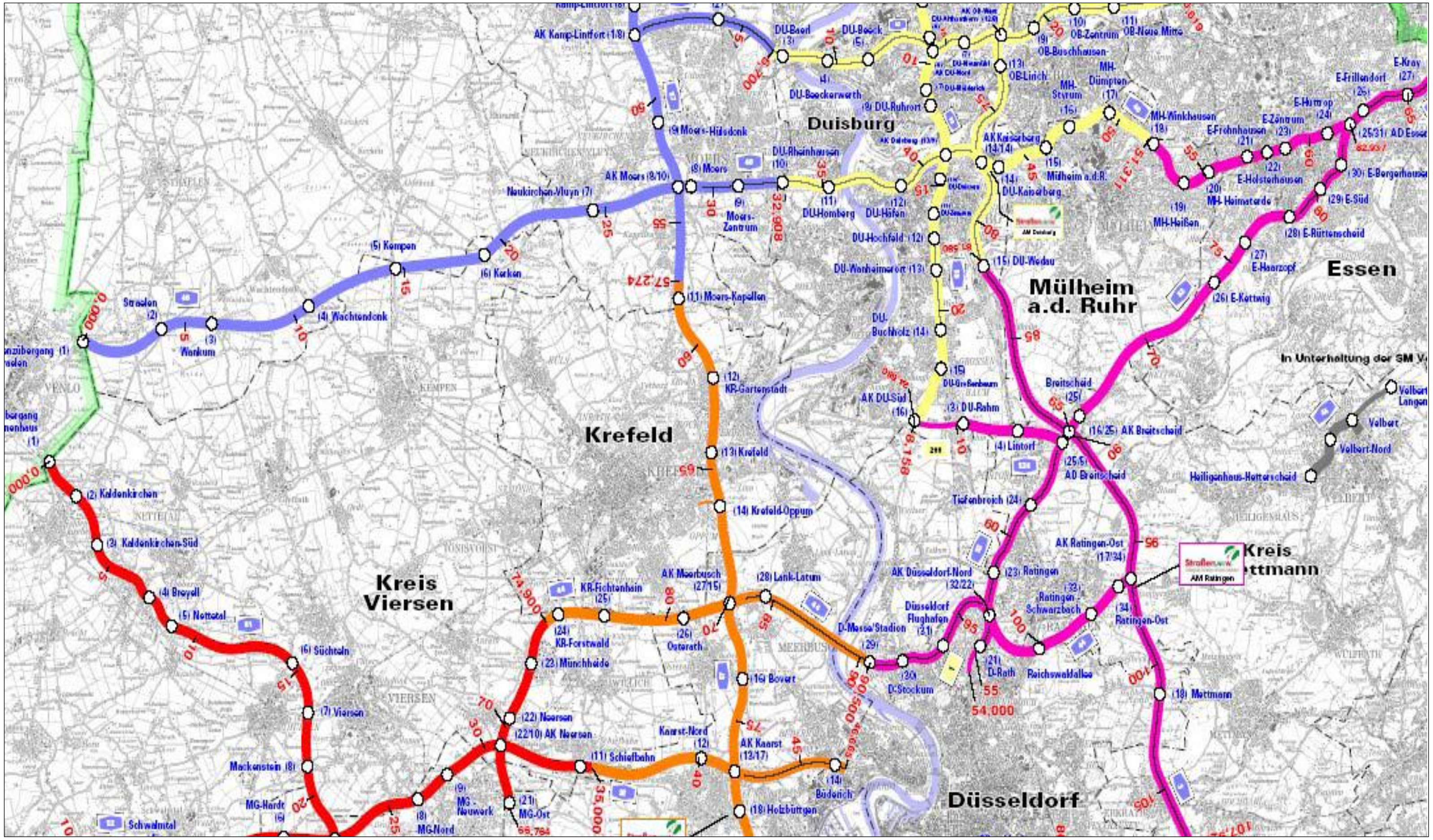


Figure 5.29: NRW Region Road Network for Ramp Metering Implementation adapted from (Kenis et al., 2001).

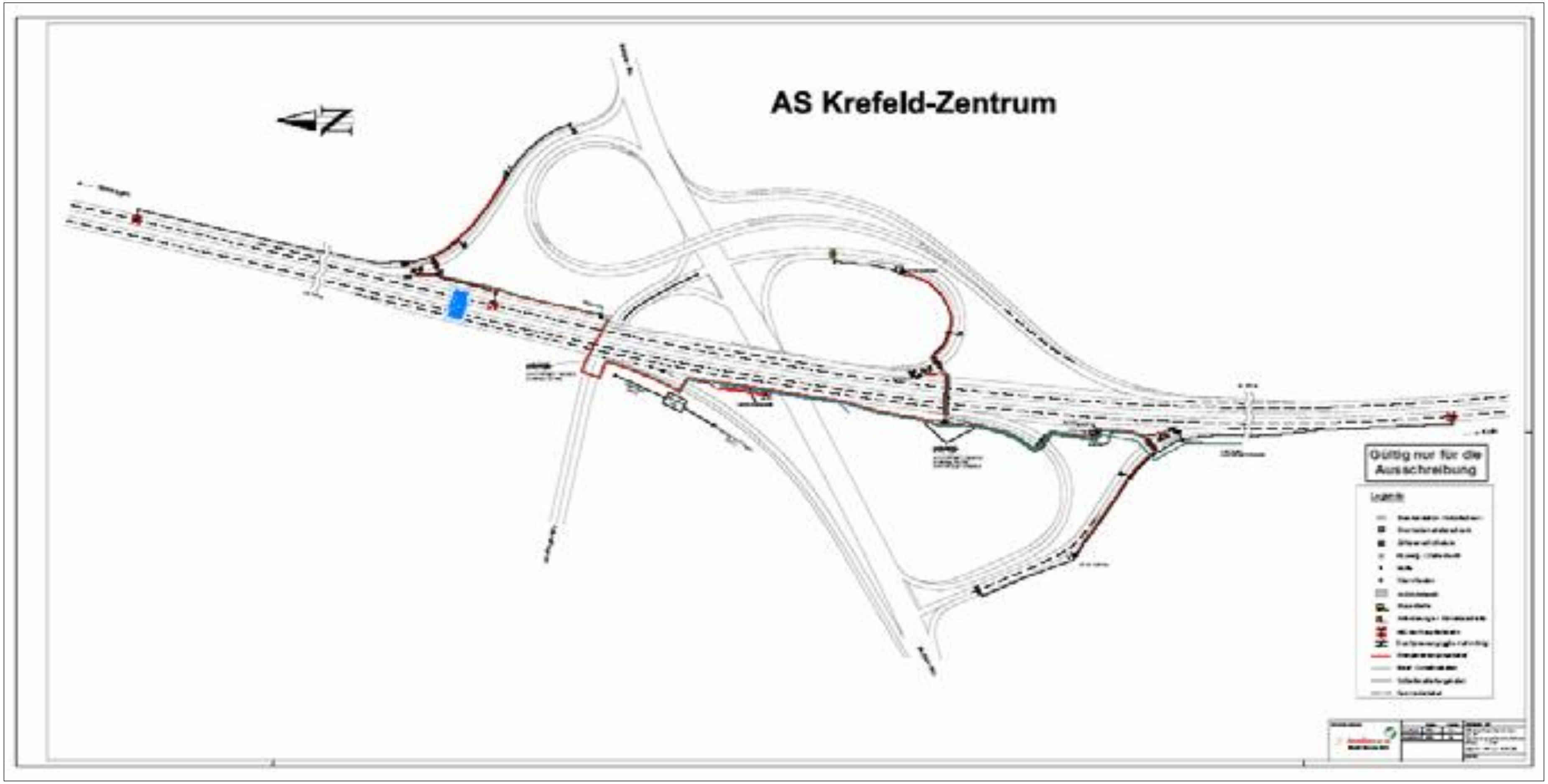


Figure 5.30: Ramp Metering Implementation Project in Krefeld-Zentrum, Germany adapted from (Kenis et al., 2001).

In Nordrhein-Westfalen implementation site, inductive detectors are used to detect vehicle presence, inductive loops are placed at freeway entrance and just before the traffic lights. Traffic data such as; traffic volume, speed and occupancy is obtained from the downstream traffic flow by the inductive loop placed at the entry of the freeway. Demand, exit and queue detection is determined by inductive detector placed on the access ramps.

Traditional traffic lights are used on site, which are; red, amber and green lights. These are located on both sides of the lane just before connecting freeway at the transition to acceleration/filtering in-lane. In peak hours, the system is supported by police enforcement for efficient operation.

The signal sequence used on particular application in Nordrhein-Westfalen is; red time (2 sec), red or amber time (1 sec), green time (0-16 sec), amber time (1 sec) therefore a cycle time duration is in a range of 4-20 seconds. Allowance of the system is one car per green, after some discussions, it has been decided to implement two cars on green strategy. If the cycle time duration is assumed to be 5 seconds than, per minute 12 cycles is present, which is equal to 12 cars allowed per minute. To sum up all, cars allowed to have access from the on-ramp to the freeway is 720 cars per hour with the theoretical values achieved. On daily operations, capacity can be higher depending upon the actual situation present on the road section. Operation of the system should be continuous in the peak hours.

Within the architecture of ramp metering deployments, pre-signing plays an important role, as their major role to inform road users about the implementation presence. In Nordrhein-Westfalen advisory signs used are; “Neutral - no announcement”, “Zuflussregelung – regulated access” and “Congestion Sign” (Kenis et al., 2001).

5.1.6.2 Algorithms

In Munich, A94 motorway, for practical reasons, ALINEA is not installed close to the test site, but instead in the main traffic control center. With this method, the results; cycle time obtained from

ALINEA algorithm is translated into a signal program number and than it is sent back to sub control center and finally the command that allows to change signal program is sent to the controller unit and signal control takes place.

Data storage is provided by a program called Wide Area Traffic Telematics Server, WATTS. WATTS is a software program which has the ability to collect and store real-time traffic data and traffic events obtained from Video Image Processing, VIP board. WATTS consist of two major components which are; the “Server” and the “Client”. Mentioned components are run on a computer within the sub control center. “Server” component stores traffic data, alarm events and alarm image sequences on a real time basis and provides a real-time connection for the clients with a TCP/IP socket. “Client” component access the database to view historical traffic flow and incidents and data can be used to generate reports.

In A94 motorway, an isolated traffic ramp metering system is used, which is controlled by ALINEA algorithm. Data for processing stage of the algorithm comes from inductive loop detectors situated upstream and downstream of the signal control and on the on-ramp. With this algorithm, traffic conditions of the whole road network is considered, regulation of traffic flow on the on-ramp is provided, by keeping downstream density close to a pre-determined values. Cycle time used for A94 motorway is, minimum 4 seconds and maximum 90 seconds. So within this range, and considering “one car per green strategy”, minimum 40 veh/h, maximum 900 veh/h of maximum input flow is achieved. For A9 motorway, an adaptive fuzzy system for traffic responsive and coordinated ramp metering; Adaptive Control Approach at Entrance Ramps based on Fuzzy Logic; ACCEZZ is being tested.

ACCEZZ is an adaptive fuzzy metering system which overcomes a great amount of disadvantages present for fuzzy control systems with an intelligent design and architecture of the ramp metering system (Papageorgiou et al., 2004).

In Nordrhein-Westfalen, ALINEA algorithm is used to maintain the levels of occupancy on the freeway section, by the regulation of the on-ramp flow (Kenis et al., 2001).

5.1.6.3 Effects of ramp metering

For first implementation on A40, results show that the congestion levels have been reduced with a percent of 50, traffic safety maintained by a reduction in accidents by 40%. During peak periods average speed increases 10 km/h and in some cases even beyond this number. Main result for selection of such a system is that, it is one of the efficient systems within ITS.

The systems simplicity allows road authorities to basically implement the system for improvement of traffic flow on freeways. Specifically it has been advised to implement the system on commuter freeways in conurbation areas.

Generally, a few implementation on NRW region have no effect on the traffic flow found within freeway section, and some of the implementations operate in an inert behavior, one car per cycle strategy ramps are congested.

For some cases, it should be born in mind that ALINEA algorithm may not be appropriate, incorrect implementation of loops and detection devices allow to obtain inaccurate results. Disconnection between the center and implementation on-site, and non-harmonization of traffic lights with ramp metering is the main causes for system to lie within the futile side.

A general conclusion is outlined within EURAMP report for A94 that, ramp metering stabilize traffic flow, prevents and postpones congestion and increases traffic safety (Kenis et al., 2001).

The following results from A9 motorway obtained as a result of simulation implementation. For outbound direction; there is high traffic flow existence in AS Frankfurter Ring as a result of incoming flow from Föhriger Ring and from signal control at Ungerer Strasse. A high peak traffic flow exists on main lanes, especially in the afternoons, as a result of traffic flow arriving from motorway beginning AS M-Schwabing and from middle ring road.

AS Frankfurter Ring, AS Freimann; 1,3 km, AS Fröttmaning; 0,9 km and AK Munich North; 1,8 km are totally 4 kilometer in length which can easily be effected by the traffic coming from AS Freimann.

On inbound directions; AS Allershausen is close to AS Pfaffenhofen, so further actions should be taken in order to eliminate disturbances in traffic flow within this entry, which can cause spillbacks.

AS Garching North and AS Garching South are close to each other at about 1,6 km distant and close to the location where AK Munich North motorway is split and major merging action takes place. The traffic comprises high proportion of heavy vehicle so disturbance of an uncontrolled inflow to this particular area should also be restricted.

5.1.7 Deployments in Japan

In the interior of this section, first the implementation examples is given for Japan Hanshin Expressway and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.7.1 Implementation

Hanshin expressway is a 239,3 kilometer network of expressways which involves Osaka, Kobe and Kyoto. In Hanshin Expressway, 242 km of the road network is in service and 900 thousand vehicles per day is the flow volume according to data sets obtained in 2008.

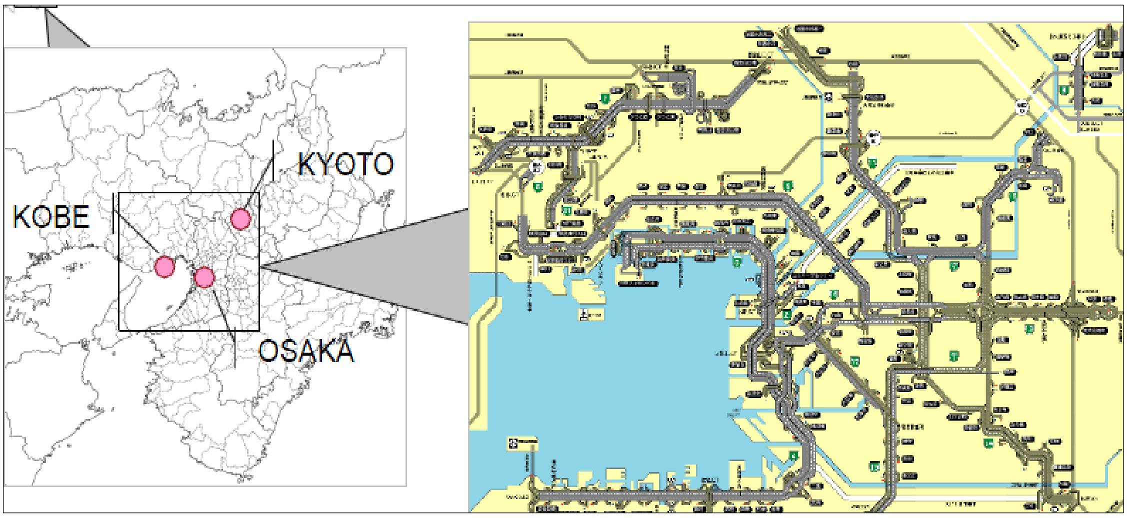


Figure 5.31: Ramp Metering Implementation Location on Hanshin Expressway adapted from (Ishibashi et al., 2008).

First stage of implementation of the Hanshin Expressway is adapted in 1969 which consists of traffic information services given to road users. For the second stage of that particular implementation, in 1980, the system is expanded and controlling on-ramp became present including closure of on-ramps and tool booth restrictions.

In 1989, the third stage of implementation for Hanshin Expressway, the enhancement of the total system was on service. In this stage, traffic information services and incident alert systems are used. In 2003, the system is reconstructed and additional equipment for traffic control is installed to the control center. On November 2003, Hanshin Expressway Real-time Observation-based & Integrated Evalutor (HEROINE) is started to be used on Hanshin Expressway (Ishibashi et al., 2008, Yukimoto et al., 2002).

5.1.7.2 Algorithms

In traditional methods used on Hanshin Expressway, the booths are closed down temporarily at a rate of 30 minutes time interval. Time interval is based on “ Traffic Control Manual” used for this particular system. With the introduction of new equipments, traffic control can be made more dynamically and flexibly. Despite the method used on Hanshin Expressway previously, on-ramp metering provides continous booth operation. System uses a control rate which aims to adjust the inflow interval of waiting vehicles. In general, HEROINE is simulator tool which is developed to simulate traffic situation particularly on Hanshin Expressway. HEROINE is a macro traffic flow based simulation model. HEROINE is a system including some major components to support traffic control system. It helps to support traffic control operation, examining the restriction plan required for construction, make decision on operational measurements and traffic forecasting for information services. Main objectives of HEROINE can be grouped into three; Traffic Control, Management of the Expressway and Service for Expressway Users. Under traffic control issue, HEROINE provides traffic forecasting and proposes traffic control; additionally it evaluates traffic control measures such as ramp metering and on-ramp closure. Under expressway management, evaluation of maintenance and rehabilitation work present on the expressway is taken into consideration and additionally it provides traffic conditions for working teams in order to reach construction and accident sites efficiently and on time. Final scope of HEROINE system is; providing traffic information including traffic condition estimations. The system configuration of HEROINE simulator is explained in the following paragraphs in a step by step approach (Ishibashi et al., 2008, Yukimoto et al., 2002).

At the first stage of the system, a transportation demand estimation module exists which is the initial set and includes; “Use route search, alternative route search, inflow time series, block condition” items. After that first step, the system goes through modeling of traffic demand stage on this particular step, identification of each vehicle is made by countings at each section. Additionally, within the frame of second step, system puts “Flow Model” into activation which includes calculation of several variables like; speed, density, occupancy, flow volume. These variables are calculated according to the number of vehicles found in each section.

Traffic information obtained from flow model renewed in each 5 minute and route value such as; travel time, congestion length, presence of a ramp control or unavailability is obtained for each particular route. With the help of route choice model, each drivers route selection is determined.

Route values obtained in the previous step is used to make estimation to calculate the probability of a driver using a detour route, containing only ordinary street link and whether the driver prefer using expressway or not. After that, the route values obtained is used to calculate probability of a driver using detour on-ramp and whether the driver prefers to use original on-ramp or not.

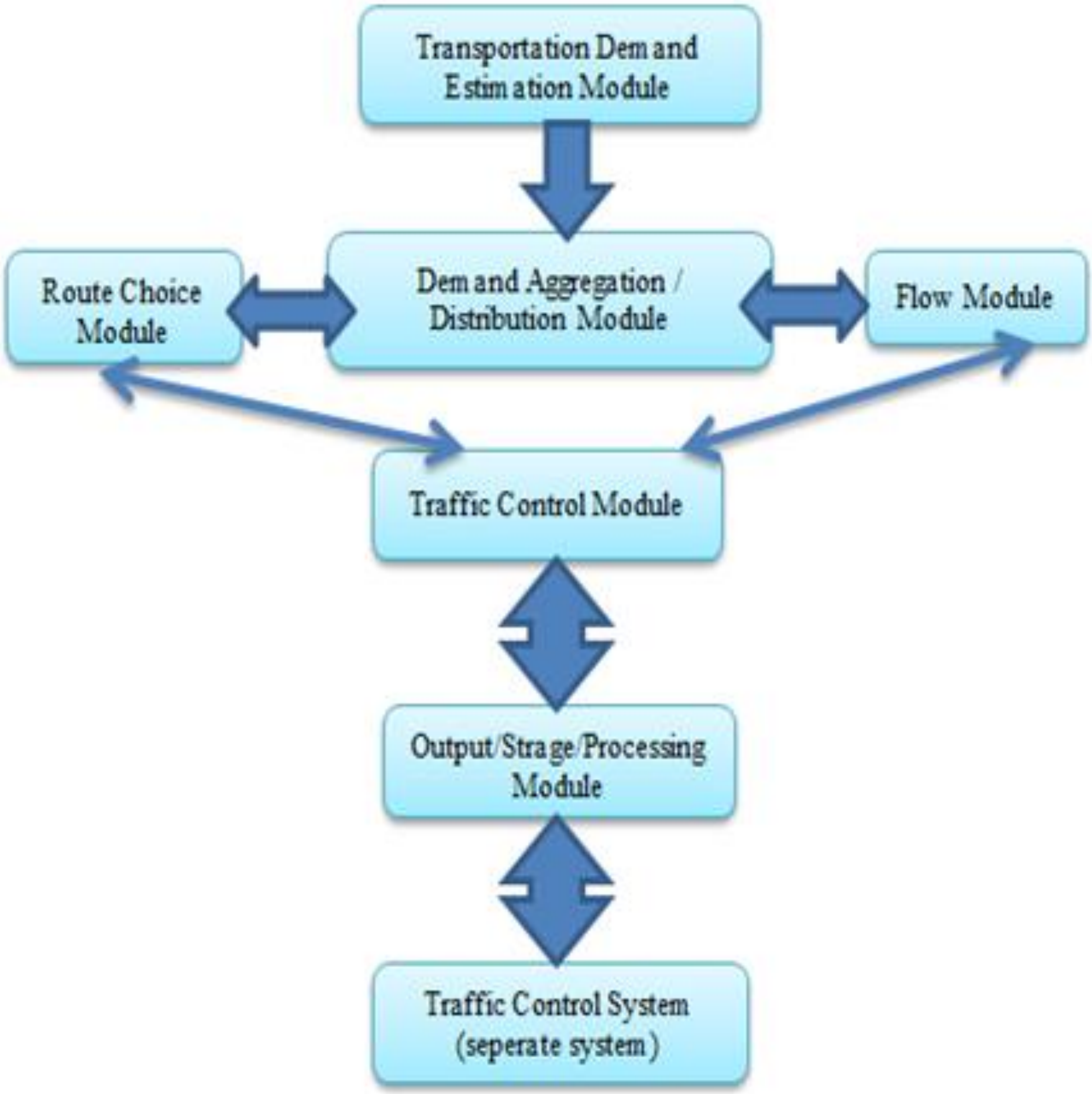


Figure 5.32 : HEROINE Traffic Simulator System Configuration adapted from (Ishibashi et al., 2008, Yukimoto et al., 2002).

Observed inflow volume is obtained as a conclusion of drivers route choice. With the observed inflow volume obtained previously, by detectors and drivers expressway usage probability, potential of inflow demand volume is estimated.

In Oasaka-Ikeda Line on Hanshin Expressway, estimated demand of inflow volume is; 10,489 vehicles (+% 3.3 up) between 06:30-08:30, 10,486 vehicles (+% 3.8 up) between 14:00 – 16:00 and 9,459 vehicles; +% 3.1 up between 17:00 – 19:00.

Inflow volumes for each ramp is calculated by using above mentioned estimated demand volumes and the following results are obtained; 10,159 vehicles; +0.1% error between 06:30 – 08:30, 10,233 vehicles; +1.3 % error between 14:00 – 16:00, 9,356 vehicles; +1.1% error between 17:00 – 19:00, when a comparison between values obtained from field observations and outputs from HEROINE is made.

From the results obtained, a consideration can be made as; difference between the estimated volume and the observed volume have slight difference.

When the congestion levels within HEROINE traffic simulation and actual situation is compared, we have come to a conclusion that the validity of HEROINE is acceptably high.

5.1.7.3 Effects of ramp metering

Each method “On-Ramp Closure and Booth Restriction Control Method”, “On-Ramp Metering Control” and current situation are evaluated by estimating results obtained from the traffic simulator HEROINE.

When a comparison between the methods are made, the following conclusion can be obtained; with the presence of an on-ramp metering control, inflow volume is higher, volume of congestion lesser and a higher average travel speed is present. Influence of ramp metering implementation on the detour traffic is just a slight difference.

To sum up all the facts listed in Table 5.5, it can be concluded that ramp metering implementation lead to more logical and beneficiary result than other implementation methods. Though, the price considerations should be taken into account in order to assess the system under monetary values as well.

In case of a ramp metering implementation present, there is a decrease in average travel time, as a result of flow diverted from the bottleneck section into the following ramp (Ishibashi et al., 2008, Yukimoto et al., 2002).

Table 5.3: Osaka-Ikeda Line on Hanshin Expressway Result Table adapted from (Ishibashi et al., 2008, Yukimoto et al., 2002).

Control Method		**Current Estimation (Not Control)**	**On-Ramp Closure & Booth Restriction Control**	**On-Ramp Metering Conrol**
Express Way	**Congestion Volume (km*hour)**	12.5	11.2	10.9
	Inflow Volume (vehicles)	10,159	10,159	10,192
	Travel Time (hour)	2,773	2,710	2,650
	Average Speed (km/hour)	29.3	30.1	30.5
Ordinary Streets	**Travel Time of Detour Trip (hour)**	82	85	75
	Travel Time of Original Trip (hour)	21,534	21,543	21,530

5.1.8 Deployments in Netherlands

In the interior of this section, first the implementation examples is given for Netherlands several freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.8.1 Implementations

First ramp metering implementation was on S101 on-ramp to the A10-West near Coentunnel in 1989. With the presence of increase on demand and technological developments, total number of equipped on-ramps was sum up to a total number of 54 by 2005.

In Netherland, the Rijkswaterstaat Region of Utrecht on some selected locations, the strategy of “two car per green” is in operation. The particular reason why ramp metering application is vitally important in predetermined sections within a freeway can be listed as; on-ramps which are close to a bottleneck and on-ramps disturbing the regulated flow of freeways arising from merging action of platoons of vehicles approaching to freeway via on-ramp from a signalized intersection. To exemplify the situations listed below, the cases are stated more clearly. For the first case; last on-ramp which connects Coetunnel to a part of ring road around Amsterdam; A10-West freeway is an essential example. Road users prefer last on-ramp in order to avoid congestion, in other words rat running. In March 1989, after the implementation of ramp metering, most of the drivers change their selection of on-ramp or routes. Positive feedbacks of the implementation; an increase present on the average speed levels on freeway, a decrease in number of rat runners, additionally an increase on number of vehicle per kilometers.

Example of second item can be seen on the on-ramp Delft-Zuid to A13 in the direction of Rotterdam. Every day, on particular time period, optimum capacity exceeds and shock waves and stop & go traffic present on the road section. This situation is a result of platoons of vehicle merging to the on-ramp to have access to freeway. In the end of 1989, after ramp metering implementation congestion levels decreased and in accordance with this the capacity of A13 freeway section increased in a visible manner. Inductive loops are the major aspects within implementation of ramp metering.

In this case, inductive loops are placed mainly on two cross-sections of the freeway; upstream and downstream of the on-ramp. Their objective is to obtain flow and average speed measurements and detect whether the current situation on-site are exceeding threshold level or not. In accordance with the threshold level, system is activated and only one or two vehicle per lane per green time allowance occurs for regulation of traffic purposes.

In the case when slip road is also used by public transport and trucks, priority access is given to those users, by introducing an adjacent to the present lanes. In Netherlands, once the detection of a bus and truck is available, their access is provided by giving a green time in the consecutive cycle.

Traffic lights are used in implementation differs from traditional traffic lights in several ways. Shield behind the traffic light used is yellow instead of black, additionally under the lights, a sign stating “one per green” is placed, signals are placed lower and closer to the stop line for easy visibility of drivers. Moreover, lane dependent signs present, in case of two-lane ramp metering, it has been supported by additional information; “linkerrijstrook”; left lane only.

Systems sustainability is provided by standard equipments such as; red light cameras. The fine paid by drivers in case of red violation is 50 euro per occurance. Red light camera usage is not applicable in all cases (Taale et al., 2006).

Cost effectiveness of the system can be recognized by knowing implementation costs. For one lane controller implementation costs are €150,000 and for a two lane controller it is €175,000 inclusive of equipments used outside.

Red light camera costs are €45000 and maintenance costs on yearly basis are €10,000. Last but not least, financial data above are exclusive of equipment situated in the center and additional infrastructural formations. For pre-signing purposes, a traffic signal is used with a accompanying text panel stating “doseerlichten”; metering signal.

In case of the system goes into operation, amber flashing signal is used for precaution purposes. Regional Directorate Utrecht’s, DUT responsibility area is 177 km of motorway network and 292 km of rural roads. As Utrecht is located at the center of Netherland, several major roads having high traffic flows passes over there (Taale et al., 2006).

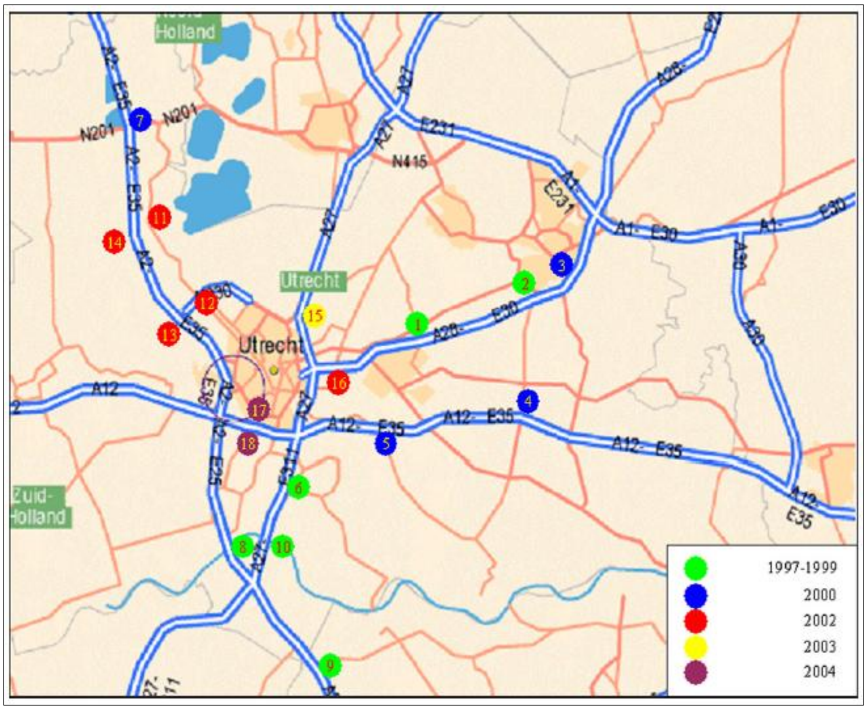


Figure 5.33: Road Network in the Vicinity of Utrecht adapted from (Taale et al., 2006).

Within RWS DUT, there are several routes which are shown in Table 5.6. First route; A2 starts from north; Amsterdam to the south; Belgium and France and also in the opposite direction. And the second route; A12; E30, A28; E30 and A1; E30 starts from the west; Rotterdam Harbour to the north part of Germany and also in the opposite direction. Existance of congestion especially in the morning and evening peak is considerably high, so with ramp metering implementation the main objective is to relieve congestion.

Ramp metering implementation located in Vianen is the first one in RWS-DUT. It is located close to a bridge, which is the main source of bottleneck on A2 north direction. In July 1999, a new adjacent bridge is opened as an alternative to the old bridge. Though there is no need for a ramp metering implementation, it has not been removed, instead a maintenance for renewing the system is made in November 2003.

Ramp meter in Hagestein is not used for a while arising from connection line failure. After renewing the system in November 2003, system starts to operate on 15 June 2004. Ramps; Breukelen and De Uithof is operating in two-car per green per lane strategy. Ramp meter in Utrecht Noord is not used for a while arising from some failures, until it starts to operate again in 11 June 2003. North Papendorp and South Papendrop ramps are ready for operation (Papageorgiou et al., 2004).

Table 5.4: Ramp Meter Systems Installed in RWS-DUT adapted from (Papageorgiou et al., 2004).

Nr.	Road	Km	Side	Name	Urban Area	Date	Lanes
1	A2	72,29	East	Vianen	Vianen	16.07.1997	1
2	A2	78,78	East	Everdingen	Vianen	01.09.1998	1
3	A27	58,45	East	Hagestein	Vianen	**-01-1999	1
4	A28	11,62	North	Soesterberg	Soest	**-01-1999	1
5	A28	15,91	North	Maarn	Leusden	**-01-1999	1
6	A27	67,95	East	Houten	Houten	**-01-1999	2
7	A12	67,80	South	Bunnik	Bunnik	**-01-2000	1
8	A12	77,5	North	Maarn	Maarn	**-01-2000	1
9	A2	43,47	East	Vinkeveen	De Ronde Venen	16.02.2000	2
10	A28	18,11	North	Leusden-Zuid	Amersfoort	**-02-2000	2
11	A2	49,27	East	Breukelen	Breukelen	29.01.2002	2
12	A2	56,25	East	Maarssen	Maarssen	29.01.2002	2
13	A2	56,84	West	Maarssen	Utrecht	09.12.2002	2
14	A2	49,62	West	Breukelen	Breukelen	09.12.2002	1
15	A28	3,40	South	De Uithof	De Bilt	09.12.2002	1
16	A27	83,19	East	Utrecht Noord	Utrecht	11.06.2003	2
17	A12		North	Papendorp	Utrecht		1
18	A12		South	Papendorp	Utrecht		1

5.1.8.2 Algorithms

In Netherlands, research on the following algorithms are made; RWS strategy, ALINEA and an algorithm based on FUZZY logic. RWS strategy uses flow on both freeway and on-ramp. This strategy's main objective is to use capacity efficiently. And to neglect and avoid variations, rounding made within the measured values. Number of vehicle access to freeway is calculated by using rk; which is the number of vehicles allowed to access freeway in time interval k, equal to the subtraction of C which is the capacity predetermined of freeway downstream the on ramp and I_{k-1} which is the measured and rounded up flow obtained from upstream of the on-ramp in previous time interval.

Cycle time, t (in seconds) for ramp metering is calculated by using n; number of lanes found on the on-ramp, multiplied by 3600 and divided by r_k value. After comparison of calculated value with the minimum and maximum value, in case of a necessity present, these values are used instead. When the speed is decreased to a certain level, access from slip road to freeway is set to a minimum value, vice a versa when queue formation present on the slip road, depending upon the condition, it can be logical to allow maximum number of vehicle access to the freeway.

Cycle time used in ramp metering implementation is calculated from the difference of upstream of freeway, downstream of freeway and number of lanes present on the slip road. And cycle time limited by a maximum value of 12-15 seconds. Green time included in the cycle time is dynamic and dependent upon reaction time of the driver and acceleration of the vehicle. In normal conditions, a green cycle time is 2.0 seconds. Amber time is also dynamic and depends on speed behind the stop line. An amber time is 0.5 seconds. And the calculation of red time is made by subtracting green time and amber time from the remaining cycle time, which is 2.0 seconds. Then, minimum cycle time is; 4.5 seconds. The controlling mechanism is always in operation, but signals are not visible in no requirements and switched off case. In case when demand on freeway exceeds a threshold level and when vehicle speeds drop to a certain level, signals are switched on. When demand lowers and increase of speeds of vehicles are present then the signals are switched off. In the presence of a two lane ramp metering implementation, one green per lane is synchronized; green time is dependent upon reaction time and acceleration speed of each vehicle.

For example, when a heavy truck accelerates, green time within a new cycle is postponed until; truck is realized by a “start amber” or “start red” detector.

Second algorithm used is; ALINEA. This strategy is based on the occupancy measurements. It aims to keep occupancy downstream of the on-ramp in a certain level. While switching on or off the system in necessary situations, the same procedure applied in the RWS strategy is used. Calculation of the vehicle allowed to enter freeway is dependent on the occupancy downstream and calculated by using components; r_k number of vehicles given access to freeway in time interval k, is equal to $\boldsymbol{r_{k-1}}$ number (rounded value) of vehicles given access to freeway in the previous time interval, plus K which is a constant, multiplied with the subtraction of O_s which is the set point of occupancy and O_{k-1} measured occupancy downstream the on-ramp in previous time interval. Cycle time calculations are also same with the cycle time calculations made by RWS strategy. The last algorithm used is FUZZY Strategy which is based on three input variables. These three input variables are; speed upstream the on-ramp, speed downstream the on-ramp and time when a queue present on the on-ramp. Cycle time is considered to be the output value. And the input values of the system is categorized as; very low, low, medium, high and very high. A fuzzification is made by directing the measured value in a particular category. Rules are in operation depending upon the measurements obtained. Rules in a FUZZY strategy are as follows: “IF; speed upstream = medium AND; speed downstream = low, THEN; cycle time = long”. These rules activate the categories and the measured values; members functions where the output variable

If we compare, ALINEA and RWS strategy algorithms, ALINEA gives better results as it increases total service of both freeway and on-ramp. But when a comparison between these two algorithms and FUZZY strategy is made, with a 5 % increase in the capacity, higher speeds and lower travel time, FUZZY strategy leads to far better results. Stemming from difficulties in operational reasons and occupancy parameter being hardly understood, RWS strategy is prefered to be used on freeways in Netherlands.

Barneveld located along A1 in the Rijkswaterstaat region East-Netherlands, selected as a pilot section for testing V-ALINEA strategy (Papageorgiou et al., 2004, Taale et al., 2006).

5.1.8.3 Effects of ramp metering

Effects of ramp metering implementation on several sites in Netherlands are assessed under several criteria. In Coentunnel S101; one on ramp exist, there is no change in capacity of the bottleneck, speed on that particular tunnel is increased by 30 km/h, the use of on-ramp is decreased by 50 percent, there is no change within the total delay; vehicle hours and travel time on the freeway is present. Red violation existence is 5-6 % for Coentunnel S101. In A10-West; 4 on-ramps exist, capacity of the bottleneck is 2 % and there is a 20 km/h speed increase present. The use of on-ramp is same before and after implementation of ramp metering. Total delay in vehicle hours present is decreased by 20 %. Neither a change in travel time within the freeway nor a red light violation is present.

In Delft-Zuid, within the 1^{sr} assessment, the capacity of the bottleneck increased by 5 % and there is no speed change exists. The use of the on-ramp is same with the value of usage before and after implementation and total delay in vehicle hours is less when compared to none ramp metering case. The travel time in the Delft-Zuid freeway is not changed and the red violation occurrence is 15 %. In Delft-Zuid, within the 2nd assessment, the capacity of the bottleneck is increased by 4 % and there is no speed change exist, same with the 1st assessment made in the Delft-Zuid. There is no change in levels of the usage of the on-ramp in Delft-Zuid and the total delay in vehicle hours is again less than the value obtained before the ramp metering implementation. No change present in the travel time for a vehicle passing the Delft-Zuid section of the freeway and the occurance of red violation is 15 %.

In Zoetermeer, bottleneck capacity is 3 % and no change present in speed on the freeway section. The use of on ramp experiences no changes after implementation and there is no total delay in vehicle hours present. One positive effect present in Zoetermeer is, travel time on the freeway which is reduced by 6 %. And red violation occurence present is 13 %.

In Schiedam-Noord, capacity of bottleneck increases, speed on the freeway also increases by 20 km/h. The use of on-ramp decreases by 8%, when there is a ramp metering implementation. There is no total delay in vehicle hours present in Schiedam-Noord. Travel time in the freeway is decreased by 6% and red light violation occurence is 3 %.

In Barendrecht, bottleneck capacity is 5% and speed on the freeway is increased by 20 km/ u. There is a visible reduction in the use of on-ramp about 35 % and no total delay in vehicle hours present for Barendrecht case. One of the positive feedbacks of ramp metering implementation in Barendrecht is reduction in travel time spent on the freeway; which is 10 %. And the red violation occurence is found in minimum levels as 2%.

In Kolkweg, there is no change exists with the capacity of bottleneck levels. Speed on the freeway is increased slightly by 4 km/h and the use of on-ramp is decreased by 10 %. There is no total delay in vehicle hours present with this respect, travel time on the freeway decreased by 3 %. In Vianen, capacity of the bottleneck is 5 % and speed on the freeway increased by 5 km/u. Use of on-ramp is decreased by 36 %, additionally there are no total delays in vehicle hours. After a ramp metering implementation present, the travel time on the freeway in Vianen meets no change and red light violation occurence is 5 %.

In Muiden; Muiderslot, capacity of the bottleneck is constant and there is no change in speed levels on the freeway. The use of on-ramp depends upon situation but not very different when a comparison is made between before and after implementation stages. There is no total delay in vehicle hours present and travel time on the freeway is same with before implementation phase. Finally, red violation occurence for Muiden; Muiderslot section is between 6-7 %. In Vinkeveen, capacity of a bottleneck is ranging between 1-3 % and speed on the freeway is increased by 10 km/h. The use of on-ramp is dependent upon situation, sometimes it is equivalent to the usage before implementations and sometimes there is no usage of on-ramp. In Vinkeveen there is no total delay in vehicle hours present with this respect travel time on the freeway increased by 5 minutes time interval. Occurence of red light violation in Vinkeveen is not present.

RWS-DUT implementation reveals out the following results; ramp meter implementation near Vinkeveen along A2 in the direction of Amsterdam presented a better performance for the freeway. Speed levels increases on the freeway mainline, less shockwave presence and improved travel times. The effects of implementation over the rural area are minor; extra delays on the slip road is present. One more beneficiary effect of the system can be listed as; traffic safety, less accidents occur on the freeway section (Papageorgiou et al., 2004, Taale et al., 2006).

Table 5.5: Overview of the Result Obtained from Ramp Metering Deployments in Netherlands adapted from (Taale et al., 2006).

	Capacity of Bottleneck	Speed on Motorway	Use of on-ramp	Total Delay (veh.hrs)	Travel Time Motorway	Redlight Violations
Coetunnel S101 (1 on-ramp)	=	30 km/h	-50%	-	-	5-6%
A10-West (4 on-ramps)	2%	20 km/h	±	-20%	-	-
Delft-Zuid (1st assessment)	5%	-	=	<	-	15%
Delft-Zuid (2nd assessment)	4%	-	=	<	-	15%
Zoetermeer	3%	-	=	-	-6%	13%
Schiedam-Noord	>	20 km/h	-8%	-	-6%	3%
Barendrecht	5%	20 km/h	-35%	-	-10%	2%
Kolkweg	=	4 km/h	-10%	-	-3%	6%
Vianen	5%	5 km/h	-36%	-	-	5%
Muiden/Muiderslot	-	-	±	-	=	6-7%
Vinkeveen	1-3%	10 km/h	= / -	-		-

5.1.9 Deployments in Belgium

In the interior of this section, first implementation examples is given for Belgium freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.9.1 Implementations

According to Centrico programme single lane ramp metering at Leuven is present. It is aimed to improve traffic flow particularly on E314 freeway. Crossing of E40; Calais-Brussels-Köln and E314; Leuven-Aachen is where Leuven situated. For further implementation opportunities regarding traffic improvements, sites taken into consideration are Brussels and Antwerp (Kenis et al., 2001).

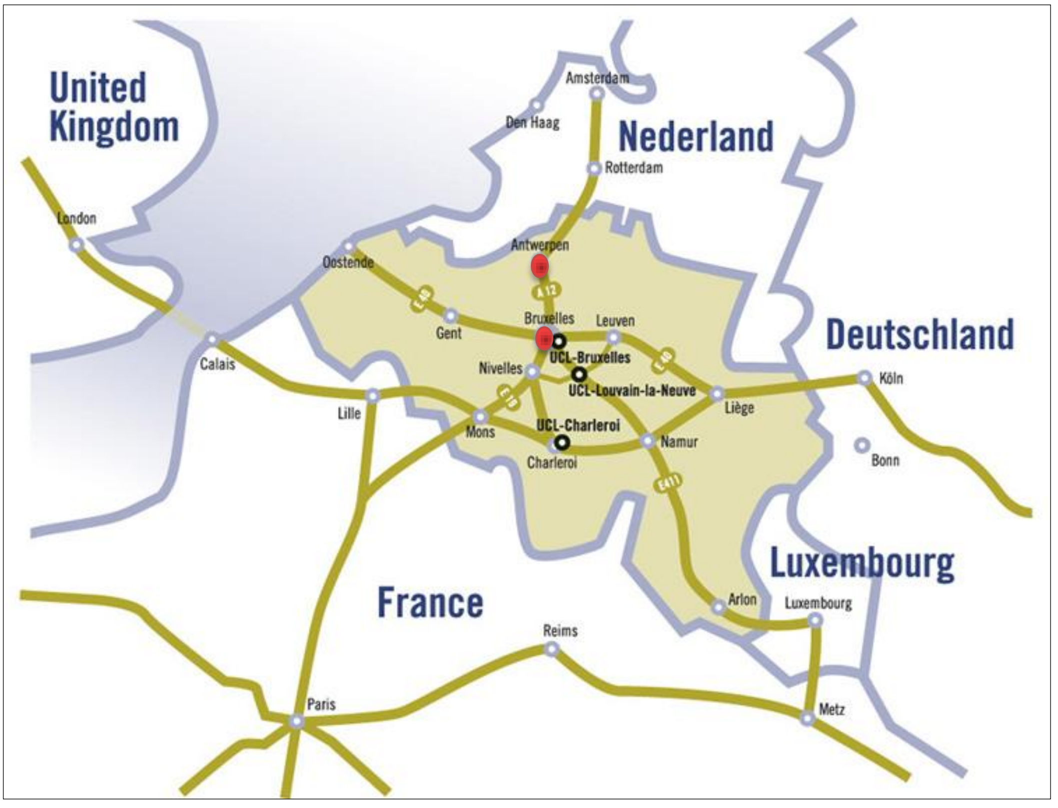


Figure 5.34: Planned Ramp Metering Implementation Sites Through Out Belgium adapted from (Kenis et al., 2001).

Main components of ramp metering architecture used for the on-site implementations are video cameras and loops situated on ramps at the entrance of freeway section and before traffic lights. Traditional traffic lights are used in the system, consist of green, amber and red colors and situated just on the right side of the road (Kenis et al., 2001).

5.1.9.2 Algorithms

The algorithm used to support ramp metering system in Leuven is ALINEA. System particularly relies on occupancy measurements, additionally an occupancy monitoring for upstream is also made for further evaluation.

Cycle time used in the system is minimum 4 seconds. Green time cycle length is 1-2 seconds, amber time cycle length is 1-2 seconds and red time cycle length is 2 seconds minimum.

Per cycle time, only one vehicle is allowed to enter the freeway, the principle applied in general is one-car-per-green.

Ramp metering system is only operated on weekdays between 06:00 and 10:00 hours and when the measured occupancy exceeds by 18 % (Kenis et al., 2001).

5.1.9.3 Effects of ramp metering

The study report written for Belgium does not include any information regarding the effects of ramp metering.

5.1.10 Deployments in Sweden

In the interior of this section, first implementation examples are given for Sweden freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.10.1 Implementations

In Sweden, there are several ramp metering implementations located in; Lahäll (E18), Klarastrandlänken – Pampaslänken and Essingeleden (Cedersund, 1995).

In Essingeleden implementation site, following components are used for system architecture of ramp metering; microwave detectors; on the mainline both on upstream and downstream, traffic lights, warning sign located on the on-ramp), inductive loops located on the on-ramp and a cabinet (Cedersund, 1995).

5.1.10.2 Algorithms

There are two algorithms present for Sweden, first one is a traffic responsive capacity based algorithm. And the second algorithm used is RWSCOR which is developed by Dutch National Road Administration (Cedersund, 1995).

Figure 5.35: Road Network, Ramp Metering Implementation adapted from (Cedersund, 1995).

5.1.10.3 Effects of Ramp Metering

Main effect of ramp metering implementation in Essingeleden can be listed under four main topics; delays, traffic safety, buses and socio-economics. When we considered the system under the frame of delay; flow on Essingeleden is improved with approximately 700 veh/h, in addition to that queues in Södra länken main tunnel is reduced.

Besides travel time within the on-ramps increased by 2-5 minutes. An additional positive effect of the system is; less congestion present at local bottlenecks. And for motorist the benefits are travel speeds improvement from 7.0 km/h to 8.00 km/h.

When the system is considered from traffic safety point; there is a slight reduction for rear end collision risk on the freeway and a significant reduction in “rat runners” within surface road network. System developed improvements for public transportation; especially for buses.

Although travel time for buses travelling along the on-ramp is increased by 3-5 minutes, on the freeway there is reduction in travel time as a result of relieved congestion.

From socio-economic point of view; travel time in Essingeleden is reduced and reached to level of 150 veh. h/day, on the other hand, travel time present on-ramp is increased to 40 veh.h/day.

Total profit of the system is greater than 2 Million Swedish Krona and total cost of the system is 5 Million Swedish Krona. As a final conclusion from economic point of view, system pays itself back in a period of 3 years time (Cedersund, 1995).

5.1.11 Deployments in New Zeland

In the interior of this section, first implementation examples are given for New Zelland freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.11.1 Implementations

One of the first ramp metering trials in New Zeland takes place in Mahunga Drive northbound on-ramp on SH20, in March 2004. Mahunga Drive on-ramp is located on the South-western Motorway; SH20 which is approximately 10 km south of Auckland's Central Business District. Figure 5.41 clearly shows the location of ramp metering implementation in New Zeland and road network.

SH20, a four laned freeway which links Manukau City and Auckland's International Airport by arterial roads located in the north of Manukau Harbour. It is expected from SH20 corridor to provide an uninterrupted freeway connection between Southern Motorway; SH 1 at Manukau City and Northwestern Motorway; SH16 near Waterview (Brown et al., 2004).

In New Zeland implementation, traffic signage equipment and software is used to operate the system. Traffic signs are used to display; "One Vehicle per Green Each Lane" as well as VMS signs informing drivers whether ramp metering is in operation or not by "Ramp Meter On, Prepare to Stop, Ramp Meter Off, Ramp Signal Off". The ramp has two lanes 3.2 m width each and lateral clearance to the barrier is; 0.3 m (Brown et al., 2004).

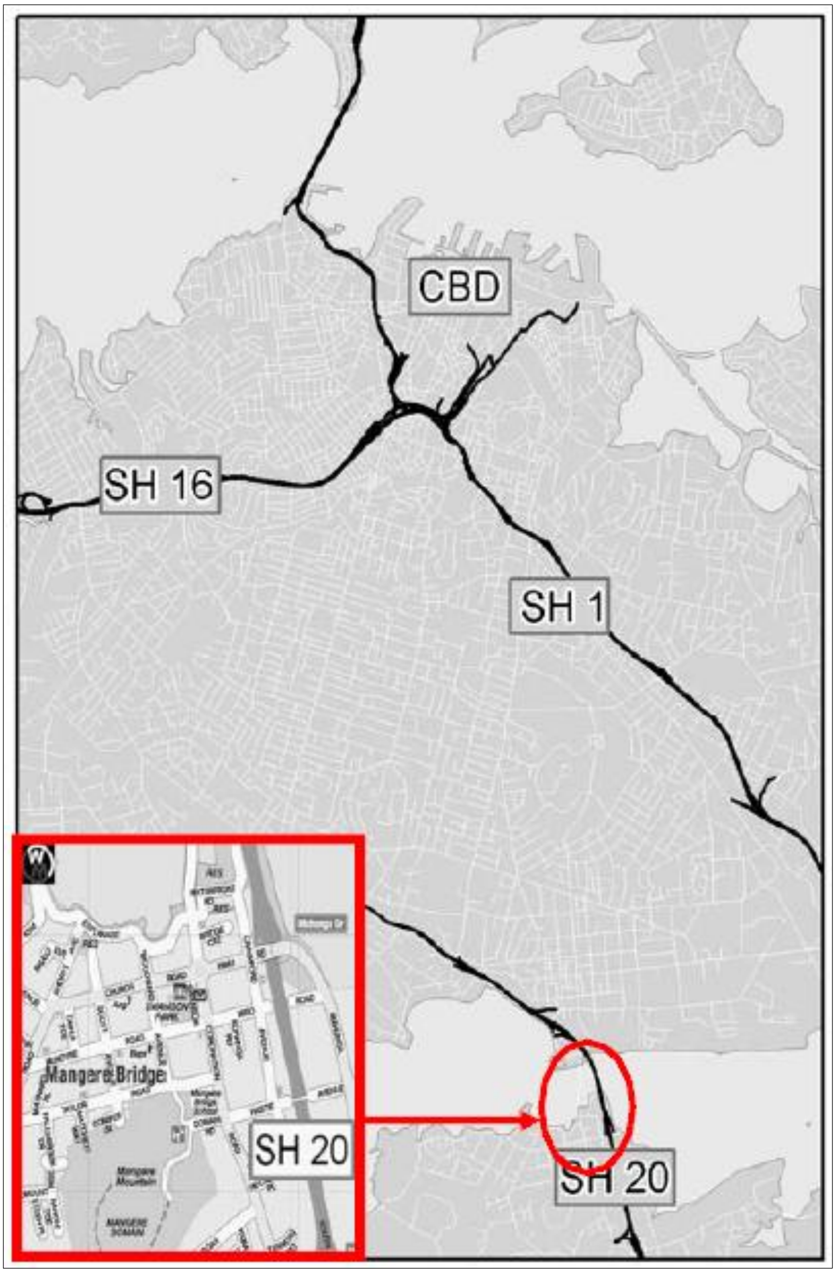


Figure 5.36: Location of Ramp Metering Site in New Zeland adapted from (Brown et al., 2004).

5.1.11.2 Algorithms

The software developed for this particular implementation is; SCATS Ramp Metering System (SRMS) which is produced by Roads and Traffic Authority, NSW (RTA).

Operation of the software need data obtained from site detectors, as a result for one ramp metering implementation, two ramp queue detectors, mainline detectors at two sites, a ramp merge detector and ramp count detector is installed.

These two variables in the case of exceeding a certain threshold level, one by one or act as a whole, system switches on the metering, and when the values go back to their normal level; below the threshold value than the metering is turned off.

Red cycle time depends on variables “a” and “b”, and yellow cycle time is 0.7 sec, green cycle time is 1.3 sec.

Cycle times are between the range of 5.5 sec to 12 sec, and within this time for a dual-lane ramp 600 vph to 1300 vph can access the freeway. And in one lane metering case, discharge of vehicles from on-ramp to freeway is 300 vph to 650 vph.

For Mahunga on-ramp arising from the exceeding demand of vehicles passing the limit of 800 vph, dual-lane ramp metering is preferred (Brown et al., 2004).

5.1.11.3 Effects of ramp metering

While assessing the system, following indicators determining adapted and achieved; increasing throughput on SH20 upstream of Mahunga Drive on-ramp; Increasing capacity at the merge area of Mahunga on-ramp and SH20; improving speeds through merge area; improving trip reliability; improving traffic flow conditions through reduced frequency and severity of flow breakdown; increasing the use of adjacent ramps, reducing “rat running” through Mangere Bridge township; and improving safety.

Assessment of the system is made with above performance indicators, by a comparison between one month before implementation and one month after implementation cases.

For further detail examination of local effects of the system, another assessment is performed six months after the implementation, a comparison between motorway speed and flow is made for 2003 and 2004.

Flow values for SH20 and Mahunga on-ramp are analyzed for 15 minutes time intervals and presented in

Figure 5.37 for morning period and in Figure 5.38 for evening period. In both cases, flow value for SH20 is reached to the capacity level which is the maximum level, additionally a there is a flow breakdown present, which reduces the capacity of Mahunga Drive on-ramp.

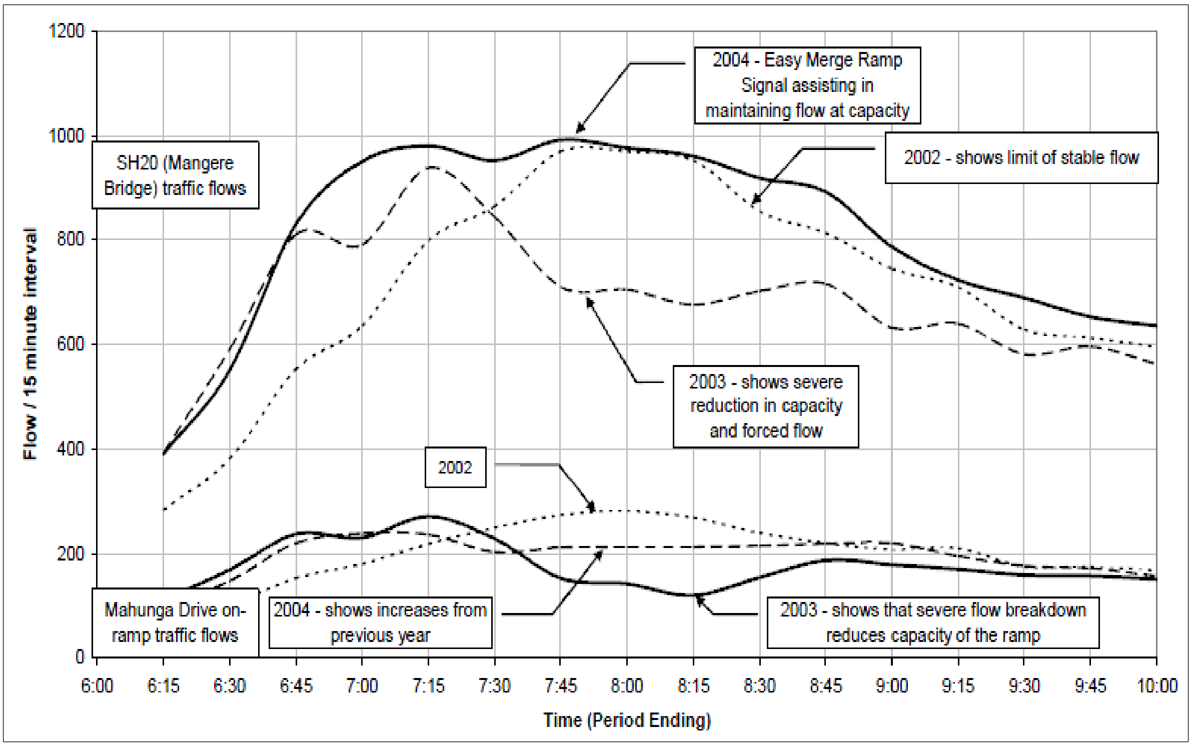


Figure 5.37: SH20 Northbound – AM Peak 15 Minute Flow Comparison (Morning Period Throughput) adapted from (Brown et al., 2004).

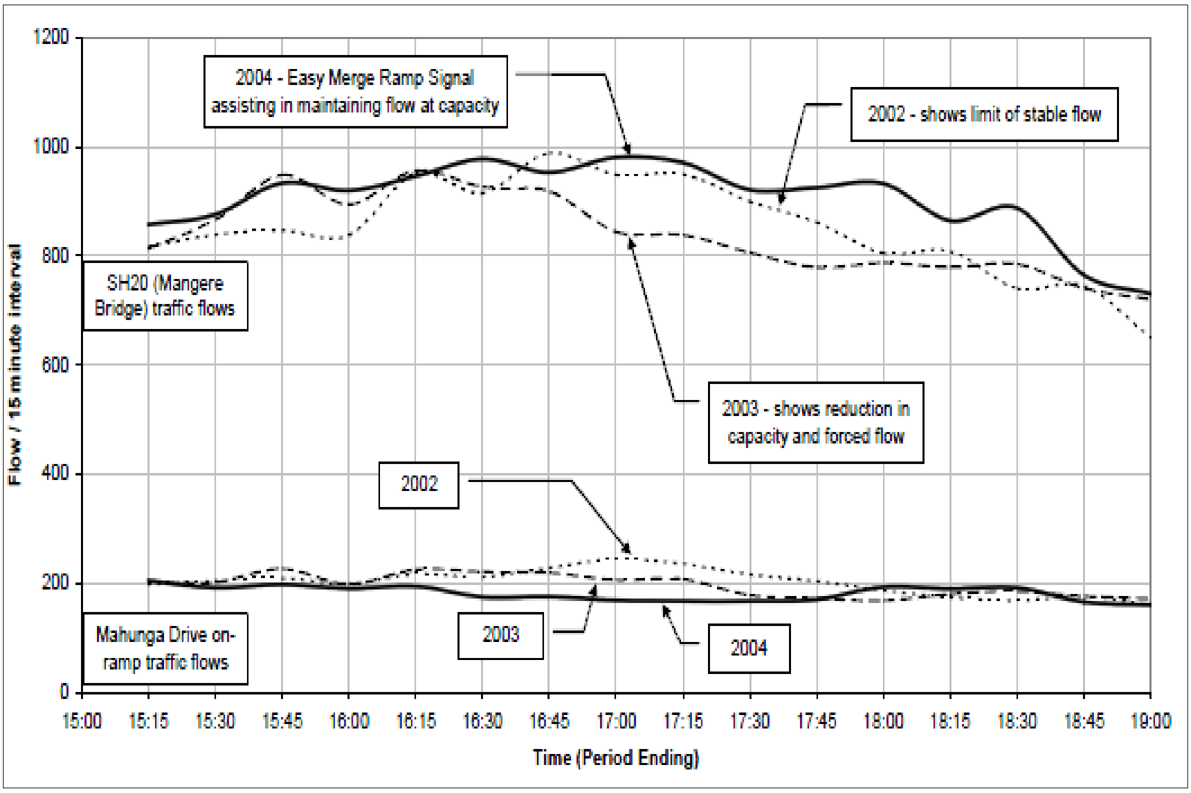


Figure 5.38: SH20 Northbound – PM Peak 15 Minute Flow Comparison (Evening Period Throughput) adapted from (Brown et al., 2004).

The study conducted to analyze effects of ramp metering implementation is made for Rimu Road / Coronation Road and Mahunga Drive. The result are shown in Figure 5.39. In the figure, average time for working days; Tuesday, Wednesday and Thursday, which queues present are beyond the specific points are shown.

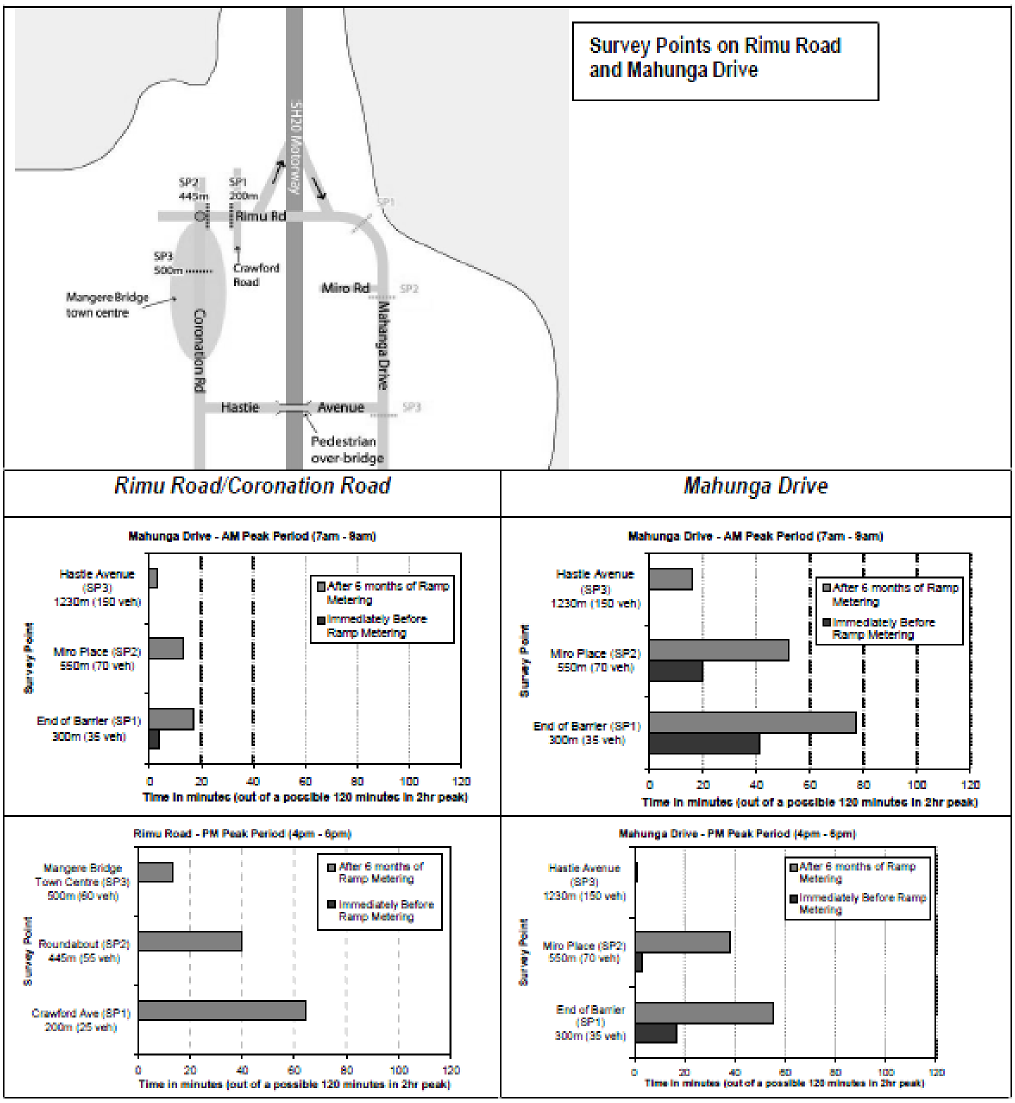


Figure 5.39: Queuing Levels Present at Two Hours Peak Periods Time adapted from (Brown et al., 2004).

Speeds are increased from 25 - 35 kph to 40 – 50 kph, this presents an increase of speed by 5kph and 15 kph when compared with the previous year (Brown et al., 2004). Impact of ramp metering implementation over local roads and other routes within the road network is assessed by calculated queue lengths. The measurements consist of, queue lengths, journey time along a queued route, change in traffic volumes at Mahunga Drive on-ramp and determining trips generated from Mangere Bridge Township and adjacent industrial sites.

To measure queue length several observations are made during predetermined workdays; Tuesday, Wednesday and Thursday, given measurements in minutes are observed within a two hour period Figure 5.39.

From the obtained field results, although queue time increased with the implementation of ramp metering, longest queue observed in not worser than observed values in the pre-installation period. Queue length is within a range of 400-500 meters, additionally in high demand conditions this value increases proportionally (Brown et al., 2004).

When assessing the system from delay aspect, it turns out to be either ramp metering is on or off, traffic conditions on the freeway determines queue length and amount of time for delay.

In Table 5.6 , the figures approve correctness of this particular statement (Brown et al., 2004). Access to Mangere Bridge for drivers moving in local road network can be managed in either with the motorway at Coronation Road or using one of local arterials and bypassing motorway with a reaccess to the motorway at Mahunga Drive on-ramp.

Table 5.6: Journey Time Present for a Queue Period at Weekdays adapted from (Brown et al., 2004).

Time Period	Rimu Road			Mahunga Drive		
	Length	Max Queued Delay	Range (based on 1 std dev)	Length	Max Queued Delay	Range (based on 1 std dev)
Morning 2 hr Period	500 m	9 min	6 -12 min	300	5 min	4 -7 min
Evening Peak Period	200 m	4 min	3 -5 min	550	10 min	8 - 13 min

After the implementation use of Coronation Road on-ramp is increased while a decrease is present in drivers using local neighborhood and shopping area to reach Mahunga Drive on-ramp.

In approximate values the reduction present on Mahunga Drive is 60 %. In Table 5.7 the observed values concerning traffic volume changes at Mahunga Drive and Coronation Road on-ramps is presented (Brown et al., 2004).

Table 5.7: The Changes in Traffic Volumes Present at the Mahunga Drive and Coronation Road On-Ramps adapted from (Brown et al., 2004).

	Morning Peak Period (2hr)			Evening Peak Period (2hr)		
	Sept 2003	After Six Months	Diff	Sept 2003	After Six Months	Diff
Mahunga Drive on-ramp	2,100	1,500	-600	1750	1450	-300
Coronation Road on-ramp	800	1,350	550	950	1250	350

In order to determine the proportion of traffic destruction on the road network, a number plate survey is conducted on Rimu Road / Coronation Road; western side of SH20 and Mahunga Drive; eastern side see Figure 5.40. Results reveal out the improvement of traffic flow generated by drivers using Coronation Road on-ramp rather than Mahunga Drive. However, this is changing on the eastern side, drivers choose local arterials rather using freeway, and in this case they prefer using Mahunga Drive. One last benefit of the system can be additionally highlighted as safety, before ramp metering implementation, there are approximately 50 accidents related with congestion; 10 injury accidents in the past 4 years. 33 of these accidents are occurred on the motorway and 17 were on local road network. Since the implementation of ramp metering system, only 13 accidents occurred, 11 took place on the motorway and only 2 of them resulted in injuries (Brown et al., 2004).

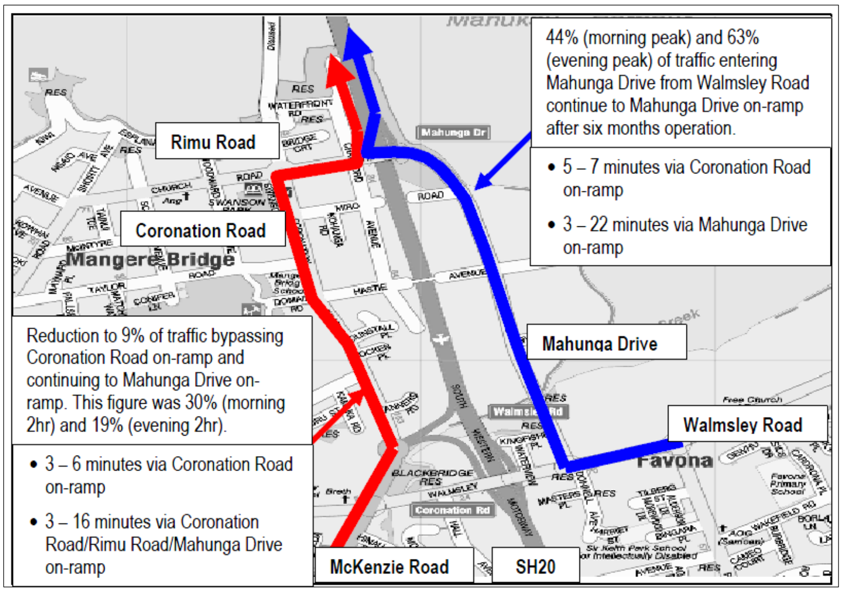


Figure 5.40: Comparative Travel Times and Strategic Traffic Levels on Local Roads adapted from (Brown et al., 2004).

5.1.12 Deployments in Switzerland

In the interior of this section, first the implementation examples is given for Switzerland freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

5.1.12.1 Implementations

In Switzerland, Lausanne by pass motorway traffic generally need an overall improvement and during peak hours traffic conditions are at saturation levels. Arising from this need, the foundations of PAPABILES project is formed.

In the first phase of PAPABILES project, approaches based on methodology according to their relevancy and simulation tools that are possible to implement are considered starting from modelling stage to evaluation and output values. The study conducted is applied for one section of the motorway and at peak hours, which means a restriction in both space and time. In the second phase, output values of the first phase are considered.

The first phase of PAPABILES reveals out that, problem faced between Morges West junction and Ecublens interchange, specifically at the Morges East junction cannot be solved by variable speed signs. As a result, two implementation suggestions are offered; between Morges East junction and Ecublens interchange constructing a 3rd lane and ramp metering implementation at the Morgest East junction (Torday et al., 2002).

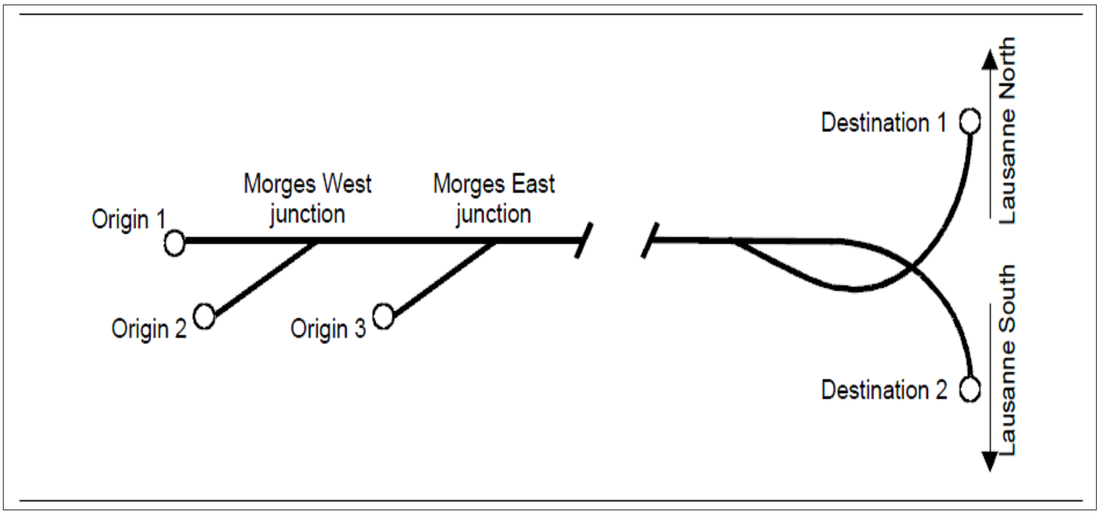


Figure 5.41: Studied Network Showing Entry Points; Origins and Exit Points; Destinations adapted from (Torday et al., 2002).

5.1.12.2 Algorithms

Real time measurements from motorway are used as input value to the algorithm. In order to avoid congestion, restriction to on-ramp flow is done, considering the value not exceeding capacity. ALINEA algorithm is used in Switzerland ramp metering implementation. Number of vehicles allowed to enter the freeway section from the on-ramp is; 2 vehicles per green time. Algorithm measurement step is; 30 seconds. Occupation factor used in ALINEA equations is; 55 % (Torday et al., 2002).

5.1.12.3 Effects of ramp metering

For different scenarios, traffic is raised between the range of 5 % and 40%. The scenarios differ from each other in number of vehicles only. In accordance with traffic level increase, scenarios are named as; OD standard matrix, OD05; standard matrix + 5%, OD10, OD15, OD20, OD25, OD30, OD35, OD40 (Torday et al., 2002). Effects of ramp metering implementation results are obtained for two cases; current and the modified networks. For each OD matrice, calculations made for ten replications.

Travel time gainings under the exitance of a ramp metering implementation is shown in Table 5.8. Global time found in the table stands for; average travel time of the vehicles left the network between 07:00 – 08:00.

Origin of these vehicles are not taken into account. And travel time from origin 3, is the average travel time of the vehicles directly affected by ramp metering. As the vehicles effected by ramp metering implementation, there is a reduction in travel time present arising from vehicles given access to the freeway in a controlled manner.

Table 5.8: Travel Time Gaining in Current, Ramp Metering Case and the Gain in Travel Time adapted from (Torday et al., 2002).

	Standard OD			OD10			OD20		
	Current	With Ramp Metering	Gain	Current	With Ramp Metering	Gain	Current	With Ramp Metering	Gain
Global Travel Time (sec)	279.2	279.2	0.1	333.1	317.3	15.8	414.4	380.3	34.1
Travel time from origin 3 (Morges East) (sec)	223.4	225.4	-2	236.8	254.4	-17,6	237.3	283.9	-46,5

Table 5.9: Travel Time Gaining in Current, Ramp Metering Case and the Gain in Travel Time under Accident Conditions adapted from (Torday et al., 2002).

	Standard OD			OD10			OD20		
	Current	With Ramp Metering	Gain	Current	With Ramp Metering	Gain	Current	With Ramp Metering	Gain
Global Travel Time (sec)	381.4	343.4	38.0	463.8	432.5	31.3	521.2	487.7	23,6
Travel time from origin 3 (Morges East) (sec)	247.1	278.7	-31,6	250.6	299.8	-49,2	252.1	278.7	-26,6

5.1.13 Deployments in South Africa

In the interior of this section, first the implementation examples is given for South Africa freeways and following this section, design concepts under the light of system necessities, algorithms and effect of each implementation is explained briefly.

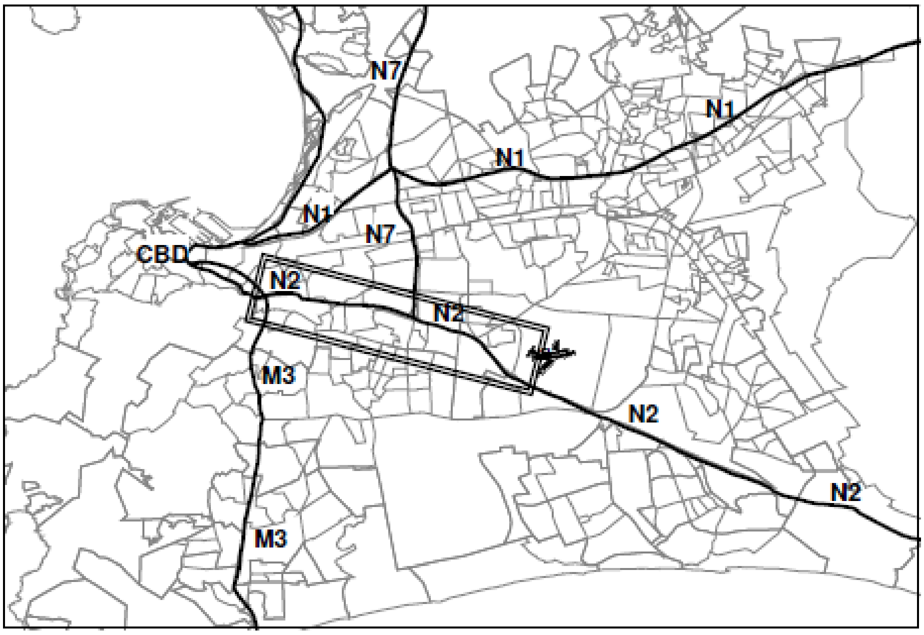


Figure 5.42: Cape Town Road Network adapted from (Vanderschuren, 2006).

5.1.13.1 Implementations

Ramp metering implementation location in South Africa is selected as Ben Schoeman Highway, due to congestion reaching to severe levels.

The network that ramp metering implementation considered, is between Braktontein and Buccleugh interchange in the direction from Tshwane to Johannesburg.

Length of the corridor is 25.5 kilometer, having several interchanges. Shortest distance between on and off ramp is 1.5 kilometers and the longest distance is 3 kilometers. BSH is a three lane highway and the maximum measured volume is 6600 – 2200 veh/h/lane.

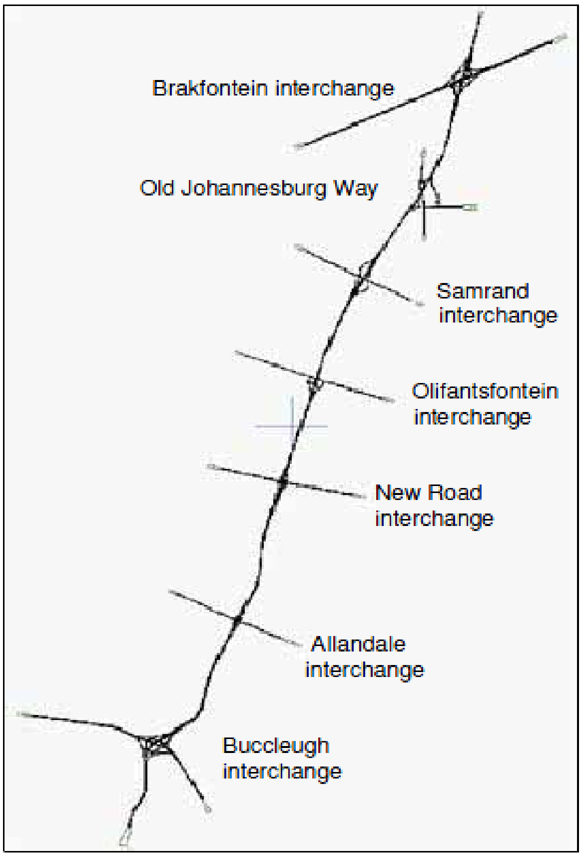


Figure 5.43: Ben Schoeman Highway adapted from (Vanderschuren, 2006).

Another corridor is selected for ramp metering which is N2. Considered ramp metering implementation for N2 is in the direction of Cape Town, from the International Airport to Hospital Bend during morning peak period. N2 is a 9.8 kilometer corridor, on and off ramps within the corridor are mainly close to each other (Vanderschuren, 2006).

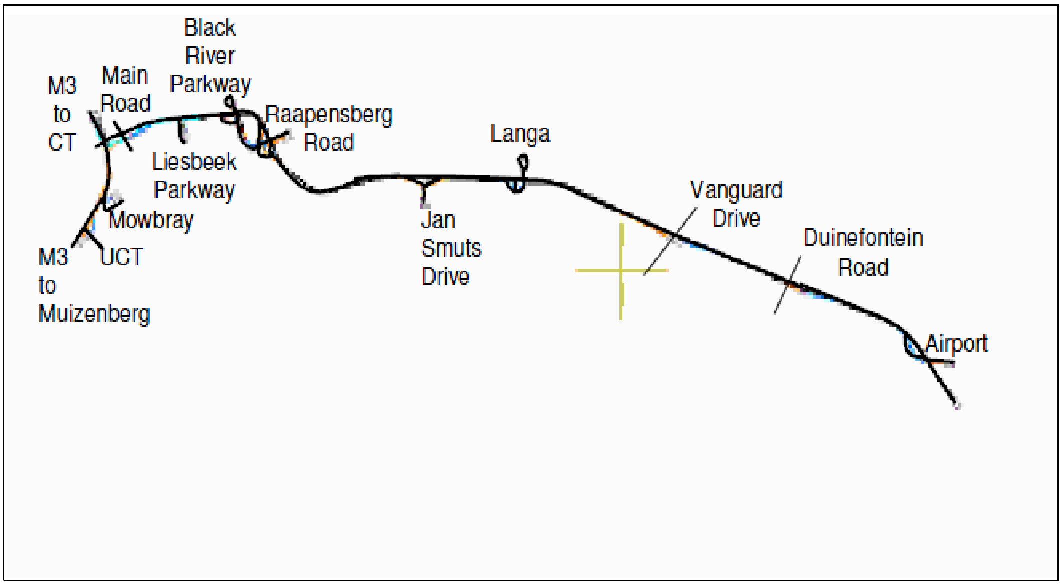


Figure 5.44: N2 corridor in Cape Town adapted from (Vanderschuren, 2006).

5.1.13.2 Algorithms

An algorithm is used based on the scenario formed by the developers of ALINEA algorithm. For this case, if the loops located on the highway section are occupied with a value of 25 % of time, then traffic lights are adjusted to turn on red for seven percent of time.

And in Netherlands, where ALINEA algorithm is used, the value is 18%. If we to consider the factors influencing occupany rates, then we can mainly name them as; local situation and length of the loops (Vanderschuren, 2006).

5.1.13.3 Effects of ramp metering

For Ben Schoeman Highway, throughput increase is between 2.2% and 8.5%. On the contrary, travel times remained unchanged. It has been detected that, accident occurance decreased alongwith an improvement on safety issues.

And for N2 corridor, arising from high demand, vehicles are not obeyed the rules while entering the freeway from the on-ramp. So, no improvement is present.

Traffic Volumes obtained from scenario implementations are presented in Table 5.10. The improvement of traffic volumes during peak periods on Ben Schoeman Highway is clearly stated in the table. And for N2 corridor, the figures are showing no positive improvement is present (Vanderschuren, 2006).

Table 5.10: Traffic Volumes Obtained for Ramp Metering Scenarios adapted from (Vanderschuren, 2006).

Scenario	Ben Schoeman Highway				N2 Near Cape Town			
	Peak Period (05:00 - 09:30)		Peak Hour (06:20 - 07:20)		Peak Period (06:00 - 10:00)		Peak Hour (06:30 - 07:30)	
	Abs	%	Abs	%	Abs	%	Abs	%
Measured Traffic Volume	17437		6200		15190		5048	
Base Case	17788	100	5412	100	15299	100	5011	100
Ramp Metering	18185	2,2	5874	8,5	14543	-5	4573	-8,8

5.2 Comparative Analysis of Existing Deployments

Ramp Metering Deployments existing in countries throughout the World is explained in the previous subtitle within Section 5. Existing ramp metering deployments are analyzed according to selected performance criteria. Criteria affecting ramp metering implementations include; travel time, speed, capacity utilization, environmental impacts and user satisfaction. Each ramp metering deployment on that particular country is evaluated according to these criteria and their success levels are examined in detail. Mainly all deployments lead to good results considering the performance criteria.

In Michigan, ramp metering implementation resulted in a volume increase by 8 % from 5600 veh/h to 6400 veh/h. From these recorded values a conclusion can be drawn as; with the increased volume that a particular road provides mean travel time reductions, increased speed and user satisfaction can be achieved by drivers. Directly proportional with these criteria, reduced travel time means less fuel consumption, resulting in a benefit from environmental side. Also, accidents are reduced by 50%, leading to safety improvements. Overall the implementation in Michigan is found to be convenient system as a result of benefits obtained from each criterion. In Long Island, travel time is decreased by 20% with a value of 26 minutes to 21 minutes resulting in an improvement on travel time. Additionally, average speed is increased by 13.1 %, from 23 to 28 mile/h, this result in an improvement on speed.

And when the system is analyzed from environmental impact criteria, fuel consumption reduction percentage is 6.7 %, additionally Green House Gases (GHG) is present. This result shows improvement of the system under environmental impact criteria. Also, there are additional improvements present for Long Island, which are presented under INFORM project in 1991. Mainline speed increase is 9%, from 40 mile/h to 44 mile/h and in the bottleneck sections from 33 to 52 mile/h and from 33 to 55 mile/h, having a percentage increase of 36% and 40 % respectively. From the studies performed, only the positive effect of one criterion, speed is given under the results of the INFORM project.

In Portland, Oregon, from the measurements obtained within northbound direction, afternoon peak speed increased from 16 mile/h to 41 mile/h and travel time reduced from 23 minutes to 9 minutes. In southbound direction, in the morning peak average speed is increased from 40 to 43 mile/h. An overall speed increase in Portland, Oregon shows that this implementation evaluation is made under travel time and speed resulting in a positive improvement.

In Minneapolis, St. Paul, Minnesota, peak hour speed is increased from 37 to 43 mph by 16 %. Peak hour volume is increased by 24 % and accidents occur in peak hour decreased by 38%. As a result, the improvement is present under criteria of speed and cause quality and safety. In Seattle, Washington, mainline volume increase is present in northbound and southbound, 86 % and 62 % respectively. Additionally, travel time reduction is also present which is reduced from 22 to 11.5 minutes. Accident rate is reduced by 39 %. As a result, improvements under speed, travel time and capacity utilization are approved by the field results obtained. In Denver, Colorado, speed increase present is by 57% and travel time reduction is by 37%, additionally accidents are reduced by 5%. Speed, travel time and capacity utilization criteria face improvements, when we consider the results obtained. In Austin, Texas, volume increased by 7.9 %, average peak period speeds increased by 60%. Mainly the increased speeds lead to improvement under speed criterion. In San Diego, mainline volume is increase from 2200 veh/h to 2400 veh/h. Capacity utilization is present for San Diego.

In England, in M1 freeway, junction 33, travel time is improved by 9.1 % and with the presence of ITM, travel time improvement present is 14.7 %. For local network travel time savings are improved by 8.7%, with the presence of ITM it increases up to 9.8% during evening peak hour. For M6 freeway, J10 and J9 ramps, travel time during peak hour period is shortened by 15 minutes, and an additional 600 vehicles start using freeway after the implementation. Though there is an increase present about 14 % on some days, rest of the days speed levels reflect no sign of improvement. Results show that ramp metering implementation for M6, M11 and M42 lead to improvement in travel time criterion.

In Scotland, for M8 and A720 models, improvement of traffic is present for both cases and this improvement can indirectly effect, travel time, speed and other evaluation criterion.

In France, for SIER site speed increase is by 3% and travel time reduction reduction is by 18%, this results in an improvement on speed and travel time criteria consecutively.

In Germany, on A40 congestion level is decreased by 50% and accidents are reduced by 40% lead to an improvement on safety. Additionally, speeds are increased by 10 km/h, as a result also an improvement under the speed criteria is also present. There are no significant effects present in the NRW region. For A94, traffic is stabilized and congestion is either prevented or postponed, as a result of an overall system improvement.

In Japan, when field results obtained from ramp metering implementation are considered, travel time reduction and congestion volume decrease is present, additionally average speed is increased. Therefore the system is improved under travel time and speed criteria.

In Netherlands, the following sites are evaluated; Coentunnel, A10-West, Delft-Zuid, Zoetermeer, Schiedam-Noord, Barendrecht, Kolkweg, Vianen, Muiden and Muiderslot, Vinkeveen, RWS-DUT. In Coentunnel S101, speed increase present is 30 km/h. Red violation existence by 5-6 %. Therefore, for Coetunnel improvement on speed and capacity utilization is present. In A10-West, speed increase is by 20 km/h, there is no travel time change or red light violation improvement. Improvement for A10- West is present only for speed criteria.

In Delft-Zuid, 1st assessment, there is no change present on travel time, on the other hand red violation occurrance is 15 %, so the improvement occurs under capacity utilization criteria as well. In Delft-Zuid, 2nd assessment, there is no speed and travel time change present, on the other hand the occurence of red violation is 15 %, therefore we can assume the improvement is present under safety issues, same with the 1st assessment. In Zoetermeer, no change is present in speed on the freeway section. Travel time is reduced by 6 % and red violation occurence is 13 %, therefore the improvement is on time and safety criteria. In Schiedam-Noord, the speed increased by 20 km/h, travel time is decreased by 6% and red light violation occurence is 3%. Improvement is present under speed, travel time and capacity utilization criterion. In Barendrecht, speed is increased 20 km/h, travel time reduction is by 10 % and red violation occurence is 2%. The improvement on speed and travel time criteria is present. In Kolkweg, speed is increased by 4 km/h, travel time on the freeway decreased by 3 %. In Vianen speed is increased by 5 km/h and red light violation occurence is 5 %. In Muiden and Muiderslot, red violation occurence for Muiden and Muiderslot section is between 6-7 %. Only improvement on capacity utilization is present. In Vinkeveen, speed is increased by 10 km/h and travel time on the freeway increased by 5 minutes time interval. 2%. The improvements in all implementations in Netherland are on the speed and travel time criteria are present. The RWS-DUT, speed is increased and less accident occurence is present. Speed and safety criteria improvements are present for RWS-DUT.

In Sweden, traffic flow is improved by 700 veh/h, travel time is increased by 2-5 minutes and travel speed is increased from 7 km/h to 8 km/h. Though travel time for buses on the on-ramp is increased by 3-5 minutes, travel time reduction on the freeway is present. Therefore, the improvement on travel time and speed criteria present.

In New Zeland, flow increase is present within the range of 3%-26%, additionally speed increase by 5 km/h and 15 km/h and accident reduction are present. Therefore in New Zeland, the improvements on speed and capacity utilization are present.

In Switzerland, travel time gain is present for Standard OD, OD10 and OD20 as; 0.1, 15.8 and 34.1 seconds consecutively. Under accident occurrence case, the travel time gainings are 38.0, 31.3 and 23.6. As a result the improvement in Switzerland, is present on travel time gainings. In South Africa, for Ben Schoeman Highway, traffic volume increase is present with 2,2 % and 8,5 for peak period and peak hour consecutively. On the contrary, for N2 corridor near Cape Town, traffic flow decrease is present with -5 % and -8.8 %.

Table 5.11: Comparison of different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering					
						Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
1	**US** Detroit, Michigan	NA	NA	NA	NA	Reduction	Increased	*Volume Increase by 8%; from 5600 veh/h to 6400 veh/h.	*Reduction of 50% in total number of accidents. *Reduction of 70 % in the accidents resulted in injuries.	NA	Excellent
	Long Island, NY	NA	NA	NA	NA	*Decrease by 20 %; from 26 minutes to 21 minutes	*Mainline speed increased by 13.1 %; from 23 mph to 28 mph. *INFORM Project; increased by 9%; from 40 mph to 44mph. *For bottleneck sections; 33 to 52 mph and 33 to 55 mph.	NA	NA	Reduction in Fuel Consumption (6.7%) and Emission Levels (13.1%).	Excellent

Table 5.11 (continued): Comparison of different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering: Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
1	Portland, Oregon	NA	NA	NA	NA	*Reduction from 23 minutes to 9 minutes	*Southbound direction; average speed increase from 40 mph to 43 mph	NA	*Peak period accident reduced by 43%	NA	Excellent
	Minneapolis, St. Paul, Minnesota	16 CCTV cameras, 5 VMS (DMS), 380 vehicle detectors	NA	Zone Algorithm	24 seconds	NA	*Peak hour speed increase by; 16% from 37 mph to 43 mph	*Peak volume increase by 24 %	*Reduction in peak hour accidents by 38%	NA	Excellent
	Seattle, Washington	NA	NA	Bottleneck Algorithm Fuzzy Logic Algorithm	NA	*Travel time reduced from 22 minutes to 11.5 minutes	NA	*Mainline volume in northbound increased by 86% * Mainline volume in southbound increased by 62%	Reduction	NA	Excellent
	Denver, Colorado	NA	NA	Helper Algorithm		*Travel time reduction by 37%	*Speed increase by 57%. *Speed increase is from 43 mph to 53 mph	*Volume increase from 6200 vph to 7350 vph	*Sideswipe accident incidence reduced by 5%	NA	Moderate

Table 5.11 (continued): Comparison of different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering					
						Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
1	Austin, Texas	NA	NA	NA	NA	NA	*Peak period speeds in the mainline increased by 60%	*Vehicle number increase by 7.9%	NA	NA	NA
	San Diego, California			Linked-ramp Algorithm	NA	NA	NA	* Volumes on the mainline increased from 2200 vph to 2400 vph	NA	NA	NA
2	**England**	Inductive Loop Detectors, Local Outstations, CCTV Cameras, Fixed Advanced Warning Signs, Slip Road Traffic Sensors, Signal Heads, Upstream and Downstream Detectors, Fixed Advanced Warning Signs	Red stop light and Police Officers	ALINEA and Demand Capacity Method	Red Time: 2 seconds Amber Time: 0.5 second	*In M1 freeway, travel time savings is improved about 9.1%	*Speed increase by 14%, on M6 freeway	*On M6, additional 600 vehicle start using the freeway	NA	NA	NA

Table 5.11 (continued): Comparison of different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering					
						Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
5	**Scotland**	Traffic Signals, Occupancy Loop Detector, VMS signage	NA	ALINEA	Amber Time: 3 seconds Flashing Amber Time: 6 seconds (min) Red Time: Depends upon the traffic conditions Maximum Cycle Time: 12 seconds	*Travel time improvement is 18%	* Mean speed is increased by 3%	NA	NA	NA	NA
6	**Israel**	Loop Detectors, CCTV, Lane Control Signals (LCS), Variable Text Signs (VTS), Traffic Control Center, Information Dissemination	NA	ALINEA	NA	NA	NA	NA	NA	NA	NA

Table 5.11 (continued): Comparison of different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering					
						Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
5	**France**	Inductive Loops, Traffic Lights, Video Cameras,Emergency Phones, VMS, police	NA	ALINEA	Amber Time: 3 seconds, Flashing Amber Time: 6 seconds	*Travel time reduction is by17%	*Mean speed increased by 3%	NA	NA	NA	NA
6	**Germany**	Inductive Loops	NA	ALINEA	Red Time: 2-3 seconds Red / Amber Time: 1 second Green Time: 0-16 seconds Amber Time: 1 second Total Cycle Time: 4 - 20 seconds	Reduced	* For A40; during peak hours, speed increase by 10 km / h is present	Increased	*For A40 ; reduction is by 40%	NA	Moderate
7	**Japan**	Simulation Tool	NA	HEROINE	NA	Reduced	Increased	Increased	NA	NA	NA
8	**Netherlands**	Inductive Loops Traffic Signs Traffic Lights	Red Light Cameras, Red Violation 50 Euro	RWS Strategy, ALINEA and a FUZZY Logic Based Algorithm	Red Time: 2 seconds Amber Time: 0.5 seconds Green Time: 2 seconds Total Cycle time: 4,5 - 15 seconds	Reduced	Increased	Increased	NA	NA	Excellent

Table 5.11 (continued): Comparison of Different Deployments throughout the World.

No	Country	System Architecture	Enforcement	Algorithm	Cycle Time	Effects of Ramp Metering					
						Travel Time	Speed	Capacity Utilization	Accident	Environmental Impacts	User Satisfaction
9	**Belgium**	Video Cameras, Loops, Traffic Light	NA	ALINEA	Red Time: 2 seconds Amber Time: 1-2 seconds Green Time: 1-2 seconds Total Cycle Time: 4 seconds	NA	NA	NA	NA	NA	NA
10	**Sweden**	Microwave Detectors, Traffic Lights, Warning Sign, Inductive Loops, Cabinet	NA	Capacity Based Algorithm, RWSCOR	Yellow-Green time max 2 seconds	NA	*Increased by 7 km/h to 8 km/h	*Flow increased by 700 veh / h	NA	NA	NA
11	**New Zelands**	Traffic Signage Equipment, Software, VMS signs	NA	SCAT Ramp Metering System (SRMS)	Total Cycle time 5.5 sec to 12 sec	Reduced	Increased	Increased	Decreased	NA	NA
12	**Switzerland**	NA	NA	ALINEA	NA	Reduced	NA	NA	NA	NA	NA
13	**South Africa**	NA	NA	A system similar to ALINEA	NA	* Ben Schoeman; 0 and for N2; +10	* Ben Schoeman; + 5.7 and for N2; - 8.8	NA	Reduction	NA	NA

5.3 Deployment Suggestion for Istanbul

In this study, evaluations are made considering sustainable transport as the main leading factor for regulating congested traffic and for using available sources. To obtain sustainability we choose one of the intelligent transportation systems; ramp metering. Under the context of this section, ramp metering implementation for Istanbul road network is suggested.

İstanbul is a highly developed metropolitan when it comes to transportation facilities, despite the fact that deficiencies in transportation planning and management detected in a high proportion of the city. Main veins for the circulation of traffic is provided by freeways; O3 E80 Europe Freeway, O1 İstanbul Ring Road, O4 Anatolian Freeway and D100. Due to lack of some intelligent transportation system applications on freeways, regulation of traffic flow cannot be made efficiently, especially at peak hours and results in extreme traffic congestion in a recurrent level.

Ramp metering architecture components used for other deployments can also be assumed as valid for Istanbul. Mainline detectors located on upstream and downstream, demand sensor, queue sensor, merging sensor for on-ramp, and CCTV to strategic points should be implemented due to present recurrent and high level congestion. Also, additional precautions have to be taken for enforcement requirements, such as cameras and police officers for feedback support.

6. CONCLUSIONS AND FUTURE DIRECTIONS

Assessing a particular transportation system can be ideally made with the assistance of transportation performance criteria. The so-called transportation performance criteria are; time, speed, cost, reliability, safety, comfort (LOS), environmental impacts, energy and convenience. In Section 5.2, all deployment examples are assessed under these criteria and suggestion for Istanbul is made in section 5.3. In Section 6, general conclusion and future directions for ramp metering deployments are presented.

The installation of ramp metering should be considered for the following locations; if the freeway limiting drivers within a speed range of 0-30 mile/h, low traffic volumes per lane, LOS level ranging between E and F and in the presence of a stop-and-go-traffic. And, if the number of accidents present on the on-ramp weaving areas at serious levels. Another reason can be listed as the merging problems faced at freeway on-ramps which are considerably affecting flow conditions. A final reason for implementing a ramp metering system can be present, under the frame of a freeway management system determined by authorities, if the traffic flow present on the on ramp is at capacity. After briefly outlining the objectives leading the implementation of a ramp metering system, then one should emphasize the benefits and disbenefits.

First positive feedback of the system is the speed increase. Speed increases occurred on freeway mainline can be listed as the first beneficiary effect. Proportional with speed increase, a reduction in travel time with the existence of the implementation is present. As a consequence decrease in travel time results in reduction of delays on freeway mainline and for the overall trip.

Increase in freeway capacity and throughput is present. Also reduction in accidents leads to improvements in safety. One of the most important and lead benefit of ramp metering implementation is the reduction in congestion, recurrent congestion levels.

Reduction of accidents lead to financial gaining from indirect sources, additionally the system reduces congestion and cost that congestion exerts reduces as well, as a result system is improved economically. Reduced congestion levels, means less traffic and less fuel consumed, this can either be accepted as an improvement from economic and environmental side. After these explanations, one can name ramp metering implementation as a cost-effective system. And the final benefit of ramp metering system is as a result of fuel and emission reduction, air quality improvement is also present, so all in all this system is an environmental friendly system.

After briefly explaining benefits of ramp metering, disbenefits are also considered in the following lines. One disbenefit of the system is spillback of traffic onto surface roads arising from increase of queue and ramp delay present on the on-ramp. Presence of a ramp delay on the on ramp is also another negative impact. Additionally, traffic diversion from the implementation site to other alternative routes is also present, which results in demand levels exceeding capacity for roads preffered by users as an alternative. When system is evaluated under cost frame, ramp metering implementation has high installation, maintenance and enforcement costs on the other hand, system has the ability to pay itself back in 3-5 years time depending on the conditions present. And the final negative effect is increased emission and fuel consumption levels present on the on-ramp, on the contrary these levels are reduced on freeway mainline.

Technological improvements also lead improvements in traffic management, like using ITS. Main expected objectives from a particular traffic management system is to provide, time reduction, speed increase, increase of safety, LOS increase under the safety issue, environmentally and energy efficient systems. Positive effects of ramp metering implementation have been observed since its deployment in 1960’s.

In this dissertation, evaluation of ramp metering implementation is made considering different strategies in various countries.

In US, improvement is mainly concentrated on travel reduction, speed increase and capacity utilization. In England, performance criteria improvement is present for travel time. In Scotland, no significant improvements are presented under the performance criteria.

In France, improvements present in speed with an increase and travel time reduction. In Germany, travel time, speed, safety, reliability criteria show improvements. In Japan, travel time and speed improvement are present. In Netherlands, improvements in travel time and speed criteria are also present. In Sweden, under performance criteria, speed increase has been highlighted. In New Zeland, improvements on travel time and speed criteria are present. In Switzerland, travel time gaining is present. Finally for South Africa traffic volume increase is present.

In Switzerland, travel time gain is present for Standard OD, OD10 and OD20 as; 0.1, 15.8 and 34.1 seconds consecutively. Under accident occurrence case, the travel time gainings are 38.0, 31.3 and 23.6. As a result the improvement in Switzerland, is present on travel time gainings.

In South Africa, for Ben Schoeman Highway, traffic volume increase is present with 2,2 % and 8,5 for peak period and peak hour consecutively. On the contrary, for N2 corridor near Cape Town, traffic flow decrease is present with -5 % and -8.8 %.

To sum up all, main improvements present for ramp metering implementation for the above listed countries are mainly concentrated on speed and travel time. Key objective of a ramp metering implementation is to relieve congestion which leads to reduction in travel time and speed increase. With this respect, it can be concluded that each implementation succeeded.

Following the explanations briefly made about advantages and disadvantages of ramp metering. We can come to a conclusion that in case of ramp metering implementation deployed in Istanbul, system benefits are higher compared to the disbenefits.

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