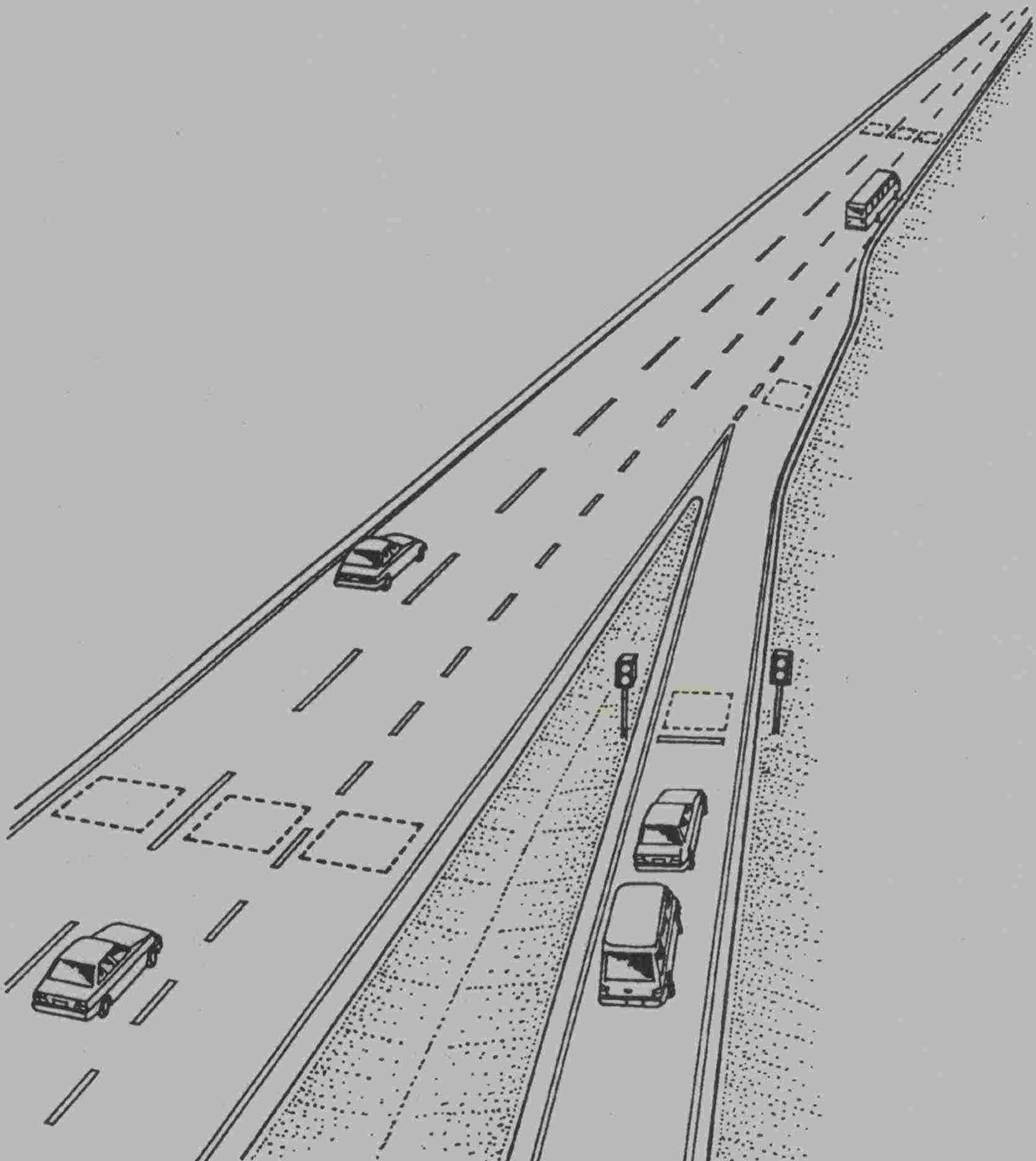
Ramp Metering Review



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ABSTRACT

This report opens with a general discussion on the subject of Motorway Traffic Management Systems and the components from which they are developed. The report then focuses specifically on the concept of ramp metering, which is a single aspect of over all Motorway Traffic Management Systems. The third section of this report reviews the costs and benefits of ramp metering and provides a two of case studies on the cost of implementing initial ramp metering systems. The last section of the report offers a set of recommendations which are intended as guide lines for Finland in regard to the possible use of ramp metering to manage recurring congestion which is appearing in some areas.

The basic idea embodied in traffic management is to achieve optimum utilization of existing roadway capacity. For motorways there are a number of traffic management tools which have proven effective for influencing traffic in a positive way. These tools include ramp metering, changeable message signs, highway advisory radio, high occupancy vehicle considerations, closed circuit television, incident management plans, and others.

These tools can be used individually or in combination with one another to more efficiently utilize motorway capacity and/or control traffic demand on a facility. The documented benefits include reduced travel times for drivers, smoother traffic flow, more efficient use of capacity, and reduced accident rates. On the other hand there are potential disbenefits as well; They include limited delay to drivers entering the motorway system, system costs political controversy, and possibility of non-compliance by drivers.

Ramp metering is one of the most widely used traffic management tools primarily because of the positive benefits that have been repeatedly documented from its use. Simply stated, ramp metering is the application of standard traffic signals at specified freeway entrance ramps for the purpose of controlling, or metering, the rate at which vehicle are supplied to the motorway. This method has proven cost effective in terms of reducing travel times, driver delays, and accident rates caused by congestion. The cases documented in this report include Britain's first ramp metering scheme on the M6 motorway in Birmingham, and the original system implemented in Minneapolis, Minnesota U.S.A.

In Finland, traffic congestion has become fairly common at several locations around the Helsinki metro area. Those areas include Pasila, an area north of the Helsinki CBD where several main motorways converg on the city street network. And Länsiväylä, which is a radial motorway to the west. Planning for the Pasila area includes a wide range of traffic management considerations. This planning appears adequate in relative to the current stage of project development.

Prior to Pasilanväylä it would be prudent to develop practical experience with traffic management concepts and equipment by first implementing a smaller scale system. Länsiväylä provides an excellent opportunity for such a system. Traffic monitoring could be up graded and ramp metering could be implemented, on a limited basis, to improve existing congestion conditions. In this way real benefits can be achieved on portions the road network while developing experience and expertise which can accommodate and maintain the larger system planned for Pasilanväylä.

PREFACE

This paper has been written as a review of ramp metering and its role in connection with motorway traffic management. The review is based on current literature about ramp metering and the practice used in existing systems in Europe and the United States. It is important to acknowledge that the study of traffic control and traffic flow theory continues to advance through research and experiment. Rather than being a review of future possibilities, the scope of this paper focuses on the current experience of practical application.

Various methods of motorway traffic management have been in use for over thirty years and one of the most widely used tools is ramp metering. This paper pursues the state-of-the-art of ramp metering and takes a look at the principles, applications, and components currently in use with respect to ramp metering in the field of motorway traffic management.

After a brief introduction of motorway traffic management the paper proceeds to give a conceptual overview of ramp metering elements and its associated components. The next section discusses effects of ramp metering from the perspective of operational efficiency and cost/benefits. The paper concludes with recommendations for the potential use of ramp metering Finland.

This report has been commissioned by the Finnish National Road Administration. The practical work of performing the literature search and writing the report was carried out by Randall Pearson, senior engineer and Ralf Granlund, principle engineer, both from Viatek Tapiola Ltd. in Finland. On behalf of the Finnish National Road Administration the work was supervised by Esko Hyytiäinen, M.Sc. (Civil Eng.) and Ari Liimatainen M.Sc. (Civil Eng.)

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SECTION 1 - MOTORWAY TRAFFIC MANAGEMENT

1.1 Introduction to motorway traffic management

Urban motorways have been built in most major cities to provide fast, safe and efficient movement of people and commodities. For the most part motorways fulfill this purpose quite well as long as the number of vehicles using a motorway remains at, or below, the functional capacity. However, when the number of vehicles approaches and exceeds the capacity, then there is usually a breakdown in traffic flow which results in congestion and other problems.

The purpose of motorway traffic management is to avoid, or mitigate, motorway congestion by fully utilizing all available transportation facilities along a motorway corridor. This includes the motorway, access and exit ramps, frontage roads or parallel arterial streets that can be used as alternative routes, public transportation and more. The intent of this technique is to implement traffic control to effectively manage the flow of vehicles on a motorway and optimize the level of service for the capacity of the whole facility.

Motorway congestion is generally divided into two categories, recurring and non-recurring. Both types of congestion occur as a result of traffic demand volumes exceeding existing motorway capacity. Recurring congestion occurs at regular and predictable times and locations. An example of recurring congestion would be morning or evening peak periods of travel to and from work such as rush hours. Non-recurring congestion is unpredictable in either time or location. It often results from accidents or other unpredictable incidents.

In either case motorway congestion has become a common occurrence in many cities throughout the world. The major problems associated with congestion include:

- Reduced speeds / Delays to Drivers
- Reduced traffic flow volume
- Underutilization of the motorway
- Higher accident rates
- Increased fuel consumption
- Severe air pollution

Appearance of these problems on motorway facilities caused people to recognize the need to improve congested motorway situations. One solution to alleviate the problem of excessive demand on motorways has been to increase the capacity of these facilities by taking more land and adding more lanes. This solution, however, is usually very expensive, often disruptive to the natural and social environment, and encourages further growth in travel demand (2).

An alternative solution was to develop ways of influencing motorway traffic flow with the intention of improving operational efficiency of these facilities. Through systematic application and coordination, various techniques have been designed to manage and control the flow of vehicular traffic on motorways. These techniques became known collectively as Motorway Traffic Management Systems. The variety of techniques is rather extensive and growing. Available options require careful consideration by engineers and policy makers who would use them to treat the problems of traffic congestion.

Implementation costs of Traffic Management Systems vary greatly depending on size, sophistication and desired degree of automation. It is often desirable, and practical, to implement smaller systems initially because they are less expensive and they can easily be expanded and made more sophisticated in the future as local staff become more knowledgeable and finances are available (1).

Motorway management strategies fall into two basic strategies: capacity management and demand management. Capacity management seeks to maximize throughput rates and to improve level of traffic service. Whereas demand management attempts to reduce the quantity of vehicular travel. Each strategy uses different combinations of available tools for the purpose of improving the operational efficiency of motorway facilities.

1.2 Overview of current tools in traffic management

The following is a quick list of traffic management tools and techniques currently used in practical application. A brief description is given for each item. It is important to keep in mind the each tool or technique requires its own set of hardware and has a (subjective) philosophy of application. Any one of these techniques could be expanded on and studied in depth; the intent of this list is to provide the reader with a brief overview.

Vehicle detectors - Vehicle detection is a way of gathering information about the vehicles using a roadway facility. Detectors provide data about vehicle speeds, traffic volumes, headway, and vehicle classification. Technology used for detection includes inductance loops placed in the pavement along travelled lanes of traffic, microwave detectors placed over or adjacent to lanes of traffic, and also the developing technology of vehicle detection using electrically manipulated closed circuit television signals.

Ramp metering - Ramp metering is used as a way to control motorway access. Vehicles entering the motorway during periods of high use are granted entrance according to a timing scheme designed to regulate vehicle entry. The purpose is to reduce mainline congestion and allow motorway traffic to move faster and more smoothly. Metering is intended to make it possible for more vehicles per hour to use a motorway corridor with an over all shorter commute time and provide a higher level of service for the facility. The timing scheme for vehicle entry onto the motorway is communicated to drivers through the use of standard traffic signal familiar to the driver from their use at intersections.

High Occupancy Vehicles (HOV) - HOV's are vehicles which carry other individuals in addition to the driver. The minimum number of occupants required for classification as an HOV is usually two or three. The upper limit for occupants in a single vehicle is what you find in buses. HOV's are encouraged as a way of transporting more people with fewer vehicles. The incentive for people to ride together in HOV's takes the form of providing preferential treatment for those vehicles such as bypass lanes around ramp metering sites to avoid the metering requirements imposed on single occupant vehicles. Another incentive is special lanes on the motorway dedicated for HOV use only.

Special use lanes - These type of lanes are present in addition to the normal number of lanes on a motorway facility. They can be used, as mentioned above, for HOV's; they can also be used as reversible motorway lanes. Reversible lanes are used to change the directional capacity of a motorway in order to accommodate peak directional traffic demands. The reversible lane usually requires special marking to be clearly identified by drivers and is directionally dedicated according to regular changes in traffic demand such as inbound traffic for a morning peak period, then outbound traffic for the evening peak period.

Changeable Message Signs (CMS) - Changeable (or variable) message signs are real time communication devices which provide driver information. The devices are designed to allow the visual word, number, or symbolic display to be varied according to the changes in traffic conditions (3). Usually these signs have the capacity to display two or more messages, using two to four lines of display. Several types of sign are in use today, they are rotating drum, disc-matrix or lamp matrix, sliding panel, and fibre optic display signs. The operating technology ranges from electromechanical to purely electrical. These signs can be controlled locally or remotely using a computer interface. CMS's are used because of their ability to address varying situations that occur on motorways (6).

Highway Advisory Radio (HAR) - HAR is also used as a real time driver communication tool. HAR is used to broadcast information to drivers about current motorway conditions so drivers can make informed decisions in regard to their travel plans such as route choice, departure times, course adjustments, etc. The sophistication of broadcast systems varies from limited range "leaky cable" systems located along roadways to commercial radio and, in some cases, dedicated frequency channels that can be used for continuous broadcasting. HAR is currently receiving increased attention as an area of development.

Closed Circuit Television (CCTV) - CCTV is used as a means of traffic surveillance which provides real time visual information of motorway traffic conditions for those portions of the roadway covered by this type of system. The CCTV signals can be transmitted in several ways. The most common is a direct link by way of a coaxial cable; Another mode of transmission is high-speed data communication over a copper wire, which again is a direct link. A third way is to send the signal using microwave data transmission equipment.

The value of the visual information is that it can be used to verify actual conditions so that subsequent decisions can be made about how to react to observed conditions. Visual information also helps to reduce the reaction time, for example if an accident is observed emergency assistance can be contacted immediately and given information concerning the exact location and severity of an incident. The visual information can further be used to feed radio broadcasts, or make decisions to manually over-ride automatic systems when necessary.

Incident Management Plans - This technique provides specific guidelines about handling incidents which cause motorway congestion. Incident management plans identify specific actions to be taken in the event of certain motorway incidents. The programs entail the establishment of dedicated resources available for the purpose of following the response plans. The resources may consist of trained personnel, specially equipped vehicles, communication networks to contact emergency medical, fire, and safety units, special equipment such as portable warning signs and temporary lane closure devices, etc.

Motorway Corridor Management - The purpose of corridor management is to attain full utilization of all available facilities associated with defined motorway corridor. A corridor includes the motorway, access and exit ramps, frontage roads, arterial streets which can be used for alternate routes to the motorway, signing, driver information systems, and any other element of traffic control that can help improve traffic flow in the corridor. The intent of this technique is to implement traffic control plans which can effectively influence the flow of vehicles in the corridor area to optimize throughput and level of service.

Traffic Management Centers - A traffic management center is not so much a technique as it is a central location in which to house equipment and exercise practical application of different techniques and strategies. In general these facilities become "nerve-centers" of activity. The style of the these facilities ranges from a single room within an existing building such as a police station to an independent building specifically dedicated to traffic management functions.

Expert Systems - Expert systems are experiencing a tremendous development effort currently, primarily because of their relation to Artificial Inteligence (AI). The application of AI covers many fields; Its appearance in transportation relates primarily to the efforts of the DRIVE project in Europe and the Intelligent Vehicle & Highway System (IVHS) in the US. DRIVE and IVHS are at the cutting edge of traffic management technology. These programs are being developed to process vast amounts traffic data for an urban motorway network and then use AI to automatically make real time interactive decisions about the most efficient area-wide operation of the traffic management system.

Additional motorway traffic management techniques include emergency motorist aid call boxes placed along motorways at regular intervals. These provide stranded motorists with access to emergency services. Accident investigation sites, also spaced at regular intervals, are used so that motorists involved in minor accidents have the option to move their vehicles off the motorway to the investigation site. In this way possible congestion can be avoided on the motorway and drivers can safely inspect the extent of minor damage.

SECTION 2 - RAMP METERING CONCEPTS AND COMPONENTS

2.1 Concept

Although ramp metering is only one motorway traffic management technique from those mentioned in Section I, one of the most widely used. Ramp metering does not solve all types of congestion problems. Congestion caused by geometric conditions or design induced traffic movements such as weaving, may require reconstruction as the solution. Ramp metering has proven effective, to varying degrees, for use in both capacity and demand traffic management strategies. This section takes a closer look at the concept of RM , its association with traffic flow theory, and the components of an RM system. Simply stated:

Ramp metering is the application of standard traffic signals at specified motorway entrance ramps for the purpose of controlling, or metering the rate at which vehicles are supplied to a motorway.

The most common form of ramp metering is to permit one vehicle on to the motorway at a time. Using this approach values ranging from 300 to 900 vehicles per hour (vph) can be allowed to enter the motorway depending on existing conditions (13); Below 300 vph waiting time begins to be longer than drivers will tolerate and they begin to disobey the signal. On the other end, 900 vehicles per hour approaches the physical limit of how many vehicles can be allowed on the motorway and still maintain controlled traffic flow. This method of one vehicle at a time is used in Holland and the United States.

Another method, used in England, is to allow platoons of vehicles onto the motorway. With this method the signal displays the green light long enough to permit a group of vehicles to merge with motorway traffic. With this method the number of vehicles per hour cannot be controlled as closely as the other method, but both methods have proven effective in helping to control motorway traffic flow.

2.2 Ramp metering & traffic flow theory

Traffic flow theory involves the measurement and comparison of vehicle speeds, flow rates, and traffic densities which can be used to define traffic congestion on motorways. Ramp metering can influence these parameters and thus influence traffic conditions as well. Traffic flow theory provides the tool to measure the extent of traffic congestion and the degree to which ramp metering may influence congested conditions.

Traffic flow theory continues to change and develop as devices for measuring field conditions improve along with improvements in data processing and transmission technology. Measuring congestion is a subjective issue; Different design factors and different traffic patterns have a direct effect on identifying congestion for any given area. Figure 2.1 shows a typical representation of traffic volumes over time during a morning peak period. The "critical" traffic volume is the treshold above which traffic flow can result in flow break down.

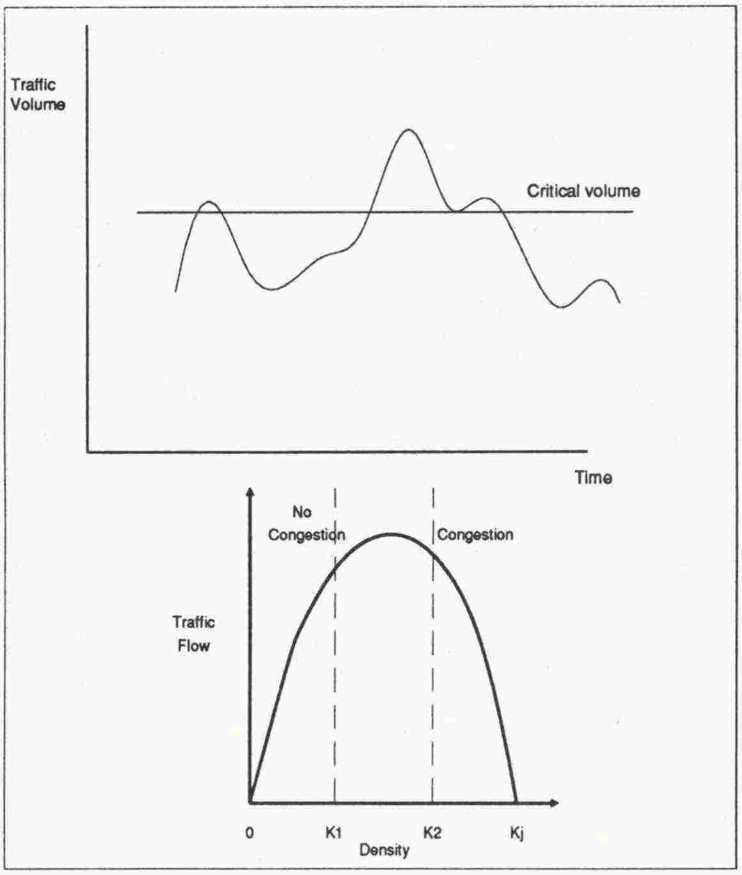

FIGURE 2.1 - Congestion and the fundamental relationship between flow rate and density

The second part of Figure 2.1 takes a closer look at traffic flow versus density and its connection with traffic flow breakdown.The Traffic Control Systems Handbook (13) gives the following general representation of congestion and the fundamental relationship between flow rate and density. As traffic density increases from zero to some value, K 1, traffic flow rate increases and the resulting operation is defined as noncongested. As density increases from K 1 to K 2, flow rates may increase a little more, however, traffic operations become unstable and the probability of serious flow breakdown increases. Further increases in density above K 2 causes a decrease in flow rate until, theoretically it reaches zero at jam density K J. Traffic flow operations occurring at densities greater than K 2 are classified as congested. Once congestion has occurred there is always additional time required to recover and return to normal conditions.

Figure 2.1 shows zone of instability, between density K 1 and K 2, where traffic flow hovers between congested and noncongested. The purpose of ramp metering is to regulate flow volumes to remain in the noncongested region of the figure while keeping flow rates as high as possible. This maximizes the efficient operation of the motorway during periods of peak usage. Although exact numerical values for the curve depend on specific details for each motorway, the principle remains the same.

Flow theory is used prior to design of a ramp meter system to evaluate effects and feasibility as a solution for congestion problems; These determinations provide guidance during system design. After design, construction, and implementation, traffic flow theory is used to analyse the results a system produces. This use of traffic flow theory in connection with traffic control systems, such as ramp metering, naturally leads to an analytical cycle which guides evolution and development of these systems. Figure 2.2 represents this cycle; Data collection - problem/congestion analysis - decision making - solution implementation - data collection - evaluation/analysis.

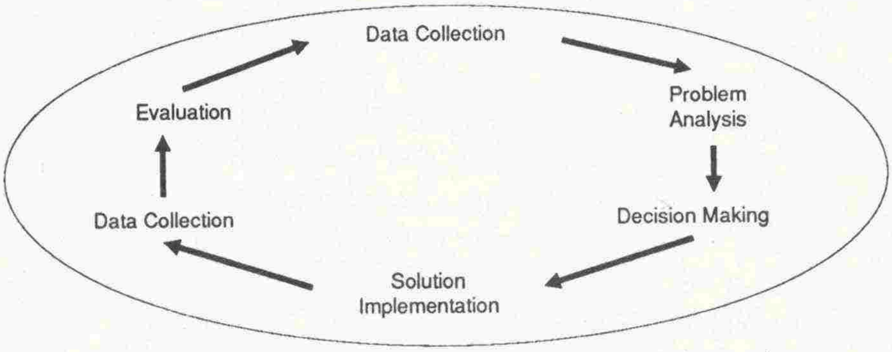

FIGURE 2.2 - Traffic control problem analysis/solution cycle

Ramp metering is usually most effective in alleviating recurrent congestion which creates a demand that regularly exceeds available motorway capacity. In this situation metering is effective because it is a way to manage the demand at key ramps so that it more accurately reflects the motorway capacity. A list of typical measures of effectiveness for motorways is given in Table 1.

MEASURE OF EFFECTIVENESS	UNIT OF MEASURE
Traffic Density	vehicles/kilometer
Average Travel Speed	kilometers/hour
Flow Rates	vehicles/hour
Travel Times	minutes
Accident Rates	accidents/year
Vehicle Headways	meters

Table 2.1 Measures of effectiveness

2.3 Ramp metering control algorithms

The control algorithm is one of the central elements of a ramp metering system. It receives varied treatment depending on traffic conditions and which geographical location it is applied. The control algorithm is essentially a piece of software which is programmed to perform the primary function of continuously monitoring and processing field data for system operation. Field data may come from vehicle detectors, time clocks, traffic control centers and other sources. Field data provides information about motorway traffic conditions which is then used by the algorithm to drive the specific operation of ramp control system. One of the most important functions of the control algorithm is to calculate the timing cycle for the metering rate.

Timing cycle & metering rate - The timing cycle is the time required for the meter signal to proceed through one cycle of Red-Yellow-Green display to permit vehicle entry. The timing cycle is calculated using numerical values for motorway capacity and the actual traffic data gathered from the motorway detectors. Figure 2.3 shows an example calculation using mainline traffic data which is translated into a metering rate for the ramp signal.

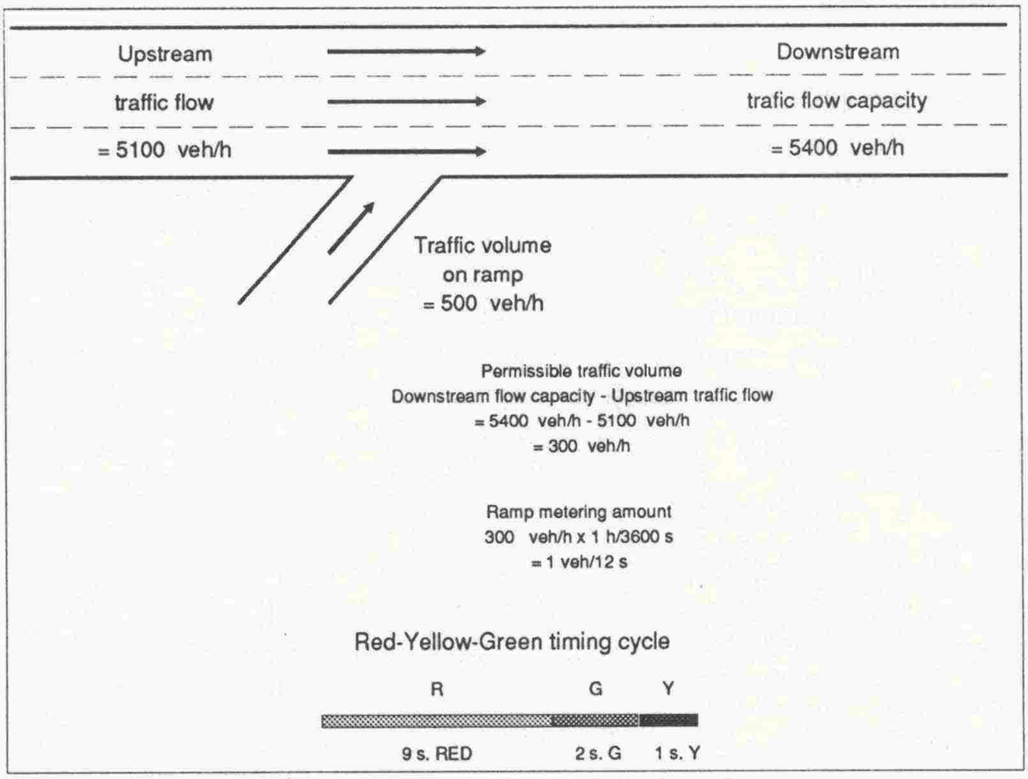

FIGURE 2.3 - Example of timing cycle calculation based on traffic flow data

The calculation uses a real time traffic flow rates taken from field sensors upstream of the entrance ramp. It then makes a comparison to the allowed value of motorway traffic flow capacity downstream of the ramp. Realizing a positive difference the algorithm proceeds to calculate that a given number of vehicles can be allowed on the motorway per hour (or per minute, etc.). The algorithm then calculates the appropriate timing cycle which in turn guides the signal controller operation. The controller, in turn, sets the signal to cycle through the green, yellow and red light display according to the timing calculations.

If the calculations show that no vehicles should be allowed on to the motorway because of existing congestion, then a programmed over-ride takes control to set the meter on an automatic predetermined slow rate. The slow rate is used rather than leaving the meter signal to display a constant red, which would cause ramp traffic to back up onto the city street network creating additional problems.

It must be emphasized that the example of figure 2.3 represents a "snap-shot" of a calculation process being performed continuously. Timing cycles of ramp metering should be dynamic and change according to observed traffic conditions through the course of peak period traffic flows. It is also important to note that traffic flow rates are the primary parameter for measuring traffic conditions on the motorway. The basic calculation can be modified to include other parameters such as traffic density, vehicle headway, average travel speeds, etc. Whatever parameters are used the main result is a timing cycle which can be utilized in operation of the ramp metering signal.

The algorithm must also continue to monitor ramp storage queues, and observe timing parameters (associated with maximum and minimum flow rates) designed to ensure safe and effective system operation.

Control algorithms

Control algorithms can be programmed into standard traffic signal controllers which operate traffic signals used to regulate traffic flow on the ramps. An alternative to programming controllers is to program a computer located away from the actual ramp site. The computer can operate as part of a larger traffic control center from which operation can be directed.

Different algorithms are designed to satisfy different traffic control needs. The difference between various algorithms depends on calculations performed and the different traffic parameters used to direct the system. The variation of algorithms also depends on the complexity of the ramp metering system.

For those systems using three or four ramp meters, the control algorithms can be programmed into signal controller at each ramp site. These controllers can operate independently or they can be linked to each other to operate in a dependant, or coordinated way. For systems larger than four ramp meters, coordinated operation requires a central computer because the computing capacity of individual controllers is limited to smaller systems. The size of ramp metering systems and their associated control algorithms relates to the desired scope of traffic control. Examples of algorithms are given below; The figures used to represent them are given in computer flow chart format.

Pretimed ramp meter algorithm - Pretimed ramp meter algorithms are the most basic form of control algorithm. They do not depend on real time traffic data gathered from pavement detectors. It requires no other input than a start/stop signal from a time clock which is built into the signal controller itself. This means that for a specified interval of time, say two hours during rush hour, the ramp control signal will display the R-Y-G sequence according to a predetermined timing cycle. On the following page, Figure 2.4 shows the flow chart for a pretimed algorithm.

Pre-timed algorithms were developed prior to traffic responsive algorithms and the timing cycle is changed by manually reprogramming the controller. The cycle timing is usually changed in response to traffic counts which show an increase (or decrease) in traffic volumes using the ramp.

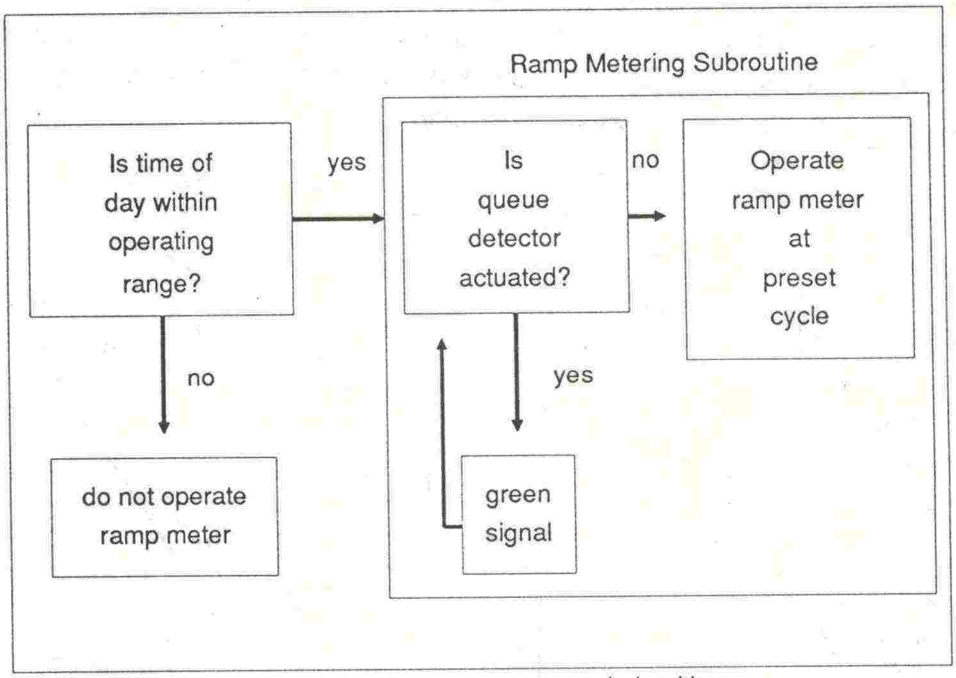

FIGURE 2.4 - Pretimed ramp meter control algorithm

Traffic responsive ramp meter algorithm - The next step up from a pretimed algorithm for ramp metering is a traffic responsive algorithm. A simplified version of a traffic responsive algorithm is shown in Figure 2.5. This type of algorithm requires more input data to accurately measure traffic conditions on a real time basis and make appropriate adjustments to the metering cycle. Traffic conditions are monitored by loop detectors in the pavement.

Merge detectors and queue detectors are also placed in the ramp pavement to ensure safe operation of the system. The advantage is that the algorithm can react to traffic fluctuations continuously during metering periods. Actuation of the merge detector indicates that a vehicle is still present in that area and subsequent green time is preempted until the vehicle merges. The queue detector prevents vehicle queues from interfering with street traffic.

Traffic responsive algorithms continuously monitor traffic volumes upstream and downstream from the ramp. These volumes are used in calculating metering rates and timing cycles. The algorithm also monitors the ramp storage queue detector and the merge detector for conditions that would override the metering cycle for the sake of safety. The purpose is to achieve more efficient and effective system operation.

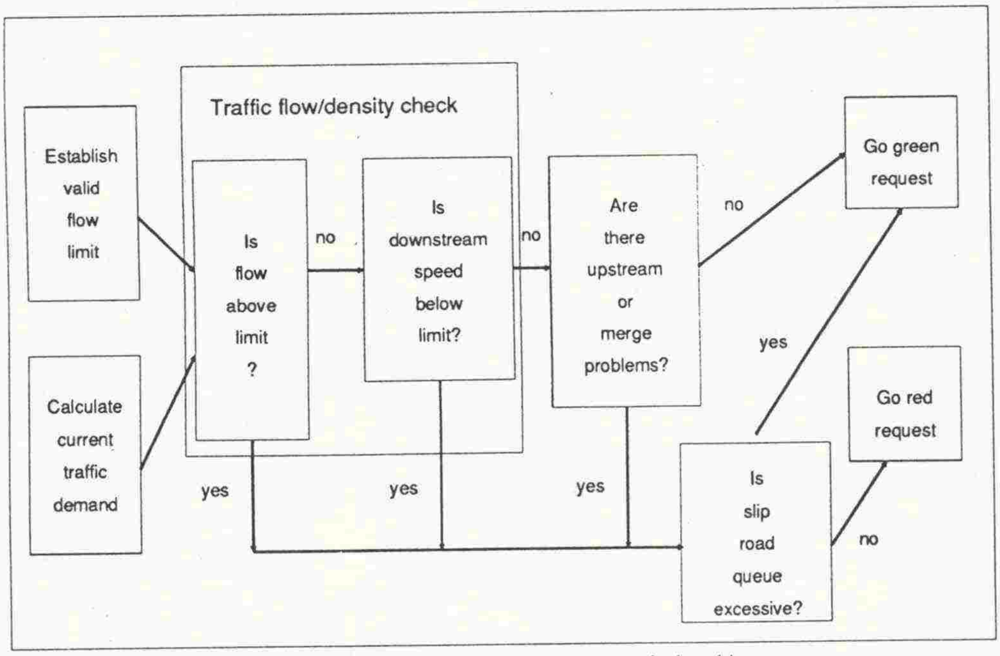

FIGURE 2.5 - Traffic responsive ramp meter control algorithm

Integrated traffic responsive ramp meter algorithm - The next step up from traffic responsive metering is an integrated traffic responsive metering control algorithm. The purpose of this approach is to achieve corridor control optimization. In this situation there is a series of ramps that are metered in sequence along a single direction of traffic. This could be a system of two or more metered ramps. The term "integrated" implies that two or more ramps are accounted for, or integrated, within a single control algorithm.

Integrated traffic responsive ramp meter algorithms can have a wide range of complexity. The simpler versions are similar to a traffic responsive algorithm with the exception that instead of continuously monitoring data for a single ramp, data for several ramps is simultaneously processed. This requires a more complex calculation routine to accurately measure the upstream and downstream traffic volumes through a sequence of ramps along a single direction of traffic flow. And also monitoring the merge and queue detectors at each site under control.

Programming for this type system gets more complex with the increase of ramps governed by a single algorithm. And to go a step further, the algorithm can become more intricate if the system incorporates additional devices such as traffic actuated changeable message signs, lane control signals, incident detection logic, etc. However this goes beyond the scope of ramp metering.

Basically, when the programming of algorithms exceeds the capacity of a standard signal controller, then the algorithms are programmed into a computer which is housed in a control center. In this way the ramp metering system is operated remotely through information exchanged between the field and the control center by way of some specified means of data communication.

2.4 Ramp metering components

The physical hardware of a RM system is similar to that used for common signal systems on city street intersections. The main difference is that the layout of a RM system is more simplified than a city street intersection in that it requires fewer signal heads and there is only one traffic movement to be considered which is the merge onto the motorway. Figure 2.6 shows a typical layout for ramp metering components and the specific list of hardware is reviewed below.

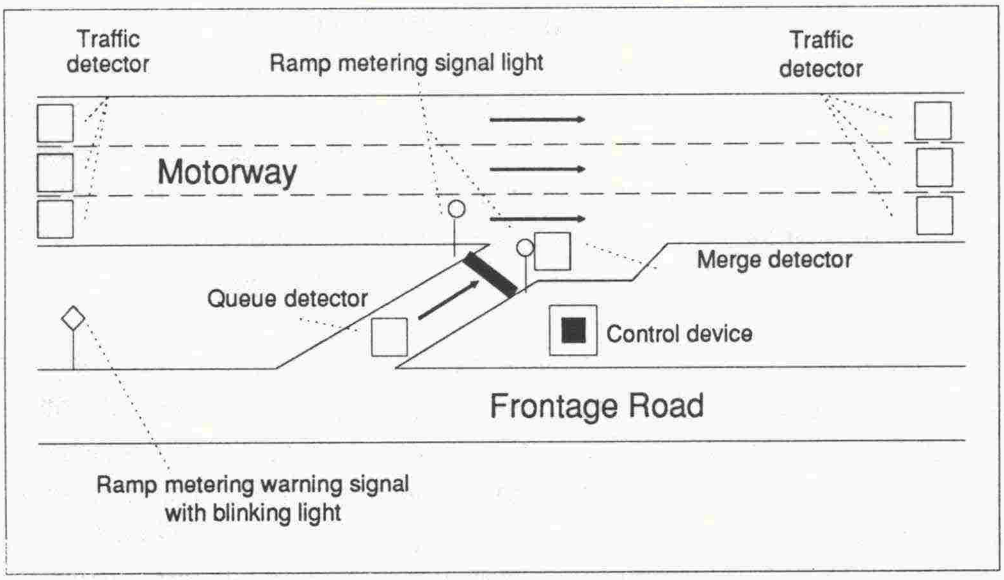

FIGURE 2.6 - Typical layout of ramp meter components

Vehicle detectors - Vehicle detectors have become a standard tool for traffic engineering in general. With respect to ramp metering they are used to provide accurate vehicular flow information which is, in turn used in the above mentioned control algorithms to establish timing parameters for the ramp metering system.

Ramp control signal - The most obvious piece of hardware is the ramp control signal which is simply a standard traffic signal with red-yellow-green lenses, illuminating lamps, housing, and necessary attachments for mounting the signal head to a support pole. Signal heads with just red-green display have also been used effectively in ramp meter applications. The timing configuration and lens color display are usually governed by traffic signal law and policy.

The placement of ramp meter signals relative to the motorway depends on two things: 1) The need to allow vehicles stopped at the meter to accelerate sufficiently up to safe merging speeds; And 2) to allow adequate space for queue storage on the ramp itself.

The support pole is usually shorter than those used for street intersections. For RM systems the signal head mounting height is usually between one and two meters above ground level. The reason for this mounting height is to allow easy visibility of the signal for drivers seated in their cars and situated relatively close to the metering signal which is placed adjacent to the ramp.

Another difference of the ramp meter signal is the timing scheme which is used to regulate the traffic movement. The timing cycle depends on different data than that which drives a typical street signal system. Also, traffic movements associated with ramp metering are fewer than a street signal system.

Signal cabinet & controller - The signal cabinet and controller are significant operational elements. These elements (in particular the controller) act as the local nerve center for the ramp metering site. The controller in ramp metering systems is a typical signal controller capable of multiphasing and data interfacing as necessary to incorporate detector information and connections to other controllers or central computer. The cabinet should be appropriately sized to accomodate the vehicle detector equipment and communication interface equipment. another significant component of the cabinet is its physical connection to a source of power adequate to supply the electricity necessary to run all the components established in the cabinet including connections to the ramp metering signals.

Data communication cable - Communication cable serves one basic function - to transmit data as necessary between system components. What is pertinent beyond the basic function is the different types of technology available to acomplish that function. In the past all data transmission has been accomplished by using direct connections through copper wire.

More recently, however, the field of fiber optics has emerged as an alternative to the tradition of copper. Fiber optic technology makes use of light pulses which are emitted into a glass fiber from either a laser source or a light emmiting diode. As fiber optics is an emerging technology it is rather expensive; However, as its use increases costs are expected to go down.

Signing - In some systems a brief information sign is also affixed to the mounting pole just below the signal head. The signs are used to instruct drivers that only one car is to proceed during the green phase.

Other signing associated with ramp metering includes advanced warning signs. These Signs are placed prior to the ramp meter at a sufficient distance so that drivers are alerted that they are entering a ramp merering situation and proceed with proper awareness of the conditions ahead. Different styles of advanced warning signs are in use depending on whether the system designer has chosen to communicate with words or symbols. In some cases amber lights are also attached to these signs and set up to flash during metering periods to add emphasis to the advance warning message.

In general advanced warning sign for a metered ramp is considered optional rather than mandatory, it's a matter of designer discretion.

Source of power - Considering all the electrical devices listed above, it is necessary to indicate the requirement of a source of electrical power to operate a ramp metering system. There is nothing special about this element; It's worth mentioning that power should be easily accessible and that all electrical components are to be operationally specified to synchronize with the available power source.

Miscellaneous hardware - The miscellaneous hardware includes all the necessary wiring, electrical transformers and circuit breakers, conduit, pull boxes to facilitate the wiring, concrete foundations for signal cabinets and ramp control signal. These are all straight forward elements.

2.5 Additional ramp metering elements

Loop Detector parameters - Loop detector parameters relate to detector sensitivity and to their placement for use in ramp metering. The sensitivity parameters ensure that detectors are able to accurately register the different vehicle classifications such as passenger cars, busses, and heavy trucks. Detector sensitivity must be calibrated according to loop size and number of turns of wire. Another sensitivity parameter relates to detector failure; If the detector is no longer functioning properly the device should display a failed indicator or send a signal to a central computer.

Placement parameters depend on the use of main line, merge, and queue detectors and how they are to be placed, or configured. This is so that appropriate logic can be programmed according to operational needs.

Horizontal & vertical ramp alignment - These are important factors to consider at each entrance ramp location. These factors influence the conditions under which a driver must accelerate from the stop line at the ramp meter to the merge location at the end of the ramp. Up hill accelerations are slower and more difficult than flat or down hill accelerations and thus require a longer distance to achieve merging speeds. By the same token tight horizontal curvature may pose problems for vehicles during acceleration to merging speeds.

Ramp storage - Ramp storage is basically defined as the number of vehicles that can be queued on an entrance ramp waiting to get on the motorway. A single ramp can store one or two lanes of cars depending on ramp width. Dual lane storage is more efficient because it cuts the queue length in half. This aspect of ramp metering is very important because of the impact it can have on city streets that provide access to motorway ramps.

When considering ramp alignment or ramp storage, it may be necessary to plan for minor improvements to certain ramps depending on existing physical conditions. Such improvements or modifications may also be necessary to accomodate HOV's. These modifications can occur in two ways; One would be to add on to an existing ramp, the other would be to include ramp modifications into upcoming reconstruction projects.

High Occupancy Vehicle (HOV) facilities - Preference is given to HOV's because they are considered a more efficient way of moving passengers. In regard to ramp metering systems this preference is accomplished by providing auxiliary ramp that allow HOV's to by-pass the ramp metering system without having to wait. This type of by-pass facility is designed into systems where HOV's provide regular service.

Maintenance plan - All ramp metering systems must include provisions for maintenance. This usually requires personnel to review the operation of the system and make any necessary repairs to equipment. The maintenance plan doesn't have to be an excessive expense, it simply requires thoughtful consideration so that system stays in proper working condition and drivers develop respect for system quality.

Public acceptance/Implementation plan - This may seem outside the realm of technical engineering, but it is a critical element to the success of any ramp metering system. The best designed and constructed ramp metering system is useless if there is no compliance by drivers.

It is imperative that drivers are informed about how to respond to the ramp metering system. For initial systems this usually requires a public information program. This program consists of several levels. One level of communication to the public is accomplished by preparing literature that can be mailed to areas where ramp metering system users are likely to originate from. It is also possible to distribute literature directly to drivers using the ramp, one or two weeks prior to starting the system.

Another level of public communication is to produce news releases prepared for television broadcast and publication in newspapers. The main point is that drivers understand how to use the system. These communications requires clear instruction to drivers explaining system operation.

It is extremely important to make sure that people understand that ramp metering is intended to benefit them by providing shorter travel times, improved level of service, safer driving environment, etc. Even if this means drivers have to spend some time waiting in a ramp queue.

Increased computer power - One standard addition of a traffic management system which grows from the foundations of ramp metering is a higher order computer such as a mini or a main frame depending on the intended scope of the overall system. A computer is basically an extension of, or high powered substitute for, the idea of a master controller. It's fair to say that the basic signal controller has a very respectable capacity to support a small scale RM system, even to the point of running a small system. However, large scale systems require larger computing capacity.

2.6 Types of ramp metering systems

Isolated - The term isolated refers to the fact that the system operates alone with no communication link to any other site. This type of system is used for a single ramp and is operated on site by a signal controller set up specifically for needs at that location.

Integrated - Integrated ramp control refers to a series of ramps where the interdependency of ramp operations is taken into account. The control of each ramp is based on demand-capacity considerations of the whole system rather than only the single ramp (13). There may be a signal controller at each site but usually one is designated as a "master" controller and coordinates information, or dictates the response, of the actions occurring at the other ramp metering sites in the series.

Integrated systems can also be effectively operated by a main computer located in a control center away from the motorway environment. This approach is usually employed when other traffic management tools are also in use. In this case the computer serves the needs of the traffic management system as a whole and ramp metering is just one part. Figure 2.7 shows a representation of how larger ramp metering systems can be controlled by a central computer with an auxiliary control by police or others when necessary.

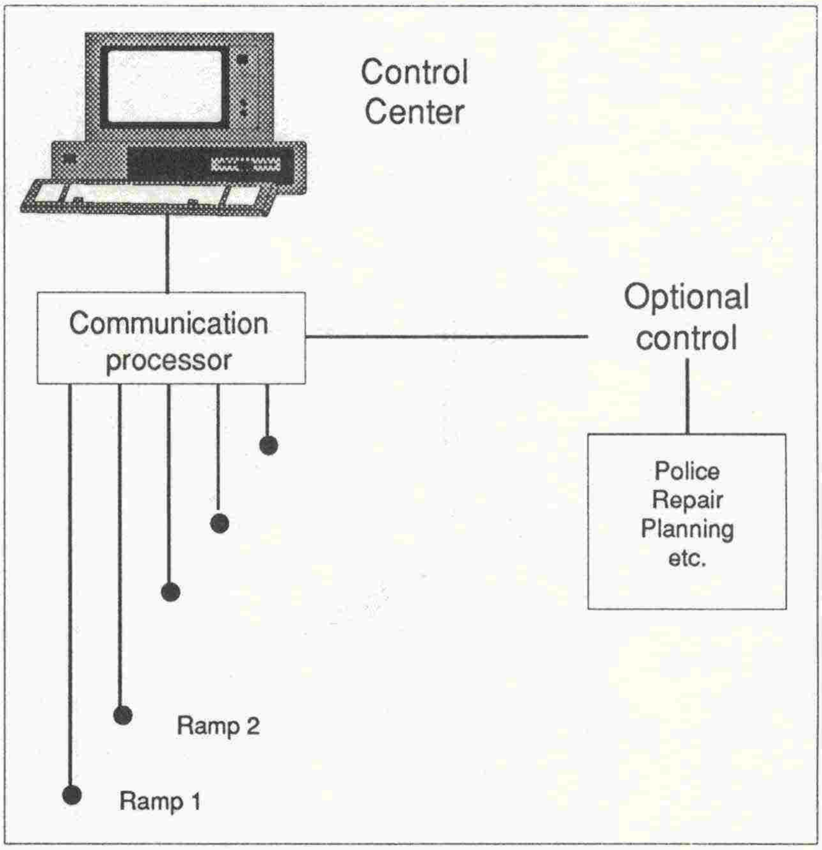

FIGURE 2.7 - Integrated ramp meter control

Examples of system layouts - Some systems require metering at only one entrance ramp. Other systems run on for some length requiring entrance control on many ramps along a segment of motorway. Figures 2.8 and 2.9 give an idea of different system scope as represented by the one ramp system implemented in Birmingham England in 1986; And the system in San Diego which uses over 70 ramp meters (4 & 5).

The topics addressed in this section are intended to provide an overview on the key aspects of ramp metering. The ideas of traffic theory and control algorithms begin to touch on the foundation of larger and more sophisticated traffic management systems. Ramp metering has been used beneficially on its own as a single traffic management tool, and has also proven to work well in conjunction with other traffic management tools. Successful implementation depends on correct understanding the key aspects of ramp metering and the traffic situation to which it is applied.

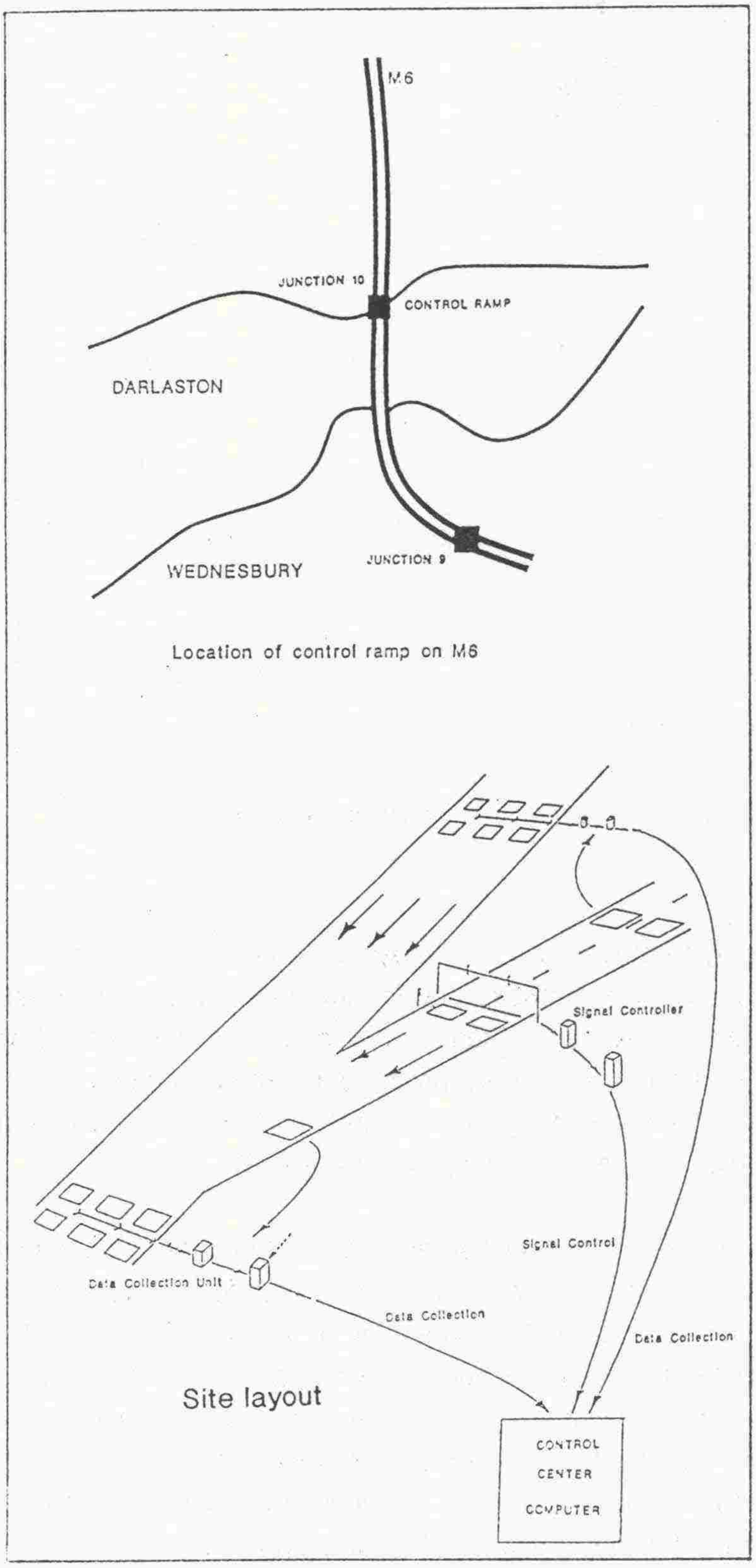

FIGURE 2.8 - Layout of Birmingham ramp metering site on M6

FIGURE 2.9 - San Diego ramp metering location map (4)

SECTION 3 - BENEFITS

The list below represents those benefits and disbenefits which are most frequently referred to when discussing the value of ramp metering systems. Ramp metering benefits are a rather subjective topic, different systems owners have different opinions about what a benefit really is and how it should be quantified or valued. The list is as follows:

3.1 Benefits of Motorway Ramp Metering:

- Minimizing travel times between origin and destination
- Efficient use of total roadway capacity
- Supports steady traffic flow and improved traffic control at bottle neck areas
- Accident reduction
- Safer merging operations
- Reduced fuel consumption and emissions
- Compatible with HOV operations

3.2 Disbenefits of Motorway Ramp Metering:

- System costs
- Increased delay on the entrance ramp
- Favoring through traffic over metered local traffic
- Non-compliance (People ignoring the system)
- Transfer of land values
- A source of political controversy

The difficulty of attaching a specific monetary value means that not all benefits or disbenefits are used in calculating a cost/benefit analysis. The most commonly calculated benefits are those related to time savings for drivers (reduced travel times) and accident rate reduction. The disbenefits used in cost/benefit analysis are system costs, including both construction and maintenance.

3.3 Birmingham, England system (5)

Traffic responsive ramp metering was established in Birmingham on a single entrance ramp of the M6 motorway and put into operation in 1986. The traffic volumes on the M6 during morning peak had become excessive to the point where significant traffic flow breakdown was occurring, on average, three times a week. In 1986 average daily traffic counts were exceeding 100,000 vehicles. The M6 is a six lane motorway - three lanes for each direction.

For this system benefits were equated to gains made by motorway traffic, they included reduced delays and increased throughput on the motorway at the expense, or disbenefit, of increased delays on the entrance ramp. Monetary values for these benefits and disbenefits were assumed and a cost/benefit appraisal was made.

In order to properly evaluate the benefits of the ramp metering system, extensive traffic studies were carried out before and after implementation of the ramp metering system so that motorway traffic changes could be accurately monitored. Comparisons were then made and calculations carried out to evaluate the changes in terms of monetary values. In the case of the Birmingham system a value of £4.70 was assumed per vehicle hour and overall time savings created by the system were also measured in vehicle hours.

According to their results the annual benefits were estimated to be between £67K and £110K. The initial capital cost of the system was £255K. They assumed that benefits of £110K reflected a return of 44% in the first year of their initial investment. This analysis was based only on time savings to drivers, no accident reduction savings are reflected herein.

Some of the problems associated with the Birmingham system included merging difficulties when larger platoons of vehicles were permitted to enter the freeway. This condition was observed for platoons approaching 30 vehicles in number. Another fact is that there were still occasions when traffic levels caused traffic flow breakdown, though not as often as before implementation of ramp metering. Also, there were some drivers who ignored the ramp meter signals, but their number was not deemed significant and enforcement efforts did help in this regard.

3.4 Minneapolis, Minnesota system, U.S.A. (14)

Traffic responsive ramp metering was established on five entrance ramps sequentially located along Interstate 35E in the southbound direction. This series of ramp meters was designed to control congestion for morning peak traffic. Traffic volumes were exceeding capacity (1900 vehicles per lane per hour) on the three lane southbound section during morning peak.

For this system extensive traffic studies were also carried out before and after system implementation to accurately measure changes in traffic flow behavior. For this system the benefits were measured in terms of time savings for drivers using the system and also the reduction of accidents for the area influenced by the ramp metering system.

The value of time savings (benefit), on average, was assumed to be (USD) $5.25 per hour; The same value was used for disbenefit time spent waiting on the entrance ramps . The value of accidents was divided into two categories: Property damage accidents were assessed at (USD) $1,100 each; And Personal injury accidents were assessed at (USD) $5,500 each. The initial cost of construction was (USD) $65,474

Using these values over a study period of ten years the annual derived benefit was worth (USD) $62,170; While the system costs, including initial construction, improvements, maintenance, and operation came to an annual worth of (USD) $8,520. This gave a benefit cost ratio of 7.3, which indicates a significantly positive system result.

There were still some occurrences of congestion after the ramp metering system was implemented. It was acknowledged that these conditions resulted from a lack of capacity which would require remedies beyond the scope of ramp metering. There was also a small percentage of drivers who were ignoring the meter signals, the percentage was not considered disruptive and enforcement efforts were provided to minimize this problem.

The results of the Birmingham and Minnesota systems are summarized below in tables 3.1 and 3.2. The results summarized here represent the costs and benefits of initial systems. Usually the rates of return are highest in these cases because the changes can be more dramatic with the installation of an initial system. As the systems grow there is usually a diminishing rate of return because more investment begins to achieve smaller increments of benefit to the overall system. Benefits can still be achieved, this requires careful planning of system expansion.

TABLE 3.1 - Birmingham ramp metering System, 1986 (5)

Initial System Investment costs	£ 255.000,00
Anual operating and maintenance costs	£ 10.000,00
Estimated Benefits (from first year time savings)	£ 67.000,00 - £ 110.000,00
Rate of return on initial investment	25% - 40%

Table 3.1 Summary of first year costs and benefits for Birmingham's M6 Ramp metering system (1986 prices £).

Table 3.2 Minnesota ramp metering system, 1968 - 1978 (14)

Initial system investment costs ($68.199,00 amortized over 10 years)	$ 6.820,00
Annual operating and maintenance costs	$ 1.700,00
Annual benefits based on time savings	$ 32.170,00
Annual benefits based on accident reduction	$ 30.000,00
Annual Benefit / Cost ratio = (32.170,00 + 30.000,00)/(6.820,00 + 1.700,00)	7.3

Table 3.2 - Summary of annuated benefit /cost over ten years of operation (1968 - 1978) for Minnesota's first ramp metering system (1978 prices USD).

The values of the benefits achieved in England and Minnesota are a matter of record. Other sources have also reported positive benefits from ramp metering. Although the exact numerical results vary from system to system, the collective experience with ramp metering is positive.

SECTION 4 - RECOMMENDATIONS

Traffic forecasts for Finland indicate a trend of increasing traffic volumes over the next twenty years. Based on this, realistic consideration is going to have to be given to traffic management options versus costs of constructing new roads in order to preserve the quality of motorway transportation. Traffic congestion, in some areas, already indicates a certain amount of stress on the transportation system. This stress is basically a case of traffic demand exceeding motorway capacities. In the Helsinki metro area, significant congestion is located at two particular areas: In Pasila, and on Länsiväylä from Espoo into Helsinki.

PASILANVÄYLÄ

Planning is already in progress for the Pasila area with the Pasilanväylä project. Pasila is an area north of the Helsinki CBD, and Pasilanväylä is a major motorway corridor planned for the area. The scope of Pasilanväylä is quite large, traffic management and ramp metering are only one part of the overall planning. It is difficult to narrow the discussion only to ramp metering because so many elements of traffic management require consideration for this project. The planning of traffic management for Pasilanväylä includes ramp metering, changeable massage sign systems, traffic monitoring, high occupancy vehicle preference, traffic advisory system, and incident management plans. It is appropriate that the current planning of Pasilanväylä includes traffic management. It is expected that planning will produce the adequate information to proceed with a system design.

The impact that Pasilanväylä will have on traffic patterns and driver behavior and alternate route choices will be rather extensive. The scope of traffic management requires treatment on an area wide basis. This includes accounting for traffic patterns around the corridor, connections of the corridor with other main roads, alternate routes adjacent to the corridor, coordination of traffic control through a centrally located traffic management center, communications links between the center and field devices, and many other considerations as well.

A special aspect of Pasilanväylä is the planned tunnel sections, one section of 1300 - 1900 meters and another of 2200 meters. These tunnels pose additional considerations from an emergency point of view. In the event of a tunnel fire or accident an emergency response should be established and understood by all emergency response teams such as paramedics, fire fighters, police, public radio, and the traffic control center. Emergency plans should also include escape routes, ventilation, lane closure capability, etc.

There will also be a need to provide alternate routes for vehicles carrying flammable payloads such as explosives, petrol, and other gases. Issues associated with tunnels are very important from a safety point of view and they can also be very expensive.

As mentioned earlier, all these topics go far beyond the scope of ramp metering alone. Implementing a traffic management system of this scope would be a significant task as a first-time attempt in traffic management. It would perhaps be prudent to develop practical experience in traffic management concepts by first implementing a smaller scale system.

LÄNSIVÄYLÄ

Länsiväylä, which is a radial motorway to the west, is another location where traffic demand is very high during morning and evening peak periods. Traffic counts, recently taken from the Finnish Road Administration's Traffic Monitoring System, indicate significant volumes and traffic density during peak periods. Field observations verify that these traffic densities are, in fact, high enough to regularly cause flow breakdown which results in congestion and stop and go conditions on the motorway.

Construction on Länsiväylä, scheduled for 1992, will not increase capacity east of Tapiola/Otaniemi. Because there will be no convenient alternate routes around it, and because traffic volumes are not projected to decrease, the probable result is that the area will become a bottle-neck for morning peak hour commuters. The heaviest traffic in the morning peak is located Eastbound from the area around Matinkylä Eastward to Lemissaari. The solution to this would be to attempt traffic control upstream to mitigate congestion converging in that area. Some preliminary system suggestions are as follows:

System for morning peak period

Any treatment of Eastbound (morning peak) traffic should focus on relieving congestion from Tapiola on into Helsinki. Reopening the off ramp to Lauttasaari at Katajaharju has been suggested (8), as was allowing commuter traffic to use the third (bus) lane. These, however, appear to be a politically complex measures.

An alternative could be to control traffic flow patterns upstream to prevent excessive traffic volumes from converging at Otaniemi and Tapiola. This would mean employing ramp metering in the area between Niittykumpu and Espoonlahti. Ramp geometrics are good and minor ramp widening would increase ramp storage. Another positive attribute of this area is the availability of an alternative route to Länsiväylä along Martinsillantie - Kuitinmäentie -Merituulentie. The logic behind identifying these locations is that traffic from that area contributes to the congestion problems down stream.

A traffic study of the area would provide accurate counts for current traffic volumes along with vehicle origin & destination information. This data would be used to identify locations of high traffic density. It would also be used to perform a system analysis which would contribute to the development of control algorithms. A review of existing and proposed ramp geometries and surrounding physical features would provide details necessary for a system design.

Expected improvements to morning peak traffic would be smoother traffic flow, some reduction in travel times, and fewer accidents. The extent of a system would not need to be large; A significant amount of traffic control could be achieved with ramp meters at a limited number of the sites in the area mentioned above. One of the most important features is providing enough storage space so that traffic on the street network is not adversely affected. The meters could operate as isolated, or they could be linked to each other to run as an integrated system. In either case they could operate in a traffic responsive fashion and there would be no need for a central control computer, the signal controllers themselves would be adequate for system operation.

System for evening peak

As for evening peak, Lemissaari has been shown to be have the most impact traffic levels. Traffic volumes begin to exceed 4000 Veh/Hr past that point (8). A single ramp meter placed at Lemissaari for Westbound traffic in the evening would provide control of traffic entering at that point. A ramp meter at this location could also run fully traffic responsive and thus alleviating downstream congestion only when necessary according to mainline volumes. When traffic on the mainline is flowing smoothly the meter would not need to be in operation. In this case also a single, on site signal controller would be adequate to run the system.

REFERENCES

1. Ahmed S.A., "Urban motorway traffic management technology," Journal of Transportation Engineering, Vol. 112, No. 4, July, 1986

2. Blay D.R., "Evaluation of the FREQ7PE motorway traffic simulation program," The Research and Development Branch Ontario Ministry of Transportation May 1988

3. Federal Highway Administration, "Traffic Control Systems Handbook," U.S. Department of Transportation, Washington D.C., 1985

4. Banks J.H., "Performance measurement for centrally-controlled, traffic - responsive ramp metering systems final report," Civil Engineering Department San Diego State University, 1987.

5. Owens D. & Schofield M.J., "Motorway access control: implementation and assessment of Britain's first ramp metering scheme," TRRL Research Report 252, 1990

6. Hyytiäinen E., "Muuttuvat opasteet," Tie Ja Liikenne 90, Rantasipi Ikituuri, Turku, 1990

7. Pursula M., "Liikenteen ruuhkaongelmat - mitä voidaan tehdä," Tie ja Liikenne 90 Luentopäivät, Rantasipi Ikituuri, Turku, 1990

8. Pursula M., "Ramppiliikenteen suuntautuminen ja matka - ajat länsiväylällä keväällä 1985," Liikennetekniikka, Teknillinen Korkeakoulu Otaniemi, 1986

9. Pursula M., Lyly S., Enberg Å., "Länsiväylän liikennevirta - tutkimukset," Liikennetekniikka, Teknillinen Korkeakoulu Otaniemi, 1988

10. "Espoon syyskuun 1988 liikennelaskentojen analysointi," Espoo Kaupunkisuunnitteluvirasto, Liikennesuunnitteluosasto, 1989

11. "Highway Capacity Manual," Special Report 209, Transportation Research Board, 1985

12. Pursula M., "Ramppiliikenteen säännöstelyn mahdollisuudet länsiväylällä," Tie ja liikenne luentopäivät, Finlandiatalo, Helsinki 1985.

14. "Ramp control on I-35E," Minnesota Department of Transportation, Office of Traffic Engineering, August 1978.

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