A309a: Understanding User Needs for Ramp Meter Control (RMC) Units Based on NTCIP 1207 v02 Standard

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Module Description

The purpose of this module is to help users learn how to identify and prepare well-written user needs. This module also helps users understand the scope and application of the NTCIP 1207 v02 standard as it addresses **on-ramp flow control**. This module relates to a freeway management systems that use ramp meters to control the flow of traffic from an on-ramp to the mainline freeway lanes. The application of this standard as it addresses on-ramp flow control facilitates efficient and safe mainline traffic flow, which improves mainline traffic speed and throughput, and reduces travel time and rear-ends crashes at merging lanes on highways. These benefits are key objectives of freeway traffic management and NTCIP 1207 is designed to aid in that process.

This module and the next companion module, A309b on RMC requirements, focuses on the **communications interface aspects**—how to configure, monitor, and control ramp meters remotely from a TMC, or locally at the front-panel using data objects provided by the NTCIP 1207 v02 standard. The metering plan includes fixed control interval, local-responsive, and a coordinated-corridor wide strategy. By deploying standard-based data objects, users will gain interoperability, maintain compatibility, and achieve vendor-independence. It will provide participants with information on how to identify the appropriate use of the NTCIP 1207 v02 Standard and acquire ramp meter control (RMC) units based on what the user is seeking to accomplish. This will be supported with tools and resources such as a management information base (MIB), conformance groups (CGs), and the systems engineering process (SEP).

Readers are advised to follow the curriculum path with modules I101, A101, A102, A103, and A201, A202, and A203 as prerequisites (the last two modules on the development of user needs and requirements will further aid in a better understanding of the RMC standard and functions it serves). Students are also advised to consult SEP-based standards such as NTCIP 1204 v03 ESS to learn how to organize and adopt user needs applicable to RMC.

1. Introduction/Purpose of Ramp Metering

The Freeway Management & Operations Handbook (Ref.8) defines Freeway Ramp Control as the application of control devices such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway to achieve operational objectives. Typically, the objectives will be to balance demand and capacity of the freeway in order to maintain optimum freeway operation and prevent operational breakdowns, or reduce collision rates associated with vehicles entering the freeway. The *ITE Handbook on Traffic Engineering* (Ref.9) states that traffic operations near ramps on freeways are affected for a distance of 1500 feet prior to on-ramps (entrances) and 1500 feet downstream of off-ramps (exits). These impacts are manifested by frequent vehicle lane changes, accelerations and deceleration within this vicinity. The geometric design of a freeway ramp (width, curvature, vertical alignment, etc.) can have a positive or negative influence on the operation of the ramp itself and on the operation of the freeway at and/or upstream of the merge point. Freeway design standards generally address those considerations. We are not concerned with the design and location of ramps issues in this module.

Our interest is in the operational aspects which require configuration, monitoring, and control of ramp meters for flow control.

Ramp control seeks to regulate the flow of vehicles at freeway ramps to achieve operational goals such as balancing demand, capacity, or enhancing safety. Other than freeway-to-freeway interchanges, freeway ramps represent the only opportunity for motor vehicles to legally enter or leave a freeway facility and is therefore the only point at which positive control can be exercised. Freeway ramp control systems have been in operation at various locations throughout the country since the early nineteen-sixties (Ref.8).

Ramp metering is part of freeway congestion management objectives. Generally speaking driver frustration, higher public and business costs, wasted fuel, decreased productivity, increased accidents, and severe degradation of regional air quality are reasons why agencies turn to ramp metering as one of the several components of a modern freeway system. Practice has shown that one successful approach to alleviate some of these congestion effects is to spread the vehicle loading on the freeways through ramp metering, which controls the arrival rates of new vehicles onto the freeway. In addition, merging on freeway's directional lanes is more orderly and responsible one, influencing drivers to safely merge with the traffic. This has safety benefits. Several slides in the module presentation outline ramp metering objectives and resulting benefits reported by agencies.

Due in part to the success of early applications and benefits (Ref.6), ramp metering has received increased emphasis in recent years under the umbrella of advanced traffic management systems (ATMS), a component of intelligent transportation systems (ITS) within the Freeway Management System operations. For further reading, readers are directed to the free-downloadable FHWA handbooks (Ref. 7, 8 for links to documents).

2. Overview of the NTCIP 1207 v02 Standard

NTCIP 1207 v02 assumes a model of operation in which RMC units possess intelligence, and the data used for ramp management and data collection is resident at the RMC unit. It refers to the RMC unit's status, control, and configuration data as the "controller database"; the standard specifies interfaces whereby this data can be manipulated by the central system.

The scope of NTCIP 1207 v02 is limited to the functionality related to RMC units used within a transportation environment. NTCIP 1207 v02 defines objects specific to RMC units and also defines standardized object Groups, which can be used for conformance statements. To achieve the functionality described in Annex A of v02 standard, which describes the typical operation of an RMC unit, some or all of the objects described in other standards are utilized.

Note on User Needs: User needs are defined and documented in NTCIP 1207 v02 since it does not yet follow the Systems Engineering Process (SEP) as other standards have done, such as Dynamic Message Signs (DMS) or Environmental Sensor Stations(ESS). NTCIP 1207 v02 also does not yet contain test procedures-plan needed for each functional requirement. This may be added in a future version of NTCIP 1207 v02. Users will need to develop both (user needs and testing plan) for their local specification. Annex A has provided operational requirements without documenting

descriptions of user needs. A better understanding of Annex A will be helpful in defining RMC user needs.

Other Standards: The following is another key standard that a reader should be familiar with:

Use of NTCIP 1203 v03 (2010)
Global Objects Definitions will also be needed to draw some common objects for completion of a specification.

3. Ramp Metering Terminology

Standard title: NTCIP 1207 v02 Object Definitions for Ramp Meter Control (RMC) Units (Ref.1)

Ramp meter is a traffic controller (Type 170 or 2070 or ATC) equipped with software/firmware and algorithms specific to a freeway ramp to control (to meter) traffic flow entering freeway lanes

Ramp metering is a rate, expressed in vehicle per hour per lane (vphpl), at which vehicles are allowed to proceed through the metered lane signal (release rate), for example, a Ramp Meter will allow 500 vph per lane (vphpl) release rate.

Ramp metering control (RMC) is a system in which the entry of vehicles onto a freeway from an on-ramp is controlled by a traffic signal allowing a fixed number of vehicles to enter from each metered lane of the on-ramp during each cycle

RMC unit consists of the field controller, its suit of sensors, and its warning signs and signals, and stop bar (a pavement marking where vehicle must stop first for Green).

RMC unit layout: Figure 1 shows components of an RMC unit function in the field environment.
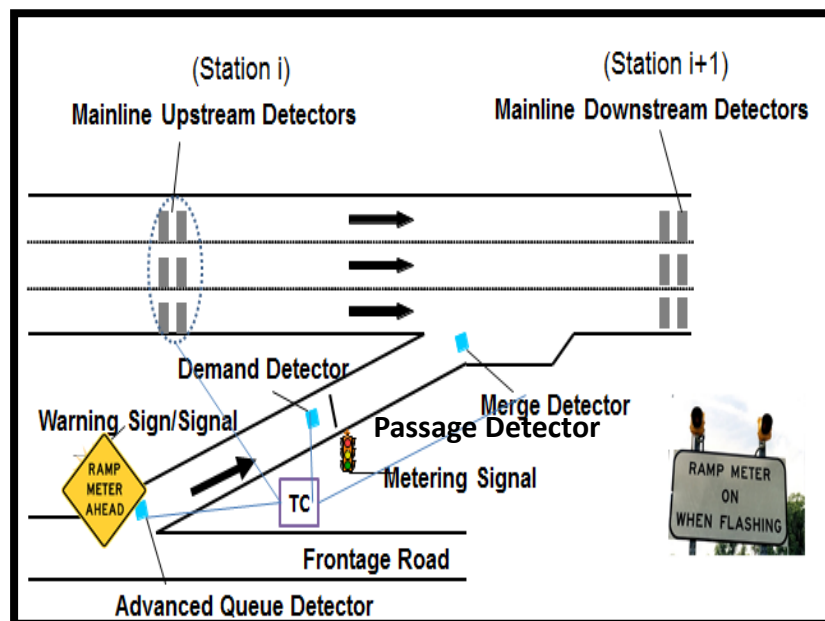
Figure 1 RMC Unit Layout

Advanced warning sign is a sign that alerts motorists of ramp meter signal operation.

Flow rate is the rate at which vehicles pass a detection zone, expressed in vehicles per hour per lane or vphpl, e.g. 400 vphpl.

Metered lane is the lane on the ramp that is equipped with a signal. Typically one lane, but in some cases two lanes are found to be metered. In some rare cases a three lane operation is possible.

Discussion on Metering Strategies Suitability (NTCIP 1207 v02 supports both Strategies)

Fixed rate metering (pre-timed) follows a preplanned rate schedule. This is the simplest form of ramp metering and requires neither mainline detection devices nor communication with a TMC (although many systems that use this technique have detection and communication capability). However, if there is no mainline or ramp detection, agencies must regularly collect data by another method to analyze traffic conditions on the freeway and determine the appropriate metering rates. The metering operation will require frequent observation so rates can be adjusted as traffic conditions change over time.

Traffic responsive metering is a calculation based response in which algorithms calculate or select ramp metering rates based on current measured conditions on the freeway. Surveillance of the freeway mainline using traffic detectors is required. Different strategies are required for local traffic responsive ramp metering and system-wide traffic responsive ramp metering as discussed in subsequent sections of this chapter.

In a **local traffic responsive metering**, algorithms keep the volume or density of the flows at the merge of the mainline and entry ramp from exceeding the values of which flow breakdown may occur. Lane occupancy, the surrogate for density, is often used for this purpose.

In an emerging **system-wide traffic responsive metering**, a series of ramps are controlled in a coordinated manner to balance demands-capacities by using more complex real-time data, sometimes referred to as an adaptive system (Ref.8). Washington State DOT, Caltrans, and Minnesota are examples of regions where system-wide ramp metering is emerging in recent years.

For readers inquiring about which of the above two strategies are used in real-world applications and how the NTCIP 1207 v02 standard supports user needs, the following detailed discussion and figures illustrates both points.

Figure 2 illustrates how a TMC operator can make a request to the RMC Unit to implement an Action from the five ACTIONS supported by the standard for which design objects are provided. Incidentally, other actions in the figure are also at times needed, although not frequently. It is therefore necessary to understand the underlying user needs (Do I need capability for all five actions?). Figure 3 depicts how operational user needs are met by the RMC unit. It shows the RMC unit collects data as inputs and controls a warning sign and the signal intervals Green-Yellow-Red as outputs. A continuous cyclic process meets "operational needs" by allowing, for example, 300 vphpl release rate on to the freeway. This is achieved by either one vehicle per Green or in some cases two

vehicles in tandem where a ramp merging geometric permits it and as per local agency policy. In more than one metering lane operation, e.g. HOV lane, alternate Green indicators are provided.
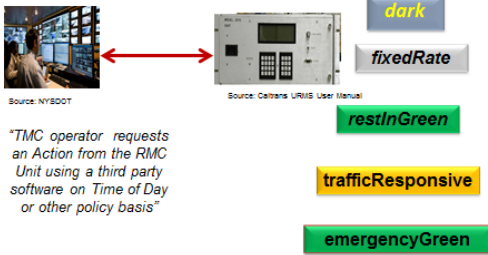
Figure 2 Remote Control of RMC Actions   **Figure 3 RMC Operations**

As the name implies, pre-timed (also referred to as time-of-day or fixed time), metering rates are pre-set based on historical conditions and are fixed accordi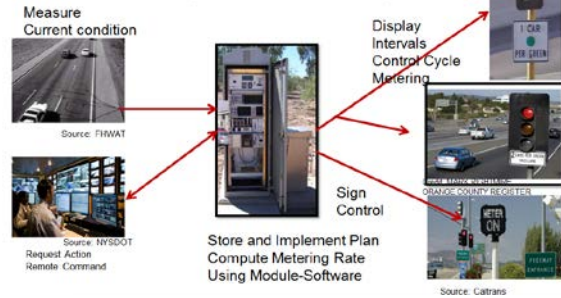ng to the time of day. Meters are activated based on pre-set schedules. Again as the name implies, a traffic-responsive method using real-time data is used to determine control parameters, perhaps including when ramp meters are active. Traffic responsive systems can also be constrained to operate only during selected times of day based on policy decisions.

- **Pre-timed metering** is the simplest and least expensive form of ramp metering for construction and installation. The low cost of this approach is due in part to the fact that detection and communication with a Traffic Management Center (TMC) is not required. However, this approach is also the most rigid because it cannot make adjustments for real-time conditions including non-recurring congestion (i.e., congestion that occurs as a result of weather, collisions, etc.). Similarly, as pre-timed metering rates are based on historical data, metering rates will typically be slightly (or significantly, if the rates are not updated periodically) too low or high for current conditions. This may result in less restrictive metering rates than optimal when congestion is heavy, resulting in more freeway congestion than necessary. It may also result in over restrictive metering rates when congestion subsides, resulting in unnecessary queuing and delays on ramps and arterials.

  As such, pre-timed metering approaches are best applied to address traffic problems that are a direct result of recurring congestion or localized safety problems that can be reduced by simply breaking up the queues of vehicles entering the freeway. In other words, pre-timed metering is best used to address conditions that are predictable from day-today. Pre-timed metering may also be effective in construction zones or for other temporary metering, including special events that do not recur at the same place or on a regular schedule. The low cost of these systems make them attractive backups to other metering approaches or for situations when the primary approach fails. If there is no mainline or ramp detection, agencies must regularly collect data by alternative means in order to analyze traffic conditions on the freeway and determine the appropriate metering rates. The metering

operation will require frequent observation so rates can be adjusted to meet traffic conditions.

- **Traffic responsive strategies** use freeway loop detectors or other surveillance systems to calculate or select ramp metering rates based on current freeway conditions. Traffic responsive metering systems often produce results that are generally five to ten percent better than those of pre-timed metering. A traffic responsive approach can be used either locally or system-wide. Both of these approaches are discussed below.

  Local Traffic Responsive: Local traffic responsive metering approaches base metering rates on freeway conditions near the metered ramp (i.e., immediately upstream and downstream of the ramp, or at the merge point). Similar to pre-timed systems, local traffic responsive systems are proven strategies that are often used as backups when system-wide algorithms fail. Unlike pre-timed systems, surveillance of the freeway using traffic detectors is required. Although more capital costs are required to implement traffic responsive systems, they more easily adapt to changing conditions and can provide better results than their pre-timed counterparts.

  System-wide Traffic Responsive: The goal of system-wide traffic responsive systems is to optimize traffic flow along a metered stretch of roadway rather than at a specific point on the freeway (as is the case of local traffic responsive systems). As such, metering rates at any given ramp will be influenced by conditions at other ramps within the system or corridor that is metered. Like local traffic responsive systems, system-wide traffic responsive systems require data from ramp detectors and local freeway detectors. In addition to these components, system-wide traffic responsive systems are unique in the fact that data is also needed from downstream detectors and/or upstream detectors at multiple locations, potentially from cross-street signal controllers, and from the central computer. System-wide traffic responsive systems have the most complex hardware configuration compared to the other metering approaches discussed so far (i.e., pre-timed and local traffic responsive).

4. User Needs Organization and Examples

The following list (partial) of user needs is organized to illustrate the extent of support provided by the standard. This list is developed based on Annex A of the standard, which provides operational requirements parameters and is found to be useful in the practice. Users may begin with the list in organizing their RMC user needs and writing them using the criteria stated after the list and also discussed in the module presentation.

Freeway Segment:
- Number of Lanes
- Lane's ID Number
- Mainline Detectors (*Volume, speed, Occupancy*)
- Upstream Station-Downstream Station

ON-Ramp Operation:
- Number of Metered Lanes
- Lane's ID Number
- Detectors: Demand, Queue, Passage

- Advanced warning signs and control
- Traffic Responsive Plans- N
- Metering Levels-N
- Signal Service-Green/Yellow/Red

Command Sources:
- Manual
- Communications
- Interconnect
- Time Base Control
- Default

Command Actions:
- Fixed Rate
- Traffic responsive
- Rest-in-Dark
- Rest-in-Green

Why are we Writing RMC Unit User Needs?

A user need is a concise statement in a specification that will dictate features in the RMC unit. A feature is a behavior of the RMC unit which cannot be taken for granted. RMC unit comes with more than one feature to serve desired (assigned) functions. The features identify and describe the various functions that users may want the device to perform. These features are derived from the high level user needs identified in the problem statement.

A procurement writer is required to develop a specification to acquire a standards-based RMC system by deriving user needs from standards. However, a problem occurs when a project needs to deploy certain standards without SEP content—RMC is one of them. These standards do not contain documented user needs from which an agency can select or customize.

A user need describes a business or operational problem (opportunity) that must be fulfilled in order to justify purchase or use. This representation may occur in many ways expressed by different users with varied understanding of the baseline case. This could lead to an incomplete system development or ambiguous statements confusing developers. To avoid such happenings, users needs need to be unambiguous and expressed in a consistent manner. This will result in desired interoperability and vendor independence.

Criteria for Writing a Well-Formed User Need

In general, ITS Standards with SEP content have followed the following SE criteria to define user needs. We need to understand this and apply it to user needs extracted from standards without SEP content as discussed below.

1. **Uniquely Identifiable**: Each need must be uniquely identified (i.e., each need shall be assigned a unique number and title).
2. **Major Desired Capability** (MDC): Each need shall express a major desired capability in the system, regardless of whether the capability exists in the current system or situation or is a gap.

3. **Solution Free**: Each need shall be solution free, thus giving designers flexibility and latitude to produce the best feasible solution.
4. **Capture Rationale:** Each need shall capture the rationale or intent as to why the capability is needed in the system.

Examples of RMC User Needs

The following representative examples of RMC unit user needs (alternatively called features) are developed using above criteria, listed in no particular order. Users are advised to complete the list as an exercise in a local specification purpose.

UN 2.1: Provide Live Data Exchange
*A management station (central software) has a need to conduct a **live data exchange** with the RMC unit to retrieve any set of data at any time.*

UN 2.2: Provide Logged Data Exchange
*A management station has a need to **log data** and to **retrieve data** at a later time from the RMC unit in a situation when communication is lost or not always on communications (e.g. dial-up links).*

UN 2.3: Provide Capability to Retrieve RMC Identity
*A TMC Operator **desires to inquire** basic information about the RMC unit such as its location, make, model and version of the device components.*

UN 2.4 Fixed Rate
*The agency desires to implement a **fixed** metering rate selected by the central system (or locally) based on a Time of Day Schedule to **control ramp traffic** for each metered lane. Currently, the agency intends to assign the left lane as Priority (HOV) lane and right lane as a common lane.*

UN 2.5 Queue Override
*The agency desires to implement a **queue override** operation, in the event that the occupancy of a queue detector reaches a certain threshold by increasing (faster) metering rate **to flush** the ramp traffic to cut delays.*

UN 2.6 Traffic Responsive
*The agency needs to **implement a traffic responsive metering** mode based on the plan selection that includes metering rate and metering levels based on occupancy thresholds to respond to change in traffic conditions as reported by the mainline and ramp detectors.*

UN 2.7   Signal Service
The agency needs to adhere to transiting from a non-metering state to a metering state within the intervals of alert, warning, and green-yellow-red intervals during a non-metering state.

UN ID 2.8 Transitioning
*During a non-metering state, the RMC unit ceases all metering and signalized control. Advanced warning signs and all signal lamps are to be dark while in this state. This mode is implemented at the **end** of a metering cycle green interval. Detector monitoring continues without interruption in processing while the controller is in the non-metering state.*

UN 2.9: Configure a RMC Unit

*A TMC operator with access to a management station has a **need to retrieve information** about the configuration of the RMC Unit to properly communicate with the device. The controlling entity may also need to alter the configuration to produce expected operations.*

UN 2.10: Command Source Priority

*The TMC operator, with access to RMC system, has a need to allow for **five priority-based** mechanisms to control the RMC unit to **take metering** action(s). The sources desired in priority order are: Manual (local at front panel), Communications from a central location (TMC), Interconnect (peer-to-peer communications from a filed master controller), Time Base Control (TBC for special events) and Default. Default mode is placed in effect after skipping all other commands due to loss failures.*

Summary of Sample User Needs (Section 2 is assigned in a typical UN documentation)

- *UN 2.1 Provide Live Data Exchange*
- *UN 2.2 Provide Logged Data Exchange*
- *UN 2.3 Provide Capability to Retrieve RMC Identity*
- *UN 2.4 Fixed Rate*
- *UN 2.5 Queue Override*
- *UN 2.7 Signal Service*
- *UN 2.8 Transitioning*
- *UN 2.9 Configure a RMC Unit*
- *UN 2.10 Command Source Priority*
- *UN 2.11 Command Source Parameters*
- *UN 2.12 Metering Action*

RMC Unit Conformance Groups (Annex B)

NTCIP 1207 v02 lists the following partial list of CGs from which a specification can be prepared. Students are urged to consult Annex B of the standard for the full list of RMC CGs.

Ref	Areas	Clause of Profile	Status	Support
B.3	General Configuration Conformance Group	NTCIP 1207 – 3.2	O	Yes / No
B.4	Traffic Responsive Conformance Group	NTCIP 1207 – 3.3	O	Yes / No
B.5	Metered Lane Conformance Group	NTCIP 1207 – 3.3	M	Yes
B.6	Dependency Group Conformance Group	NTCIP 1207 – 3.4	O	Yes / No
B.7	Queue Detection Conformance Group	NTCIP 1207 – 3.4	O	Yes / No
	- Length Based Queue Detection		O	Yes / No
	- Occupancy Based Queue Detection		O	Yes / No
	- Quick Occupancy Based Queue Detection		O	Yes / No
	- Rate Adjusted Queue Adjustment		O	Yes / No
	- Level Adjusted Queue Adjustment		O	Yes / No
	- Fixed Rate Queue Adjustment		O	Yes / No
B.8	Passage Detection Conformance Group	NTCIP 1207 – 3.5	O	Yes / No
	- Long Stop	NTCIP 1207 – 3.5	O	Yes / No
B.9	Time Base Conformance Group	NTCIP 1207 – 3.6	O	Yes / No
	- Mainline Scheduling	NTCIP 1207 – 3.6	O	Yes / No
B.10	Physical I/O Conformance Group	NTCIP 1207 – 3.7	O	Yes / No
	- Metered Lane Output	NTCIP 1207 – 3.7	O	Yes / No
	- Dependency Group Output	NTCIP 1207 – 3.7	O	Yes / No
B.11	Block Object Conformance Group	NTCIP 1207 – 3.8	O	Yes / No
B.12	Configuration Conformance Group	NTCIP 1201 - 2.2	M	Yes

The summary list of sample user needs, presented previously as an example (and additional user needs developed for project), is traceable to the conformance groups table shown above for specification conformance purpose. As the table shows, Mandatory (M) Metered Lane CG from the NTCIP 1207 and Configuration CG from NTCIP 1201, are minimum requirements for conformance to an RMC specification. Specification should also include Optional (O) CGs selected by the user to meet local project needs. The last column reflects project level support required for each CG.

As shown in the table below, user needs are traced to one or more CGs. Note the example table shown below is only an outline and does not list user needs titles shown above. However, users can adopt it and populate their own user needs in the columns accordingly.

Traceability with Conformance Groups

- Identified RMC User Needs can ONLY be traced to the CGs in this standard

User Need	Conformance Group	Requirement	Object Support
UN 1 Configure RMC Unit	B.3 General Configuration		
	B.5 Meter Lane		
UNs	B.4 Traffic Responsive		

5. References

1. *NTCIP 1201 v03 Global Objects*, http://ntcip.org/library/documents/
2. *NTCIP 1207 v02   RMC Units*, http://ntcip.org/library/documents/
3. *NTCIP 9001: Information Report- NTCIP Guide v04*, http://ntcip.org/library/documents/
4. *A202: Identifying and Writing User Needs When ITS Standards Do Not Have SEP Content,* www.pcb.its.dot.gov/stds_training.aspx
5. Kansas City SCOUT-Video on Ramp Metering (4 min.) http://www.kcscout.net/RMWatchTheVideo.aspx
6. *Ramp Metering: A Review Of The Literature, Arnold, VIRGINIA TRANSPORTATION RESEARCH COUNCIL,* http://www.virginiadot.org/vtrc/main/online_reports/pdf/99-tar5.pdf

7. *Ramp Management and Control 2006, FHWA,* http://ops.fhwa.dot.gov/publications/ramp_mgmt_handbook/manual/manual/pdf/rm_handbook.pdf

8. *Freeway Management and Operations Handbook, Updated in 2006, FHWA* http://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/report_info.htm

9. *Traffic Engineering Handbook, 6th Edition, ITE, Washington DC.*

Further Reading on Ramp Metering Design and Development

10. *Georgia DOT* NaviGAtor *-ITS Design Manual,* 2010, http://mydocs.dot.ga.gov/info/designbuild/Shared%20Documents/751580-/GDOT%20ITS-ATMS%20Requirements/GDOT%20ITS%20Design%20Manual%20Final.pdf

11. *Arizona DOT Ramp Metering Design Guide, 2013,* http://www.azdot.gov/docs/default-source/intelligent-transportation-systems/adotrampmeteringdesignguide_november2013.pdf?sfvrsn=2

12. *Developing an area-wide system for coordinated ramp meter control, Y. Wang et el. University of Washington,* 2008, http://www.lib.washington.edu/msd/norestriction/b60995592.pdf

13. *Feedback Ramp Metering in ITS, Pushkin. Kachroo and Kaan Ozbay, 2003,* Kluwer Academic/Plenum publisher (Researchers and Software developers may find this book on adaptive system stimulating and useful in modeling process.)

6. Study Questions

1. **Which of the following statements is <u>FALSE</u> as applied to the NTCIP 1207 standard?**

   a) Standard is independent of the type of traffic controller
   b) RMC design objects are organized by functions in the MIB
   c) RMC user needs are listed
   d) Ramp metering module resides in the traffic controller

2. **Which of the following is a <u>FALSE</u> statement related to traffic responsive operation?**

   a) A TMC operator can remotely retrieve traffic flow data
   b) Communications command source has the highest priority
   c) Multiple metering levels are established with a metering plan table
   d) RMC-module is located within the RMC unit.

4. **What is the best source of user needs?**

   a) Freeway Traffic Management Concept of Operations (ConOps)
   b) Regional ITS Architecture Ramp Metering Service Package
   c) NTCIP 1207 v02 Standard Documentation
   d) All of the above sources

5. **Which of the following is a <u>FALSE</u> statement related to the NTCIP 1207 RMC v02 Standard?**

   a) Only Metered Lane CG is required to conform to the standard
   b) Traffic Responsive CG is optional
   c) V02 standard is NOT compatible with the previous version
   d) A CG represents one or more RMC unit function