قطــر تستحــق الأفضــل
Qatar Deserves The Best

INTELLIGENT TRANSPORTATION SYSTEMS
STRATEGIC DOCUMENT

DEPLOYMENT GUIDELINES

Infrastructure Affairs
Roads Design Department

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1 Introduction

1.1 Purpose of the Guide

The purpose of this publication is to provide guidance to designers, systems integrators, civil engineers and ITS vendors to enable the consistent deployment of an Intelligent Transportation System (ITS) to support Ashghal's transportation operations and requirements. This document is not prescriptive nor is it to be treated as a standard, but a guide to decision making and design considerations. Designers are expected to utilize and leverage their own specialist skills in the development of ITS related designs, adding to the value of their offerings in line with international standards.

1.2 Intended Audience

This document is directed at individuals and organizations involved in the design and deployment of ITS devices. Expected users of this document are expected to be designers, systems integrators, contractors and equipment vendors.

1.3 Supporting Resources and References

REFERENCE	DESCRIPTION
Ashghal Civil and Structural Standards for Intelligent Transportation Systems	The intent of these documents is to standardize the design of infrastructure elements that support ITS. This series should be referred to by Ashghal and their consultants for all ITS projects.
Qatar Construction Specifications 2010 (QCS 2010)	The Qatar Construction Specifications are intended for use with the General Conditions of Contract. Contractors shall comply with every requirement of the Qatar Construction Specification that is relevant to the type of work forming any part of the Contract and shall adopt whichever permissible option or alternative that is best suited to the needs of the construction work being undertaken. Where there is a conflict between this document and the Qatar Construction Specifications 2010 (QCS 2010) the QCS 2010 shall apply.
Qatar Traffic Manual (QTM)	This manual provides guidance on the basic principles of traffic signage and road markings.
Qatar Highway Design Manual (QHDM)	This manual provides the guidelines for the design of roadways and intersections in Qatar.

Ashghal's ITS Specifications	The ITS Specifications should be referred to by Ashghal and their consultants for all ITS projects.
The National Transportation Communications for ITS Protocol (NTCIP) Guide	The NTCIP Guide is a document created to assist in understanding, specifying, and using a consistent set of defined and standardized communications protocols and methods for ITS devices, (The NTCIP Guide is supported with freely available and open protocol based data definitions for all types of ITS devices). The NTCIP collection of data and protocol definitions should be used to assure that devices and systems, both at the roadside and between control centers, use open protocols and can easily communicate with each other.

Table 1-1 Client Resources

The references supplied above are provided as a *starting point* for designers with regards to supporting documentation. In addition to these references, additional resources and references may be required or identified during the system's engineering lifecycle and project development process. The local environment, requirements and specifications need to be taken into consideration when designing for ITS elements as part of any scheme for any type of roading infrastructure program in the State of Qatar. Pragmatic equipment selection, connectivity and system functional choices should always be made in the interests of creating a holistic and workable ITS framework by designers using this or any other ITS reference materials. It is expected that the designers' reference material will be the most current version of a particular standard or specification which includes any interim amendments or inclusions.

It is the designers' responsibility to ensure that designs comply with the most up-to-date standards and specifications at the time of the design, with reference to current international practice in the industry.

2 Systems Engineering Process

The Systems Engineering (SE) approach to the delivery of technology projects is accepted internationally as the best method to follow when undertaking the planning, designing, and implementing of ITS projects. As such, the SE process is the recommended approach to be taken in Qatar for the delivery of ITS programs. This section leads the user step by step through the entire project life cycle and describes the SE approach at each step. The section describes how to use the SE approach on ITS projects to achieve the following goals:

- Increase the likelihood that an ITS project will meet the user's needs.
- Reduce the risk of schedule and cost overruns.
- Develop more flexible, resilient systems and reduce the risk of obsolescence.
- Verify functionality and reduce defects through structured testing and correct validation and verifications processes
- Improve documentation.
- Clearly demarcate project completion

2.1 Systems Engineering Overview

SE focuses on defining customer needs and required functionality early in the development cycle, documenting the requirements, and then proceeding with design development/evolution and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, testing, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.[1]

SE it will help to identify issues earlier in the project schedule and will improve the chances for a successful project in the end. SE does this by focusing on the following key principles[2]:

[1]International Council on Systems Engineering (INCOSE), What is Systems Engineering?, http://www.incose.org/practice/whatissystemseng.aspx, 14 June 2004.

[2] Principles are taken from USDOT, Systems Engineering for ITS, An Introduction for Transportation Professionals, January, 2007.

- **Stakeholder Involvement**

  Successful projects involve the customer, users, operators, and other stakeholders in the project development. The SE process includes reviews and decision points intended to provide visibility into the process and encourage stakeholder involvement. The SE process involves stakeholders through all stages of the project, from initial needs definition through system verification and acceptance.

- **Start with a clear definition of success**

  Consensus should be reached at the beginning of the project on what will constitute success at the end. This means that the stakeholders should start with an agreement of what the project should accomplish (through a definition of user needs) and the metrics that will be used to measure the success of the project.

- **Delay Technology Choices**The choices available when a project is initially conceived may well be replaced by even better technology by the time the project is implemented. Specifying technology too early will result in outdated technology or constant baseline changes as you try to keep up with technological advancements.

  Baseline, a frequently used term in SE, is a reference point against which all members of a project team works.

- **Simplify and Componentise**

  Many systems are large and complex. A key SE strategy is to break down such a system into smaller subsystems, and subsystems into more manageable hardware and software components. These simpler components are easier to understand and define and ultimately are easier to build.

- **Implement Full Traceability**

  As a project or system moves from one step to the next in the SE process, it is important to be able to relate the items in one step with those of another step in the SE process. The relationship between items is called *traceability*, which is used to relate a requirement to the subsystem that will fulfill the requirement. Traceability connects many items together. The requirement will be related to a user need as well as to a test that will be used to verify the requirement. Traceability should allow a direct transparent and complete relationship between technologies selected and user requirements to be established including what the technology will do and how it is to be used.

2.2 The Systems Engineering Process

What exactly is the SE process? There have been many representations of it over the years, but one that is commonly used in transportation is called the Vee model. This model defines a set of steps that any project using SE can follow and covers the entire life cycle of the system being developed, from the planning that occurs prior to the start of the project development all the way through to the decisions that are taken to retire or replace a system once it is at the end of its life cycle.

The Vee model includes a series of major milestones where the output of the previous step is reviewed and the customer and project team determine whether the project is ready to move to the next step in the process. The project moves forward only if the criteria for the decision point have been satisfied. These decision points /gates are important control points for the project and provide visibility into the project's development, allowing for issue identification and course correction during development phases.

The steps of the SE process are summarized below.

2.2.1 ITS Architecture

ITS Architecture is intended to define the technical, functional, practical and institutional ITS requirements planned for ITS deployments in a specific region. It is a macro level tool to support ITS planning in the region, serving as a guide for how different ITS-related projects should fit together into an overall plan for the best use of ITS & ICT technology, operations, Stakeholders and processes to meet Transportation objectives. Every outcome which meets a functional requirement for ITS shouldbe able to be described completely within the Architecture and forms a Transportation Package that delivers that outcome. With reference to Qatar, this macro viewpoint is provided by the State of Qatar ITS Architecture, which is available through Ashghal.

2.2.2 Project Planning

A Project Management Plan (PMP) and Systems Engineering Management Plan (SEMP) for the development of the project are required. The PMP identifies the detailed work plans for both the administrative and technical tasks. The plan estimates the resources (people, equipment, and facilities) needed for each task along with an estimated budget for each task. The plan also identifies key events and the technical and program milestones/gateways and establishes a schedule for the project. The PMP is the primary document for tracking the schedule and budget of the project.

The SEMP is the top-level plan for organizing and managing all engineering activities for the project. The SEMP defines how the SE portion of the work item will be organized, structured, conducted and how the total engineering process will be controlled to provide a product that fulfills customer requirements. The SEMP will be used in technical management of this project, describing the process and steps to be performed in the conduct of the project, and the roles and responsibilities of the participants in the project. The SEMP describes how each SE subtask of the PMP will be performed and completed, and defines the controls to ensure that each subtask is completed correctly and on-schedule. The PMP focuses on the management processes whereas the SEMP concentrates on applying the SE structure. Templates for the PMP and SEMP are shown in Table 2-1 and Table 2-2, respectively.

SECTION	CONTENTS
1.0 Purpose of Document	The purpose of this document is the plan for the execution of the project, including defining all necessary tasks and their products.
2.0 Scope of Project	This section provides a brief description of the planned project and the functional purpose of the system to be built. Special emphasis is placed on the project's complexities and challenges to be addressed by the project's managers. This section also defines the project's relationship to the State of Qatar ITS Architecture. It defines the relationship of the project's system to other systems with which it interfaces, either physically [with a data interface] or operationally.
3.0 Project Tasks	This section is the heart of the PMP. It defines each task of the project in terms of the task inputs, approach, and outputs. **Inputs:** Identification of the inputs to each task. Inputs can be a variety of things, including, but not limited to: documents from outside the project or from other tasks of the project, or products other than documents from other tasks that are a necessary precursor to the performance of this task. **Approach:** A description of the approach to be taken by the team performing the task. This may include a description of the products of the task or a breakdown of the tasks into sub-tasks. This description may include identification of procurement activities that need to be taken in this task. For SE and design tasks, this description may be expanded as necessary in the SEMP, which would be an activity and output of one of the tasks. **Outputs:** A description of the products of the task. As with inputs, the outputs may take many forms, including, but not limited to: • Documents to be produced by the task team, such as specifications or Verifications Plans. • Meetings, including management meetings and technical reviews • Other products, such as software code, procured hardware, and integrated or verified sub-systems.
4.0 Work Breakdown Structure and Task Budgets	This section provides a hierarchical structure of all tasks and sub-tasks of the project, identifying the name of the task or sub-task, the allocated budget, and the team or organization with the authorization and responsibility to perform the task. The budget may not be allocated to each sub-task but may be allocated to a higher level group of sub-tasks, tasks, or group of tasks, as necessary to manage the project.

5.0 Schedule	Development of a schedule for each task, for each sub-task, and for each output of a task. This schedule is under complete control of the project's management by a variety of means, including the assignment of more or fewer resources. This schedule takes into account the necessary precursors [inputs] to each task or sub-task.
6.0 Deliverable Requirements List	This section is, as much as possible, a complete and precise list of the tangible deliverables of each and every task. In general, a tangible deliverable may include, from the list of outputs of a task: • Documents, especially documents to be reviewed by stakeholders and documents to be used after the system is built. • Meetings and reviews to be attended by project stakeholders. • Other products, such as deliverable hardware [by name, part number, and quantity] and deliverable software products, such as source code and executable codes.
7.0 Referenced Documents	This section lists the applicable documents that are inputs to the project [that is, are needed by but not produced by the project].

Table 2-1: Project Management Plan (PMP) Template

SECTION	CONTENTS
1.0 Purpose of Document	This section is a brief statement of the purpose of this document and the plan for the SE activities with special emphasis on the engineering challenges of the system to be built.
2.0 Scope of Project	This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's complexities and challenges that must be managed by the SE efforts. This section defines the general process for developing the SEMP, including the draft framework version prepared by Ashghal or their Systems Engineer and the complete version prepared in conjunction with the Systems Engineer and development teams.

3.0 Technical Planning and Control	This section lays out the plan for the SE activities. It should be written in close synchronization with the project's Project Plan. Unnecessary duplication between the Project Plan and the SEMP should be avoided. The purpose of the section is to identify the products of each SE activity, such as documentation, meetings, and reviews. This list of required products will control the activities of the team performing the activity and will control the satisfactory completion of the activity. Some of these plans may be completely defined in the SEMP. For other plans, the SEMP may only define the requirements for a particular plan. The plan itself is to be prepared as one of the subsequent SE activities, such as may be the case with a Verification Plan or a Deployment Plan. Almost any of the plans described below may fall into either category. • **Configuration Management Plan** describes the development team's approach and methods to manage the configuration of the system's products and processes. It will also describe the change control procedures and management of the system's baselines as they evolve. • **Risk Management Plan** addresses the processes for identifying, assessing, mitigating, and monitoring the risks expected or encountered during a project's life cycle. It identifies the roles and responsibilities of all participating organizations for risk management. • **Validation & Verification Plan**, this critical plan is written along with the requirements specifications. This is the heart of all testing and includes all test planning and executions. • **Verification Procedures** are developed by the development team and this defines the step-by-step procedure to conduct verification and must be traceable to the Verification Plan. • **Other plans** that must be considered for inclusion are, Software Development Plan, Hardware Development Plan, Technology Plan, Interface Control Plan, Installation Plan, Operations & Maintenance Plan, Training Plan, Data Management Plan, and a Validation Plan.
4.0 Systems Engineering Process	This section describes the intended execution of the SE processes used to develop the system. The SEMP describes the processes specifically needed for a project in sufficient detail to guide the work of the SE and development teams.

Table 2-2: Systems Engineering Management Plan (SEMP) Template

2.2.3 Concept of Operations

The purpose of the Concept of Operations (ConOps) is to clearly convey a high-level scenario driven viewpoint of the system to be developed, which each stakeholder can understand and develop a perspective on. This step of the process identifies the user needs that must be addressed by the project – that is, what transportation problem/packages or operational needs is the project or system trying to address. It documents a clear definition of the stakeholders' needs and constraints that will support system requirements development in the next step.

This is a foundation step that frames the overall system and sets part of the technical course for the project. A good ConOps answers who, what, where, when, why, and how questions about the project from the viewpoint of each stakeholder, as shown in below.

- Who – Who are the stakeholders involved with the system?
- What – What are the elements and the high-level capabilities of the system?
- Where – What is the geographic and physical extent of the system?
- When – What is the sequence of activities that will be performed?
- Why – What does your organization lack that the system will provide?
- How – What resources are needed to develop, operate, and maintain the system?

The ConOps is a powerful tool for defining needs since it forces the stakeholders to think about the way the system will behave and how it will interact with users and other systems. Interviews, workshops, and surveys are some of the techniques that are used to develop a ConOps.

The following criteria should be used as the basis for documenting well-written needs:

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.

The list of user needs that is generated also should be prioritized by the stakeholders. Once stakeholders start to compare and rank the user needs, they will discover that some of their “needs” are really “wants” or “nice-to-haves”. A template for the development of a ConOps is shown in Table 2-3.

SECTION	CONTENTS
1.0 Purpose of Document	This section is a brief statement of the purpose of this document. It is a description and rationale of the expected operations of the system under development. It is a vehicle for stakeholder discussion and consensus to ensure that the system to be built is operationally feasible. This will briefly describe contents, intention, and audience. One or two paragraphs will suffice.
2.0 Scope of Project	This short section gives a brief overview of the system to be built. It includes the purpose and a high-level description. It describes what area will be covered and which agencies will be involved, either directly or through interfaces. One or two paragraphs will suffice.
3.0 The Current System	Here is a brief description of the current system or situation, how it is used currently, and the drawbacks and limitations of the current system. This leads into the reasons for the proposed development and the general approach to improving the system. This is followed by a discussion of the nature of the planned changes and a justification for them.
4.0 Justification for and Nature of Changes	This section contains a discussion of why the changes are needed and describes the user needs that the proposed system should meet. The user needs are one of the key outputs of the SE process. User needs are summarized in the Ashghal Contract 5 - Concept of Operations document, and one or more of the needs found in the comprehensive list of user needs for Qatar in that document can be used as a starting point for this section. Needs selected from this document for a specific project may need to be edited to correspond with the intended scope of the project.
5.0 Concept for the Proposed System	This section is an overview of the system to be developed. The section describes the project scope, the users of the system, what it interfaces with, the states and modes of the system, the planned capabilities, the goals and objectives, and the system architecture. Note that the system architecture is not a design [that will be done later]. It provides a structure for describing the operations, in terms of where the operations will be carried out, and what the lines of communication will be. This section can be developed by starting with a selection of one or more customized service packages from the Qatar ITS Architecture. Start by reviewing each of the customized service packages in the Qatar ITS Architecture (found at http://consystec.com/qatar/web/services.htm), and select those that are relevant to the project. These selected customized service package diagrams can then be combined and edited to create a project architecture identifying stakeholder ITS elements and architecture flows of information between the selected ITS elements.

6.0 Operational Scenarios	Each scenario describes a sequence of events, activities carried out by the user, the system, and the environment. It specifies what triggers the sequence, who or what performs each step, when communications occur and to whom or what [e.g., a log file], and what information is being communicated. The scenarios will need to cover all normal conditions, stress conditions, failure events, maintenance, and anomalies and exceptions. There are many ways for presenting scenarios, but the important thing is that each stakeholder can clearly see what his expected role is to be. Examples of project operational scenarios are shown in the Ashghal Contract 5 - Concept of Operations document.
7.0 Analysis of Proposed System	This section describes the concept exploration, if one occurred, but will be removed if no set of alternatives was evaluated. It starts with a list and description of the alternative concepts examined. The evaluation and assessment of each alternative follows. This leads into the justification for the selected approach. This is not a design, but a high-level, conceptual, operational description. It uses only as much detail as needed to be able to develop meaningful scenarios. In particular, if alternative approaches differ in terms of which agency does what, that will need to be resolved and described. An example would be the question of whether or not a regional signal system will have centralized control.
8.0 Applicable Documents	This section is a place to list any supporting documentation used and other resources that are useful in understanding the operations of the system. This could include any documentation of current operations and any strategic plans that drive the goals of the system under development.
9.0 Appendices	This is a place to put a glossary, notes, and backup or background material for any of the sections.

Table 2-3: ConOps Template

2.2.4 System Requirements

One definition of a requirement is a condition or capability needed by a user to solve a problem or achieve an objective (see Institute of Electrical and Electronics Engineers (IEEE) Standard 1233-1998). Requirements comprise the basis of Ashghal’s Specifications that are used for testing and play a cross-cutting role in governing the expectations of a system across the entire system life cycle.

This purpose of this step of the SE process is to identify the system requirements that will completely fulfill the user needs to be addressed by the project. One of the most important attributes of a successful project is a clear statement of requirements that meet the stakeholders’ needs. When considering the implementation of a project, it is good practice to understand the requirements of the devices and/or systems being implemented. Knowing these requirements early in the project life-cycle can alleviate potential problems during subsequent phases. Successful projects rely on the understanding of functional, design, and testing requirements before any procurement, development, or implementation.

It is important to involve stakeholders in requirements development. Stakeholders may not have experience in writing requirements, but they are the experts concerning their own requirements. The system requirements ultimately are the primary formal communication from the system stakeholders to the contractor. The project will be successful only if the requirements adequately represent stakeholders' needs and are written so they will be interpreted correctly by the contractor.

Each developed requirement should be documented and uniquely numbered to support traceability throughout the project. Note that each user need maps to a number of requirements; just one for each need is shown as an example.

Each requirement should use "shall" in the sentence, and above all, the requirement should be measurable and testable. Functions should be defined in a manner reflective of the nature of the operation, such as manual, automated, or semi-automated. The following criteria should be used when documenting and writing requirements:

1. Is it a "well-formed" requirement? Some of the attributes of "well-formed" requirements are:
    a. Necessary – Is the requirement an essential part of the system?
    b. Clear – Can the requirement be interpreted one and only one way?
    c. Complete – Is the function fully defined without needing further clarification?
    d. Consistent – Does the requirement contradict or duplicate another requirement?
    e. Achievable – Is the requirement technically feasible at a reasonable cost and in a reasonable time?
    f. Verifiable – Can one unambiguously determine if the requirement has been met?
    g. Concise – Is the requirement described succinctly and without superfluous text?
    h. Technology independent – Is the requirement statement technology independent?
2. Is the requirement mapped to one or more user needs? This will also address whether the requirement is in fact needed.
3. Does the requirement satisfy the intent and all key items of the need?

A template for the development of System Requirements is shown in Table 2-4.

SECTION	CONTENTS
1.0 Scope of System or Sub-system	• Contains a full identification of the system. • Provides a system overview and briefly states the purpose of the system. • Describes the general nature of the system. • Summarizes the history of system development, operation, and maintenance. • Identifies the project stakeholders, acquirer, users, and support agencies. • Identifies current and planned operating sites.
2.0 Reference	Identifies all needed standards, policies, laws, concepts of operations, concept exploration documents and other reference material that support the requirements.
3.0 Requirements	• Functional requirements [What the system should do]. These requirements can be used as a resource for initially developing the project functional requirements. • Performance requirements [How well the requirements should perform]. An example of this type of requirement might be requirement defining how quickly (in seconds) traffic sensor information is displayed at the center. • Interface requirements [Definition of the interfaces]. Recommended open standards, where they exist, should be used. • Data requirements [Data elements and definitions of the system]. • Non-Functional requirements, such as reliability, safety, and environmental requirements [e.g., temperature range over which the equipment must operate]. • Enabling requirements [e.g. Production, development, testing, training, support, deployment, and disposal requirements]. This can be developed through references to other documents or embedded in these requirements. • Constraints – [e.g., technology, design, tools, and/or standards]. For example, the continuation where appropriate of legacy technology investments in Qatar.

4.0 Validation and Verification Methods	The Validation and Verification Plan is a critical requirement and shall be provided by all ITS vendors and contractors in support of their proposed ITS designs and solutions, this requirement shall be documented as a contractual requirement in any ITS tender process: • Demonstration is a requirement that the system can demonstrate without external test equipment. • Test is a requirement that requires some external piece of test equipment, e.g., logic analyzer and/or volt meter. • Analyze is a requirement that is met indirectly through a logical conclusion or mathematical analysis of a result, e.g., algorithms for congestion. The designer may need to show that the requirement is met through the analysis of count and occupancy calculations in software or firmware. • Inspection is verification through a visual comparison. For example, quality of welding may be done through a visual comparison against an in-house standard.
5.0 Supporting Documentation	Catch-all for anything that may add to the understanding of the Requirements without going elsewhere [Reference section] Examples: diagrams, analysis, key notes, memos, rationale, stakeholders contact list
6.0 Traceability Matrix	This is a table that traces the requirements in this document to the user needs contained in the ConOps.
7.0 Glossary	Terms, acronyms, definitions.

Table 2-4: System Requirements Template

2.2.5 Design

The design step in the SE process can be broken into three distinct parts which will be described below:

- High-Level Design
- Preliminary Design & Specifications
- Detailed Design

In High-Level Design, conceptual design elements and transportation packages are identified which are going to be required to satisfy the operational and functional requirements of the Concept of Operations. This step is intended to provide a collection or list of required systems that need to be in place to achieve functional objectives. Subsystems are therefore identified and broken down further into smaller, more manageable pieces of functionality, called components. Interfaces are specified in detail, requirements are analyzed and derived, and all requirements are allocated to the system components. The definition of interfaces in high-level design permits identification of the standards that will be used. The definition of subsystems and interfaces defines a project architecture, which can be developed as a subset of the regional ITS architecture. If the project architecture, as envisioned, differs from the representation in the regional ITS architecture, a revised project architecture should be created that accurately reflects the project. If there are alternative approaches to implementing the project, alternative architectures should be developed and evaluated in order to select a desired approach.

One of the key activities of high-level design is to develop and evaluate alternative high-level designs. To do this, the system is partitioned into subsystems and the subsystems are partitioned into smaller assemblies in turn. The partitioning process continues until system components – the elemental hardware and software configuration items – are identified. The partitioning is driven by many factors including consideration of existing physical and institutional boundaries, ease of development, ease of integration, and ease of upgrading. One of the most important objectives is to keep the interfaces as simple and as standard as possible.

There are times when an informal high-level design is all that is required. If the ITS project being developed is a stand-alone system or a system that is in a single “box” that will be developed by a single group, the project doesn’t need a lot of high-level design because the project will be dealing with few external or internal interface issues. Take a look at the size and complexity of the project, particularly the number of components and interfaces, to determine whether a formal high-level design is warranted.

Detailed design involves the specification of hardware and software in sufficient detail to be able to procure or develop the products. Detailed “build to” design specifications are created for each hardware and software component to be developed. If products are procured, procurement specifications are created. In the case of standards-based interfaces, the detailed customization of the standard that will be used on the interface is defined for use in procurement. A simple user interface prototype is developed as a quick way to help users visualize the software and several iterations are created based on user feedback. Any necessary requirements and high-level design changes are identified, evaluated, and incorporated as appropriate.

There are key decision points that occur at the conclusion of High-Level and Detailed design. These usually take the form of design reviews, where the customer and the project team review the design and approve moving to the next step in the development process. In addition, in parallel with the development process the project team must obtain any approvals required to deploy the project (such as environmental approvals).

A template for the development of design documentation is shown in Table 2-5 and Table 2-6.

SECTION	CONTENTS
1.0 Purpose of Document	This section is a brief statement of the purpose of this document. It is a high-level description of the architecture [hardware and software] of the system. It summarizes the contents of the document.

2.0 Scope of Project	This section gives a brief description of the planned project and the purpose of the system to be built. This section can be copied from a previous document, and is included for completeness. This may be the only document which some project participants and stakeholders may see.
3.0 Sub-systems	This section describes the architecture of the system and how it is divided into sub-systems, when that is found to be necessary. Simpler systems may not need to be subdivided, and if so, this section is void. When sub-systems are needed, each is described in terms of the purpose, functionality, interfaces with other sub-systems, and component parts [hardware and software]. If the requirements call for different capabilities at multiple sites, the allocation of the sub-systems to these sites is shown. In order to describe the functionality of a sub-system, it is necessary to allocate system requirements to each sub-system. All requirements must be covered by at least one sub-system. However, some requirements [and especially performance requirements] may be applicable to several sub-systems. An explicit trace of all requirements from the Requirements Document into the sub-systems is a part of this document.
4.0 Hardware Components	This section identifies the hardware components of each sub-system. It identifies them by name, function, capabilities, source [manufacturer], and quantity. It shows the interconnections between the components [e.g., point-to-point or local area network]. If a hardware component needs optional components or features, they are listed and defined at this time. This section also includes a trace of requirements, where applicable, into the hardware components.
5.0 Software Components	This section describes the preliminary design of the software application. It shows the allocation of the software to sub-systems and to hardware elements. It shows and identifies the COTS software packages to be used, and their allocation to sub-systems and to hardware components. It also shows/identifies all custom-designed software packages and their allocation to sub-systems and hardware components. It shows the architectural relationship between the various software packages, both custom and COTS. The high-level design of each custom software package is described. The method used for this description depends on the methodology being used for software design. That methodology may be object-oriented design, data flow design, structured design, or any other method chosen by the project and the software development team.

6.0 Sub-system Requirements	This document may be used to describe additional requirements that were not covered in the requirements specifications. These may include, but are not limited to: • Showing greater detail of previously defined functional requirements based on additional functional analysis; for instance, defining the details of a complex algorithm. • Providing complete details of complex requirements, such as a detailed description of a complex operator interface where considerable work with operations personnel is necessary before a definitive statement of the requirement can be made. • Providing complete details of an interface with an external system. • Stating requirements which result from the separation of the system into sub-systems; that is, identifying functional requirements for the way these sub-systems work together. These types of requirements [with the exception of the last type] also may be included in the Requirements Document or documented in separate documents, as deemed appropriate.

Table 2-5: High Level Design Template

SECTION	CONTENTS
1.0 Purpose of Document	This section is a brief statement of the purpose of this document. The purpose is to expand and complete the preliminary design descriptions included in the High-Level Design Document.
2.0 Scope of Project	This section describes the project and may be copied from the High-Level Design Document.
3.0 Sub-systems	This section completes the description of the system architecture and the sub-systems, as necessary.
4.0 Hardware Components	This section completes the description of the hardware components. It contains a detailed list of the exact hardware items to be procured by name, part number, manufacturer, and quantity. If necessary, it lists any hardware component specifications or drawings which have been prepared by the design team.

5.0 Software Components	This section completes the description of the software components. It contains a detailed list of the COTS software products to be procured, by vendor, name, part number, and options. If the project involves custom software applications, this section becomes the dominant and largest part of the Detailed Design Document. The section's purpose is to provide enough information so the code can be developed, and understood for maintenance and system upgrades. As a result, the overriding requirement is that the descriptions of the software components are complete and the link between these descriptions and the actual source code is clear and explicit. The Detailed Design Specification is primarily a completion of the preliminary information in the High-Level Design Specification. Any corrections to the information in the previous document should be made at this time. Again, if a software design tool is used, it may produce most of the Detailed Design Specification.

Table 2-6: Detailed Design Template

2.2.6 Development / Installation

The next step of the SE process is the procurement, development, and installation of the various hardware and software components of the project, based on the project specifications. This step may involve the selection of a contractor to provide the desired components of the system to be procured, based on the requirements and design from the previous steps. Once a development team is on board, the SE team primarily provides technical oversight as an implementation team of hardware and software specialists create the detailed component-level design, fabricate the hardware, and write the software programs. Some of the key activities of this step are:

- Plan software/hardware development (if the project includes hardware or software development) – The implementation team documents their development process, best practices, and conventions that will be used. The plan should address development methods, documentation requirements, delivery stages, configuration control procedures, and technical tracking and control processes for the implementation effort, including reviews. This is one of the key documents that should be reviewed by the customer and the broader project team.

- Establish development environment – The development environment is assembled and integrated, including design and development tools, source control tools, third party application libraries, test simulators, etc. Every tool that is used should be documented specifically enough so that the development environment can be replicated if necessary.

- Procure commercial off-the-shelf products – Commercial Off-the-shelf (COTS) products are compared and COTS solutions are selected and procured. An alternatives analysis documents the alternatives that were considered and how the superior alternative was selected. The evaluation of COTS products should be reviewed to verify that the evaluation criteria were properly defined, an appropriate range of products was considered, and the evaluation criteria were applied fairly.

- Develop software and hardware – The software is written and the hardware is built based on the detailed design. On most projects, there is an easy transition from detailed design to software/hardware construction because the same person that does the detailed design for a specific part of the project also writes the software for that part. The current state of the practice is to develop the software incrementally and release the software in stages. The initial releases implement a few core features and subsequent releases add more features until all requirements are satisfied. This incremental approach enables early and on-going feedback between the customer and the implementation team. If this approach is used, a staged delivery plan should define the order in which the software will be developed and the staged release process.

- Develop Supporting Products – Enabling products such as training materials, user manuals and on-line help, installation and conversion software, and maintenance manuals are also developed. It is natural to focus on the hardware and software in the "end product", but there is also a need to also develop and account for all the ancillary products that are needed in a working system.

2.2.7 Testing

After the development and installation of the system, the next step of the SE process involves testing. All tests required and testing outlined in this document may be superceded by an officially published Validation and Verification plan reviewers of this document should check to see if this is available before planning any form of testing. From Ashghal's perspective, the primary purpose of testing is to verify that the requirements stated in Ashghal's Specifications are delivered by the contractor. Technically, testing is performed for verification and validation:

- Testing verifies that the requirements (hardware, software, and device communications interface) identified in Ashghal's Specification are fulfilled; that is, that the system was built right.

- Testing also validates that the system satisfies the user needs; that is, the right system was built.

A complete ITS device testing program consists of many phases of testing, taking place in a methodical approach. Overall, the testing program should cover all requirements leading to a complete system, including electrical requirements, mechanical requirements, operational requirements, communications requirements and design requirements. Each phase may be described in a separate test plan covering a set of test items: one for hardware and environmental requirements (e.g., structural, mechanical, electrical or environmental), one for software-related requirements (e.g., functional, operational), and one for communications requirements (e.g., communications interfaces).

For ITS projects in Qatar, the following minimum testing requirements apply:

- Factory Acceptance Tests (FAT)
- Site Acceptance Tests (SAT)
- System Integration Test (SIT)
- 400-Day Operational Support Period
- Any test deemed required either by the project owner or the supervising consultant

All systems must be iteratively tested and incrementally tested as more equipment is added to those systems. In short all equipment irrespective of what its function is including communications equipment is subject to the minimum tests as outlined above.

Shoud firmware or software or any other change occur to a piece of equipment or software that materially changes that element of a system then that element of the system will need to be fully retested and the system which it is part of in line with the minimum tests outlined above.

Please note the 400 Day Operational Support Period places an obligation on the contractor/vendors to not only provide fault resolution but also preventative maintenance services for the system/equipment installed.

Test documentation is a key element of a testing program. Test documentation is based on Ashghal's Specifications and are traceable to requirements. Ashghal will utilize test documentation on all ITS deployments, which specifies what and how to verify that the delivered product fulfills Ashghal's Specifications and the defined requirements. Test documentation specifies the extent of testing that is required for the ITS device. For example, a custom-designed ITS device with new hardware and software is likely to require significantly more testing and more stringent testing than an unmodified device with extensive field deployments. Based upon the risk involved in the project development, Ashghal should decide upon the level of testing that is needed. Test documentation includes:

- *Integration Plan, Verification Plan, Deployment Plan, and Validation Plan* - Templates of each are provided in Table 2-7, Table 2-8, Table 2-9 and Table 2-10 respectively.
- *Test Plan* **-** Describes the scope, approach, resources and schedule of testing activities.
- *Test Design* **-** References the test cases applicable to a particular test plan associated with the test design. The test design also references the features (requirements) to be tested.
- *Test Cases and Procedures* **-** Describe the inputs, outputs, expected results and procedures used to verify one or more requirements. A Verification Procedure Template is provided in Table 2-11.

- **Test Reports.** Document the test plan execution. A Verification Report Template and Validation Report Template are provided in Table 2-12 and Table 2-13, respectively.

SECTION	CONTENTS
1.0 Purpose of Document	A brief statement of the purpose of this document. It is the plan for integrating the components and sub-systems of the project prior to verification.
2.0 Scope of Project	This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's deployment complexities and challenges. This section may be copied from earlier documents. It is important only to people [stakeholders] who will be introduced to the project for the first time by this document.
3.0 Integration Strategy	This section informs the reader what the high-level plan is for integration and, most importantly, why the integration plan is structured the way it is. As mentioned before, the Integration Plan is subject to several constraints, sometimes conflicting constraints. Also, it is one part of the larger process of build, integrate, verify, and deploy, all of which must be synchronized to support the same project strategy. For even a moderately complex project, the integration strategy, based on a clear and concise statement of the project's goals and objectives, is described here at a high, but all-inclusive, level. It may also be necessary to describe the analysis of alternative strategies to make it clear why this particular strategy was selected. This section covers and describes each step in the integration process. It describes what components are integrated at each step and gives a general idea of what threads of the operational capabilities [requirements] are covered. It ties the plan to the previously identified goals and objectives so the stakeholders can understand the rationale for each integration step. This summary level description also defines the schedule for all the integration efforts.

4.0 Phase 1 Integration	This, and the following sections, define and explain each step in the integration process. The intent here is to identify all the needed participants and to describe to them what they have to do. In general, the description of each integration step should identify: • The location of the activities. • The project-developed equipment and software products to be integrated. Initially, this is just a high-level list but eventually the list must be exact and complete, showing part numbers and quantity. • Any support equipment [special software, test hardware, software stubs, and drivers to simulate yet-to-be-integrated software components, external systems] needed for this integration step. The same support equipment is most likely needed for the subsequent verification step. • All integration activities that need to be performed after installation, including integration with on-site systems and external systems at other sites. • A description of the verification activities [as defined in the applicable Verification Plan] that occur after this integration step. • The responsible parties for each activity in the integration step. • The schedule for each activity.
5.0 Multiple Phase Integration Steps [1 or N steps]	This, and any needed additional sections, follows the format for section 3. Each covers each step in a multiple step integration effort.

Table 2-7: Integration Plan Template

SECTION	CONTENTS
1.0 Purpose of Document	This section identifies the type of verification activity to be performed within this Verification Plan. For instance, this activity may verify the entire system, a sub-system, the deployment at a site, a burn-in test, or any other verification activity.
2.0 Scope of Project	This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's complexities and challenges that must be addressed and verified by the SE efforts.
3.0 Referenced Documents	This is a list of all documents used in the preparation of this Verification Plan. This almost always includes the Project Plan, the SEMP [if one was written], and the applicable Requirements Documents. However, reference of other documents, such as descriptions of external systems, standards, a ConOps, and manuals may need to be included.

<table>
<tr>
<td>4.0 Test Conduct</td>
<td>
This section provides details on how the testing is accomplished. It defines who does the testing, when and where it is to be done, the responsibilities of each participant before, during, and after each test; the hardware and software to be used [and other systems as well], and the documents to be prepared as a record of the testing activity. Another very important part of this section defines how testing anomalies are to be handled [that is, what to do when a test fails].
In general, the following information should be included in this section:

A description of the participating organizations and personnel, and identification of their roles and responsibilities.
Identification of the location of the testing effort.
The hardware and software configuration for all of the test cases, including hardware and software under test and any supporting test equipment, software, or external systems. Several configurations may be necessary.
Identification of the documents to be prepared to support the testing, including Verification Procedures, a Verification Report, and descriptions of special test equipment and software.
Details on the actual conduct of the testing, including:

Notification of participants
Procedures for approving last minute changes to the procedures
The processes for handling a test failure, including recording of critical information, determination of whether to stop the testing, restart, or skip a procedure, resolution of the cause of a failure and determination of the retesting activities necessary as a result of the failure.

</td>
</tr>
</table>

5.0 Test Identification	This section is the heart, and largest, section of the Verification Plan. It identifies the specific test cases to be performed. A test case is a logical grouping of functions and performance criteria [all from the Requirements Documents] that is to be tested together. For instance, a specific test case may cover all the control capabilities to be provided for control of a changeable message sign. There may be several individual requirements that define this capability, and they all are verified in one test case. The actual grouping of requirements into a test case is arbitrary. They should be related and easily combined into a reasonable set of test procedure actions. Each test case should contain at least the following information: • A description name and a reference number. • A complete list of the requirements to be verified. For ease of tracing of requirements into the Verification Plan and other documents, the requirements are given numbers. They can be accurately and conveniently referenced without repeating all the words of the requirement. • A description of the objective of the test case, usually taken from the wording of the requirements, to aid the reader understanding the scope of the test case. • Any data to be recorded or noted during the test, such as expected results of a test step. Other data, such as a recording of a digital message sent to an external system, may be required to verify the performance of the system. • A statement of the pass/fail criteria. Often, this is just a statement that the system operates per the requirements. • A description of the test configuration. That is a list of the hardware and software items needed for the test and how they should be connected. Often, the same configuration is used for several tests. • A list of any other important assumptions and constraints necessary for conduct of the test case.

Table 2-8: Verification Plan Template[3]

SECTION	CONTENTS
1.0 Purpose of Document	A brief statement of the purpose of this document. It is the plan for deploying the systems of the project over one or more phases and into one or more physical locations [sites].

[3] IEEE 1012-1998 Independent Verification and Validation

2.0 Scope of Project	This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's deployment complexities and challenges. This section may be copied from earlier documents. It is important only to people [stakeholders] who will be introduced to the project for the first time by this document.
3.0 Deployment Strategy	A complex deployment, involving multiple deployment steps at multiple sites, is based on certain goals and objectives. This section lists those goals and objectives and is used to "sell" the Deployment Plan to the stakeholders. It is also important that the deployment participants understand why the deployment is proceeding as it is so they can work with and support the plan. The significant goals and objectives guiding the deployment strategy should be relatively few [no more than a dozen] and need to be clearly stated in this section. Some typical examples of goals and objectives include: • The funding profile for a multi-year project which limits the scope of deployment in a single year. • Development and installation prerequisites. An analysis of the system may show that feature A must be deployed first before features B, C, or D, all of which need A to function. • Construction activities that must precede deployment. • Deployment of interfacing systems [especially by other agencies] that must precede deployment of a system feature. • The need to create a viable operational capability at each stage of the deployment. This influences how much of the system must be deployed at each step.

4.0 Phase 1 Deployment	This, and the following sections, define and explain each phase of the deployment. The intent here is to identify all the needed participants and to describe to them what they have to do. In general, each phase description should identify: • The location of the deployment activities. • The project-developed equipment and software products to be deployed. Initially this is just a high-level list but eventually the list must be exact and complete, showing part numbers and quantity. If detailed hardware installation drawings have been prepared, they are referenced here. • All site work [including construction and facilities] that is needed before installation can begin. Again, reference to drawings may be required. Also, any necessary inspection and testing of this work is defined. • All integration activities which need to be performed after installation, including integration with on-site systems and with external systems at other sites. • All verification activities [as defined in the applicable Verification Plan] that must occur prior to acceptance of the site. • All supporting activities that must be completed before site acceptance, such as training and manuals. • The responsible parties and schedule for each activity.
5.0 **Multiple Phase Deployment Steps [1 or N steps]**	This, and any needed additional sections, follows the format for Section 4. Each covers each step in a multiple step deployment effort.

Table 2-9: Deployment Plan Template

SECTION	CONTENTS
1.0 **Purpose of Document**	This section identifies the type of validation activity to be performed within this Plan. For instance, this activity may validate the entire system, a sub-system, the deployment at a site, or any other validation activity called for in the PMP or in the SEMP.
2.0 **Scope of Project**	This section gives a brief description of the planned project and the purpose of the system to be built. Special emphasis is placed on the project's complexities and challenges that must be addressed by the SE efforts. This section also describes the environment in which the project operates. It identifies the organization structures that encompass all stakeholders. It also gives a brief description of the role to be played by each stakeholder. This includes ad hoc and existing management work groups and multi-disciplinary technical teams that should be formed for supporting the project.

3.0 Referenced Documents	This is a list of all documents used in the preparation of this Validation Plan. This almost always includes the PMP, the SEMP [if one was written], and the ConOps. However, reference of other documents, such as descriptions of external systems, standards, and manuals may need to be included.

4.0 Validation Conduct	This section provides details on how the validation is accomplished. It defines: who does it; when and where it is to be done; the responsibilities of each participant before, during, and after each event/activity; the hardware and software to be used [and other systems as well]; and the documents to be prepared as a record of the activity.
	
	In general, the following information should be included in this section:
	
	• A description of the participating organizations and personnel, and identification of their roles and responsibilities.
	• Identification of the location of the activity.
	• The schedule of when Validation will occur including a sequencing of the events that make up the Validation activity.
	• The system configuration for all of the activities, including the main system hardware and software and any supporting equipment, software, or external systems. Several configurations may be used depending on the type of system and type of development that was just completed.
	• Identification of the documents to be prepared to support the validation, including any special scenarios, a Validation Report, and descriptions of special test equipment and software.
	• Details on the actual conduct of the activity, including:
	  o Notification of participants
	  o Procedures for approving last minute changes to the scenarios
	• The processes for handling anomalies, including recording of critical information, resolution of the cause of a failure [e.g., fix the software, reset the system, change the ConOps, record planned future changes], and determination of any retesting activities necessary.

5.0 Validation Event Identification	This section identifies the specific scenarios and other events to be performed. For Validation, scenarios can be clustered around a typical operator's use of the system. It may also be structured around the operational needs defined in the baseline ConOps. Each event should contain at least the following information: • A description name and a reference number. • A complete list of the needs to be validated. For ease of tracing into the Validation Plan and other documents, the Needs are given numbers. They can be accurately and conveniently referenced without repeating all the words from the ConOps. • A description of the objective of the event, usually taken from the wording of the Needs. • Any data to be recorded or noted during the event. • A statement of the pass/fail criteria. Often, this is just a statement that the system satisfies the needs. • A description of the system configuration. This is a list of the hardware and software items needed and how they should be connected. Often, the same configuration is used for several events/scenarios. • A list of any other important assumptions and constraints necessary for conduct of the event.

Table 2-10: Validation Plan Template

SECTION	CONTENTS
1.0 Purpose of Document	This section identifies the type of verification performed. For instance, the activity may verify the entire system, a sub-system, the deployment at a site, a burn-in test, or any other verification activity called for in the PMP or in the SEMP. This section can be taken from the applicable Verification Procedure.
2.0 Identification of the Configuration Under Test	This section identifies the equipment and software verified. It also identifies all equipment and software necessary for this verification activity that is external to the system / sub-system configuration under test. This may include special test equipment and any external systems with an interface to the configuration under test. This section can be taken from the applicable Verification Procedure.

3.0 Individual Test Case Report	This section summarizes the purpose and results of each test case performed in the applicable Verification Procedure. Special attention is paid to any test case where a failure occurred and how the failure was resolved. This section covers: • Test case overview and results. • Completed Verification Procedure pages annotated with pass / fail results. • Description of each failure, if any, from the expected result called for in the Verification Procedure. • Any back-up data or records related to the field procedure. • Details of the resolution of each test failure, including procedure modification, software fix, re-testing and results, regression testing and results, and required document changes [including changes to the requirements].

Table 2-11: Verification Procedure Template

SECTION	CONTENTS
1.0 Purpose of Document	This section identifies the type of verification to be performed. For instance, this activity may verify the entire system, a sub-system, the deployment at a site, a burn-in test, or any other verification activity called for in the Program Plan or in the SEMP.

2.0 Verification Configuration and Software Under Test	This section identifies the equipment and software to be verified. It also identifies all equipment and software necessary for this verification activity that is external to the system / sub-system configuration under test. This may include special test equipment and any external systems with an interface to the configuration under test. For the hardware / software configuration under test, this section identifies:
	• Each hardware item by part number and serial number.
	• Each item of COTS software, by part number and version number.
	• Each source code file of custom developed software, by file name and version number.
	• For all special test equipment / software, this section identifies:
	    o Each hardware item by part, serial, and version number
	    o Each item of COTS software, by part number and version number
	    o Each source code file of custom developed software by file name and version number.

3.0 Verification Setup	This section describes the steps to be taken to set up each verification configuration, including, but not limited to, tuning of the hardware, configuring and starting the software, starting the special test software, and set-up steps at each external system to be used.

4.0 Verification Procedures	This section describes the step-by-step actions to be taken by the verification operator for each verification case. Each step includes: • Operator action to be taken. This operator action may be, for example, an entry at a workstation, initiation of a routine in the special test software, or an action at an external system. • Expected result to be observed. This too may take several forms, for example, display of certain information at a workstation, a response at an external system, recording of data for subsequent analysis, or an action by a field device. • Pass / fail entry space. Here the verification conductor records whether or not the expected result occurred. If the expected results are not observed, the procedures for dealing with failures contained in the Verification Plan are invoked. • A trace of each verification step from a verification case in the applicable Verification Plan and a trace from a requirement in the applicable Requirements Document.

Table 2-12: Verification Report Template

SECTION	CONTENTS
1.0 **Purpose of Document**	This section identifies the type of validation performed. For instance, the activity may validate the entire system, a sub-system, the deployment at a site, or any other validation activity called for in the PMP or in the SEMP. This section can be taken from the applicable Validation Plan.
2.0 Identification of the Configuration Under Test	This section identifies the equipment and software validated. It also identifies all equipment and software necessary for this validation activity that is external to the system / sub-system configuration. This may include special test equipment and any external systems with an interface to the system. This section can be taken from the applicable Validation Plan and updated to reflect the actual system as delivered.
3.0 Individual Validation Reports	This section summarizes the purpose and results of each event performed in the applicable Validation Plan. Special attention is paid to any situation where a failure (or deviation from the expected System performance) occurred and how the failure was resolved. This section covers: • Event overview and results. • Completed Validation Plan pages annotated with results. • Description of each anomaly, if any, from the expected result called for in the Validation Plan. • Any back-up data or records related to the experience. • Details of the resolution of each anomaly, including procedure modifications, software fix, re-testing and results, regression testing and results, and required document changes [including changes to the ConOps, new requirements for next version].

Table 2-13: Validation Report Template

Test documentation may be developed by the manufacturer, Ashghal, a test laboratory, a consultant, a contractor, or perhaps it is based on test documentation used by another traffic authority as part of their qualified products program. Testing is conducted by a combination of manufacturer, Ashghal, a contractor and possibly an independent laboratory to verify that an ITS device complies with Ashghal's ITS Specifications.

Reviewers shall check to ensure that the version of test documentation template and instructions being used is the latest version.

3 Traffic Detection and Monitoring Systems

3.1 System Purpose & Design Flow

Traffic Detection and Monitoring Systems (TDMS) consist of a collection of detectors connected to a back office subsystem, which detect the presence of vehicles and their characteristics. They are typically used to detect and provide near real-time and historical data. Detectors can supply data of different types, including speed, volumes, vehicle presence, occupancy, gaps and incident occurrence. This data can then be analyzed by either the related software supplied by the detector vendors or other subsystems in the back office environment, and to complete a variety of functions, including:

- Real-time traffic and incident management detection.
- Traveler information though aggregation of detection information.
- Historical analysis though aggregation of detection information.
- Origin-destination information though aggregation of detection information.
- Roadway capacity analysis using near real time measures.
- Performance measures – data analysis based on historical vs near real time data.
- Planning and design purposes using statistical metrics derived from the above.

To design a detection location, consideration must be given to what the fundamental detector purpose and system needs are and to fit with existing back office and subsystems that interpret the data. This information can be used to consider the selection of an appropriate technology and relevant deployment criteria such as structure type and orientation of the detector or sensor. The design process of a TDMS is illustrated in the following diagram:

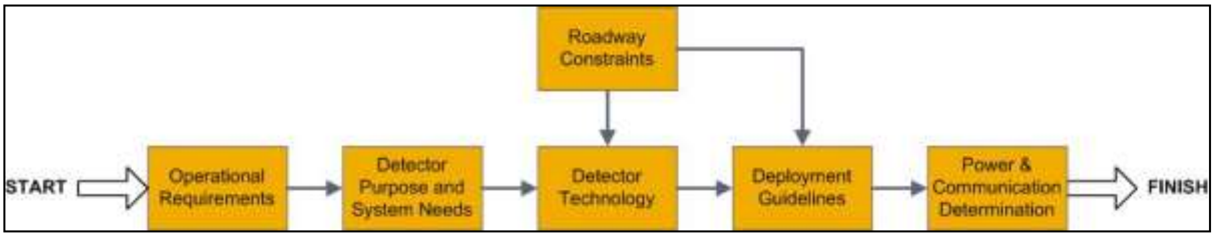

Figure 3-1: Detector Design Operational Needs

Please note the above diagram is relevant for both Expressways and Local Roads.

There are several industry standards/requirements related to detectors. Table 3-1 below identifies some of these.

CRITERIA	RELEVANT STANDARD
Communication and Software	NTCIP – needs to conform to, or comply with at least one of the protocol stacks outlined in the NTCIP communications diagram see Figure 13-1.
Structure	Ashghal Civil and Structural Standards for ITS. QCS 2010

Table 3-1: Traffic Detection and Monitoring Systems Standards

3.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with a TDMS design. Each section of the list corresponds to a section of this document chapter. The background, details and specific regulations or guidance related to the design process for a TDMS are contained in those referenced sections.

The criteria contained in this publication should be considered when designing a new TDMS. It is important to note/clarify, however, that there may be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria, should be outlined by the designer and presented to Ashghal for review or approval. The goal of this process is to provide practitioners with overall guidance as well as to provide consistency with respect to TDMS installations.

Note that whilst Bluetooth as a technology has been shown in this document, it is expected to be obsolete by 2016 and shouldn't be considered as a viable option. It has been left purly to demonstrate existing technologies and give comparisons of functionality.

Table 3-2 contains a high level summary of some design considerations contained in this chapter and an outline of the chapter in general.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with "needs" outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture? • How does this deployment fit within the context of either an Expressway or Local Roads Project?	
System Requirements	**Section 3.3**
• Does the detector deployment satisfy the precision considerations established in the system needs? • Does the detector deployment satisfy the spacing considerations established in the system needs? • Does the detector deployment satisfy the accessibility considerations established in the	

system needs? • Is the detector of the correct type for the situation (i.e. do not use intrusive detectors on bridge decks)	
Detector Technology Selection	**Section 3.7**
• Does the detector technology satisfy the safety, accuracy, accessibility, and constructability established in the system needs? Does it meet cost requirements?	
Deployment Guidelines	**Section 3.8**
• Does the detector installation take steps to minimize new structures and co-locate devices where possible? • Does the detector installation include sufficient detector coverage to satisfy functional needs? • Is detection installed to ensure correct lane identification and spaced within a reasonable distance for an Expressway network and on each relevant entry and relevant exit ramp? For a 'Managed' motorways approach normally a collection of detectors may be spaced at regular intervals in every lane for incident and speed/volume detection purposes. • Does the installation ensure that detection for every approach at traffic signal junctions is in place? • Has detection been designed for every entry/exit to major traffic generating venues and public car parking facilities?	
Enclosure	**Section 3.9**
• Is an enclosure required at this location and what type should be used? Note that enclosure types for Local Roads Projects may vary from those specified in the National ITS Standards for the State of Qatar, which is aimed at Expressways –Designers should check with the Ashghal on enclosure selection prior to finalizing design considerations. • Can personnel safely access the enclosure? • Is the enclosure located within the manufacturer's recommended distance to the detector? • Is the enclosure mounted on an existing structure (where possible)? • Does the location and orientation provide adequate protection? In some cases enclosure poles and enclosures may need to be treated with a suitable anti-corrosive paint or powder coating. • Has a maintainer's pad been provided at the enclosure's main door? This may not be required in a number of circumstances depending on the size and site of the enclosure.	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the detector type, site and all of the system components been determined?	

Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down transformer requirement calculations been performed? (Assuming that these are required). • Have metering options for power been determined? This may present issues across both Local Roads and Expressways and any liaison with Kharamaa, if required, needs to be prioritized as an urgent activity per scheme. • In terms of the selection of Detector for the site, the power requirements may vary between sites depending on what detection type is used at each one. It is critical that power calculations consider the type of detector and that designers do not either oversupply or undersupply power to a site.	
Power Conditioning	**Section 12.2**
• Have any UPS and or power back-up options been determined for the detector site? In most cases, for Local Roads implementations UPS may not be needed for detector installations – however, a UPS provides a significant power cleaning and regulating function and should always be considered in an enclosure as an option. Please note UPS do require maintenance and battery replacement on a regular basis.	
Communication	**Section 13**
• Have the communication requirements for the detector type and subsystem been determined? • Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with the Ashghal. • Is the communication protocol consistent with what can be supported by the TMC Master Software?	
Environmental	
• Have all the necessary environmental, community and cultural impact studies, processes, and concerns been addressed? • Are the enclosures or any other infrastructure within or located next to any form of irrigation or watering system? • What seasonal issues will impact on the works (i.e. is it Summer or higher than usual temperatures which will impact on material expansion etc.).	

Table 3-2: Vehicle Detection Design Considerations

3.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

3.2.1.1 Communications Interface for Traffic Detection and Monitoring

The communications interface between the traffic detection and monitoring (field) devices and the TMC is needed between the detectors and relevant back office/subsystems to facilitate the following functions:

- Configure the traffic detection and monitoring devices:
    - This feature allows an operator to determine the identity of the field device and its capabilities, and to configure the detection zones and outputs.
- Control the traffic detection and monitoring devices:
    - This feature allows an operator to reset the field devices, initiate diagnostics, and manage the camera detection zones for video detection devices.
- Monitor field device status and report equipment malfunctions:
    - This feature allows an operator to monitor the overall status of the field device, the status of each sensor, the output states, and the status of each zone.
- Upload event logs:
    - This feature allows an operator to upload any event logs that are maintained by the field devices.
- Collect data from the field devices:
    - This feature allows an operator to retrieve the data from the in-progress sample period (started but not yet completed), the current sample period, and historical sample periods.

The communications protocol should support all the features desired for these devices. Conformance with the NTCIP standards listed below shall ensure these requirements are met for point detection systems. Probe detection systems are exempt from the NTCIP *compliance* requirement; however, the features listed above must be fulfilled by the communications interface chosen and all devices must *conform* to NTCIP.

3.2.1.2 NTCIP for Traffic Detection and Monitoring

The following NTCIP Information Level standards are relevant and may apply. Please note that any detector systems or devices which natively support TCPIP and can be clearly shown to have interfaces or communications protocols consistent with NTCIP may be considered conforming but not necessarily compliant. In this case guidance from Ashghal should be sought by designers.

- NTCIP 1206, Object Definitions for Data Collection, is a data dictionary standard used to support the functions related to data collection and monitoring devices within a transportation environment. This standard defines data elements specific to transportation data collection sensors – it supports the collection of information about each vehicle, such as number of axles, vehicle dimensions (such as length, width and height), vehicle weight, and axle weight. Other information that may be collected includes vehicle headways, vehicle speeds, and vehicle acceleration.

- NTCIP 1209, Object Definitions for Transportation Sensor Systems, is a data dictionary standard used to support the functions related to transportation system sensors within a transportation environment. This standard defines data elements specific to transportation systems sensors – it supports the collection of traffic volumes, percent of occupancy, and the average speed of traffic over the defined sensor zone.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

3.3 Corridor Detection Systems

Detection systems are expected to be used on all categories of roads throughout the State of Qatar. These systems will include point vehicle detectors that collect presence, speed, and occupancy data at each detection location for each lane of travel. In addition, floating vehicle (probe vehicle) data will also be collected for a representative sample of vehicles on all corridors/roads/links to provide for link travel time and origin-destination data. The information from the point vehicle detectors and the probe vehicle detectors will be utilized together to provide a comprehensive set of data for all corridors, including near real-time and historical data, such as speed, volumes, vehicle presence, occupancy, gaps, and incident occurrence. This data can then be utilized to complete a variety of functions, including:

- Real-time traffic and incident management
- Traveler information
- Historical analysis
- Travel time information
- Origin-destination information
- Roadway capacity analysis
- Performance measures

- Planning and design purposes

Primary considerations for the placement of suitable detection technologies are:

1. Spacing and Lane Coverage (Point Detectors) – Point vehicle detectors need to be spaced regularly at measured intervals. A good example of this type of spacing is every 0.5km. In some instances, the interval spacing may be larger or small depending on the roadway layout and location. The quantity and frequency of detectors determine the spatial granularity with which data can be captured for incident detection, congestion measurement, etc. It is important that the detector spacing remain consistent on a given roadway segment to maintain the same granularity. In general terms all lanes of travel should be covered by the detector(s) at each detection point.
2. Spacing and Lane Coverage (Probe Vehicle Detectors) – Probe vehicle detectors should also be spaced regularly on all minor and major arterials and expressways in urban locations, (and in some cases Rural areas such as Wakra), e.g., Doha) to build logical road segments over which journey times can be calculated. In most cases these can be placed at distances which support the type of detection in use. For instance a placement every 150m would only make sense for a limited highly congested section of road in the center of Doha whereas placement every 500m may make more sense on an urban expressway. Outside of urban areas and on inter-urban expressways, probe vehicle detectors could be spaced at major intersections and interchanges, with an effective spacing of 2.0km. However it is entirely possible that depending on circumstances such detection may only be required every 10km. One of the key outcomes is the ability to build logical road segments over which journey times can be calculated. On EXW there should be consideration made for detection on entry and exit ramps. More use of detection points will improve data usefulness and accuracy. It is preferable to detect slip roads separately from main line and for merges upstream and downstream of diverge to allow for future ramp metering and/or monitoring of flow breakdown at merge areas.
3. Cost – Because multiple detectors should cover all lanes of travel at a detection location, the cost of the system can (depending on technology selected) quickly escalate. Choose detection extents based on requirements for accurate information including, detector types, locations, and communication methods that minimize the overall cost of the system. Co-location of detectors on existing structures (e.g., CCTV poles) where possible can help to minimize the need for new structures, provided the detector spacing remains consistent for that section of road.
4. Accessibility – Accessibility of the device for maintenance and repair purposes is of high importance, especially when many devices are necessary for a system. Inaccessible devices or devices embedded in the pavement, lead to higher costs and the potential need to close lanes to perform maintenance, which increases the potential for disruption of traffic.
5. Comprehensive Data Capabilities – For incident detection and congestion measurement, speed, volume, and occupancy are typically required.
6. Accuracy – Speed data (where collected) must be accurate within a range of approximately 5 km/hr. Expected minimum aggregated accuracy levels should be in the vicinity of 90% for

volume, 90% for occupancy, and 90% for speed for all lanes within a defined detection area or extent.

7. Location Precision – Precision is secondary to detector spacing. The exact location of the detector is not of high importance, provided the integrity of the detector spacing remains intact. Detection position variations of 1-2m are irrelevant in terms of the overall position of detectors in a 6km scheme for example. Exact detector spacing is a function of the scheme and data collection technology to be used.

When placing point vehicle detectors, spacing is the key design consideration. Regular spacing is necessary for an effective system in dense urban environments or where there are specific issues such as high accident or incident areas. In rural areas spacing of detectors should be arranged on stretches of road at intervals which are determined by functional evaluation of needs for monitoring of those roads.

When placing probe vehicle detectors, it is important to keep in mind the overall road segment being monitored when determining the detector location.

3.4 Point Detection Systems

Point detection systems, including WIMs and OH sensors, may be utilized for specific locations such as detection at traffic signals as part of the traffic signal system, urban traffic control (UTC) system and at entrance or exit ramps along the expressway network, etc. On expressways, point detection systems provide overall count, speed and occupancy data to determine congestion levels on roadways. This data is generally polled by a central system that then calculates the current congestion level and provides it on a real-time map display.

As a result, it is important that the spacing integrity of point detectors be maintained to provide a consistent spatial granularity of congestion information on the real-time map display at the central system.

On major and minor arterials, point detection systems may also be used to provide saturation levels at signalized intersections and provide important feedback to traffic controllers for adjustment of signal timing plans.

It is important to consider the intended use of the point detection system (congestion information vs saturation level measurement) in arterial and non-arterial roads when considering their positioning.

(Inductive loop, radar, video, laser, lidar and magnetometer) can be used for point detection systems.

3.5 Probe Detection Systems

Probe detection systems may be utilized to determine average travel time over a roadway segment. Probe detection systems function by uniquely identifying individual vehicles and transmitting its detection points for a specific trip to a central system for further processing. The central system is then responsible for aggregating and averaging the data to provide useful information regarding journey times for that particular roadway segment.

It is important to logically position probe detection systems so that these trips can be created by the central system.

Bluetooth matching systems and LPR systems are examples of systems that can be used for probe detection systems.

3.6 Vehicle Detection Systems for Tunnels & Bridges

Vehicle detection systems used in tunnels shall ensure compliance with all requirements of National Fire Protection Association (NFPA) 502 - Standard for Road Tunnels, Bridges, and Other Limited Access Highways. Refer to the NFPA 502 standard for design requirements. The selection of these detection systems should be in line with expected design limitations for tunnel structures for energy produced by a fire of at least 7.4 MW and detectors should be opto electronic in order to survive such an event long enough to report it.

The use of any intrusive (loops, magnetometers) detector system on a bridge deck or any structure resembling a bridge deck where cuts or drilling of cores is required, is not acceptable for any reason. In the case where there is a compelling requirement for such detection, it should take the form of video or radar based detection.

3.7 Select Vehicle Detection Technology

The detector technologies currently approved for use in Qatar for traffic management purposes vehicle detection are inductive loops, microwave radar, video image, and magnetometer. In the case of less accurate probe vehicle detection, Bluetooth detection systems and LPR systems can be utilized. Table 3-3 should be used as a starting point for selecting the appropriate detector technology. Table 3-4 displays how each of the technologies fulfills the Detection System Requirements. Table 3-4 also displays additional design considerations and advantages vs. disadvantages for each system.

When selecting a point detector technology, consider the expected vehicle classification distribution and the limitations of the technology. E.g. Microwave/radar detectors may suffer from shadowing of smaller vehicles by larger ones whereas loops or magnetometers may not experience this degradation. Pre-fabricated loops may be cost effective on new roadways where construction has not yet started. High temperature requirements must always be considered in Qatar.

When selecting a probe detector technology, consider the overall segment that is to be monitored. As stated in Section 3.5, probe detector technology will be primarily used to determine Origin-Destination time travel information. It is important that the deployment of the selected technology be done along logical corridors or roadway segments where the probability of detecting a vehicle along its journey from one probe detector to another is high. Moreover, consider the sensing limitations of the technology being used. It may not be practical to use Bluetooth matching systems along roadways with low traffic volume due to its dependence on active Bluetooth radios.

Alternatively, LPR systems may be practical for strategic routes of high importance that do not require close spacing to avoid high deployment costs. All movements as far as practical should be detected irrespective of scheme type.

The designer should use the Detection System Requirements in Table 3-3 as a guide to determine the appropriate detection technology for the proposed system. Note that there are other detection systems and these may be considered. The remainder of this chapter identifies design considerations and guidelines for the detection systems listed.

Detector Technology	Structure Type	Available Data	Accuracy	Accessibility	System Cost
Inductive Loop	None (In or under surface)	-Speed -Volume -Occupancy -Classification (special software and additional detectors required)	High	Intrusive – requires either pre-formed layer before wearing course or cuts in wearing course.	Well proven and medium low cost. Installation costs are low based on volumes and materials,(wire).
Microwave /Radar	Pole or Existing Structure	-Speed -Volume -Occupancy (special software required) -Classification (special software required)	High	Medium to Easy – typically mounted 9-12m above the deck – requires cherry picker.	Moderate to high. Radar units vary in terms of quality with higher quality 3D tracking diode based units being very expensive and lower end dual diode units being moderately priced.

Detector Technology	Structure Type	Available Data	Accuracy	Accessibility	System Cost
Video Image Vehicle Detection Systems (VIVDS)	Pole or Existing Structure	-Speed -Volume -Occupancy -Classification -Stoppages -Debris	High	Moderate to difficult requires mounting on very stable platforms to work best.	Moderate-High – These systems are complex and frequently require specialist parts and assistance to make them work.
Magnetometer	In-Pavement	-Speed -Presence -Counts	Low to Moderate (needs to operate in pairs to be accurate at a minimum)	Intrusive requires core removed from road and sensor put in. Higher level functions such as occupancy/travel time/classification require bespoke programming.	Moderate to High Due to the numbers of these units required to set detection zones up they have a moderate installation cost. Battery life in MENA is subject to confirmation and testing.
Bluetooth®	Pole, existing structure or GME (enclosure top attennas)	-Speed -Travel Time -Origin-Destination	Moderate to High	Moderate needs to be installed at the right height a specific distance from the roadway to work a single unit is not functional requires a network of units and sophisticated back office software.	Moderate to High Due to changes in the Bluetooth Standards effectiveness may be compromised based on new security measures introduced in ver 4.2

Detector Technology	Structure Type	Available Data	Accuracy	Accessibility	System Cost
License Plate Recognition	Full span gantry	Speed -Travel Time -Origin-Destination	Moderate-High	Difficult/ Intrusive	Moderate-High (Also must consider additional hardware/software needed)

Table 3-3: Detector Technology Options

Detection Technology	Design Advantages	Design Disadvantages
Inductive Loop (point detector)	• Mature and tested technology. • Provides an array of data: volume, presence, occupancy, gap, and speed. • Is not affected by inclement weather. • Is able to be sized to fit relevant sites and lane widths.	• Installation requires pavement cut or layering under new pavement. • Cannot perform maintenance on loop itself without interrupting traffic – however if installation is coordinated with resurfacing then this less of an issue. • Will require series of detectors to provide vehicle classification capabilities. • High temperature requirements must be met.

Detection Technology	Design Advantages	Design Disadvantages
Microwave/Radar (point detector)	• Widely used and tested technology. • Non-intrusive technology – no pavement work is necessary. • Multiple lanes can be detected using a single detector. • Can be mounted on existing structures. • Low installation costs.	• Obstructions such as barriers, road signs, roadway cut sections, and retaining walls may decrease accuracy. • May cause problems in situations where right-of-way is limited. • High temperature requirements must be met.
Video Image Vehicle Detection Systems (VIVDS) (point detector) (AID)	• Widely used and tested technology. • Non-intrusive technology – no pavement work is necessary. • Dedicated units are not normally used for other surveillance.	• May be affected by shadows, fog, sandstorms and vibrations. • Requires processing technology either in the camera or at an adjacent enclosure or TMC over a network. • High temperature requirements must be met.

Detection Technology	Design Advantages	Design Disadvantages
Magnetometer (point detector)	• Provides an array of data. • Is not affected by inclement weather. • Has a battery which allows for wireless connection to an access point. • Uses access points to collect data from a number of units. • Wired Magenetometers share the same advantages/disadvantages as loops but because they are buried deeper in the pavement in a duct are not likely to be removed during resurfacing.	• Magnetometers are required for every travel lane, increasing costs and complexity. • Difficult to detect stopped vehicles. • Some magnetometers can have small detection zones. • Questionable battery life in high temperature environments. • Requires smart back office systems to make sense of the data. • May require access points on both sides of the road for dual carriageway installations. • Wired Magnetometers require infrastructure at the side of the road (similar to loops). • High temperature requirements must be met.

Detection Technology	Design Advantages	Design Disadvantages
Bluetooth® (probe vehicle detector)	• Non-intrusive technology – no pavement work is necessary. • Multiple lanes can be detected using a single detector. • Can be mounted on existing structure. • Low installation costs.	• Cannot directly provide volume data. • When installed in series on a corridor can provide travel times and origin and destination data. • May require technical support from vendor. • Obsolescence, vulnerable to revision of Bluetooth standards and changes in cellular phone technologies. • Not Secure • High temperature requirements must be met.
License Plate Recognition (probe vehicle detector) (LPR)	• Mature technology. • Can be mounted on existing full span structures. • Can provide travel time and origin-destination data.	• Installation and maintenance of cameras is intrusive. • Camera required for each lane, can result in high cost of deployment. • Performance can be degraded during adverse weather conditions (heavy fog, sandstorm, direct sunlight). • High temperature requirements must be met. • Issues with black license plate types In the State of Qatar at night.

Table 3-4: Detector Type Advantages and Disadvantages

3.8 Deployment Guidelines

This section identifies deployment guidelines and criteria for each detector technology type. The designer should use this section as a guide for deployment of the detector or system of detectors.

3.8.1 Loop Detection

Loop vehicle detectors consist of a metal/wire loop buried several centimeters (typically 70mm) beneath the pavement surface (wearing course) of the roadway, and are positioned in the center of the travel lanes. They use small electrical AC currents passing through the loop to make a magnetic field, which alters when metal from car axels typically passes through the field, creating an electrical induction. This disturbance is used by the detector to determine a profile for what has just passed over the loop(s) this profile (signal) is then compared to a typical set of profiles to determine what the vehicle in all probability was.

For specifics and additional guidance concerning the size and placement of the loop within the travel lane, the Designer should refer to QCS, Section 29, Part 2 – Traffic Detection and Monitoring, and the Ashghal Civil and Structural Standards for ITS.

3.8.2 Radar Detection

Radar detectors typically consist of a sensor mounted on the side of the road, angled down towards the travel lanes of the roadway. These sensors use a radar beam to collect vehicle data, including speed, volume, and sometimes occupancy, depending on the manufacturer and signal type. The detector software divides this area into user-definable “detection zones,” where one zone corresponds to one lane.

When designing a microwave/radar detector location, the designer should consider the following steps outlined below.

1. Identify Detector Location

   Detector location will vary based on its use – either data collection or incident detection.

   - If the detector is used for point data collection, the system needs may require a very specific detection area (e.g., a specific lane or entrance ramp, or a point on the main line). The designer should not place the detector outside of this detection area.
   - If the detectors are part of a corridor data collection system, they must be spaced at regular intervals.
   - Radar detectors shall not be utilized within tunnels unless they are specifically designed for this function such as 360 degree incident management radar units or 3D tracking radar units.
   - Verify the cross section of the roadway to determine the detection zone is covered by the proposed detector.

2. Detector Quantity

   Radar vehicle detection units have a maximum recommended range, in most cases this lies between 61m and 25km from the detector structure to the farthest detection point – this depends on the type and model. At locations where the detection zone exceeds 75m, in general multiple detectors must be used. This typically occurs at locations where two directions of travel must be captured. When the zone exceeds the detection capabilities of a detector, one detector on either side of the roadway is necessary to capture all travel lanes.

3. Mounting Height and Setback

   Mounting Height **-** The radar sensor unit should be mounted approximately at the height recommended by the manufacturer. Note that if the detector structure is located on an embankment or hill, the mounting height may be more or less than 5.0m to 8.0m from the base of the structure, depending on the structure elevation.

   Offset **-** Detector offset is the distance from the edge of the nearest travel lane in the detection area to the detector itself. This offset is required so that the detector's radar beam can expand to cover the detection area at the correct angle. Please note an offset can include the height off the sensor from wearing course level and should consider the angle of the 0 Degree perpendicular detection Axis at center to the position of the first lane. Some radar detectors do not require an offset or angle adjustment.

Table 3-5 is an example of some typical offsets including height requirements as a function of lanes. This will vary substantially depending on the actual equipment used and offset from first travel lane, so manufacturer's recommendations must always be considered during the site design.

Number of 3.6 m Lanes **Including Median note if barriers in median additional adjustments are needed**	**Minimum Offsets** **(Meters)**	**Recommended Height from Wearing Course (Road Surface)** **(Meters)**
1-3	3.0-4.0	5.0
4	5.0	5.0
6	6.0	5.0
8	8.0	6.0
8 + Median	> 9.0	> 7.0

Table 3-5: Radar Sensor Recommended Height and Offsets

4. Structure Type

Radar Sensors can be either free-standing on a steel or concrete pole, or collocated with an existing structure such as:

- Sign structure
- Overhead Truss structure
- Bridge structure
- CCTV pole
- DMS structure

Radar Sensors are amenable to mounting configurations that vary from those listed above, including being mounted overhead on a lane on traffic signal mast arms, if the situation warrants this kind of deployment. This could include curve warning system detectors or other ITS systems. Note some units such as LIDAR laser systems can and are often configured with Radar Sensors for enforcement systems – in these cases the Radar Sensors or the LIDAR units can be used in curtain mode effectively beaming a side fire detection zone vertically from a mast arm above the lanes to the road surface with the alternative technology again either Radar or LIDAR being used for coverage of the lanes in the horizontal mode. This configuration provides highly accurate vehicle classification.

The designers may locate radar sensors on any of the above structures where the structures coincide with required detector spacing, where the structure satisfies the mounting height and setback guidelines, and where the structure meets the wind speed and vibration/deflection requirements identified by the manufacturer.

Mounting Radar Sensors on existing or new wooden poles is technically workable but is not advisable in the State of Qatar as a permanent installation.

5. Obstructions

Radar Sensors can experience interference and disruption when obstructions such as barriers or high retaining walls are within the detection area. To minimize this interference, locations should be selected to reduce the impact of these obstructions. If obstructions are unavoidable, the designer should consider using multiple detectors to avoid the conflict. For example, if a roadway is separated by a jersey barrier median, one detector on either side of the roadway may be needed to capture all travel lanes.

3.8.3 Video Image Vehicle Detection System (VIVDS)

A Video Image Vehicle Detection System (VIVDS) consists of a video camera system mounted above or along the roadway, angled towards the travel lanes. The system is configured using software to collect data only from predetermined zones (overlays) within the travel lanes. This video image is either then run through software processing locally on site or remotely in a back office to detect vehicle presence, speed and volumes.

When designing a VIVDS system, the designer for either Local Roads Projects or Expressways projects should try to follow the steps described below.

1. Detector Location

   Detector location areas are determined by system use – either data collection or incident detection.

   - If the detector is used for point data collection, the system needs may require a very specific detection area (e.g., a specific lane or entrance ramp, or a point on the main line, or a traffic signal structure). The designer should not place the detector outside of this detection area. Typically, this type of camera would be a FPOV type with a suitable lens.
   - If the detectors are part of a corridor data collection system, they must be evenly and consistently spaced across the corridor to be effective. Maximum spacing is to be determined by detection zone requirements and frequency per application, for example in a managed expressway example spacing around 0.5 km apart would suffice.
   - Full coverage of all tunnels should be provided for incident detection, as per the requirements of NFPA 502. In the case of Tunnels the use of VIVDS must be exclusive for this function and utilize fixed POV cameras not PTZ.

2. Detector Structure

   Because VIVDS detectors are above-roadway systems, it is highly recommended that they are located on existing structures such as:

   - Bridges
   - Trusses
   - Poles
   - Tunnel ceilings/walls

   If co-location is not possible because of spacing or other system needs, new overhead structures must be constructed. Traffic signal mast arms are not a preferred structure for mounting VIVDS cameras in the State of Qatar due to excessive deflection under wind conditions. If mast arms are utilized, they must meet the vertical clearance wind speed and deflection guidelines contained in this deployment guideline and on the standard drawings. Typically, any above-lane structure must provide a minimum of 6.5m clearance.

3. Detector Vertical Clearance and Quantity

   VIVDS can detect vehicles on as many lanes as are contained in the video image. At a height of 9.0m, most VIVDS can detect up to three lanes simultaneously. At a height of 6.0m, VIVDS can detect several lanes simultaneously.

4. Configure Detection Zones

   VIVDS systems detect vehicles on the roadway based on detection zones established within the software. Typically these are seen as virtual detection overlay “boxes” located in each relevant lane. Each proprietor of VIVDS technology utilizes a proprietary software system to define the detection zones. Once installed, these zones must be defined for each travel lane that data is to be collected from.

   Each detection zone must be defined such that only vehicles within the detected lane cross the zone. This will make certain that each detection zone gathers lane-specific data, and that vehicles are not counted more than once.

There are also back office VIVDS that utilize existing CCTV cameras, adding analytics to the “back-end” of the CCTV image. These systems require additional hardware (video servers) in which the analytics are added prior to being used by a TMC Operator. These systems have no adverse effect on the actual video, but can provide input into an existing Advanced Transportation Management System (ATMS) in which, once an incident has been detected, it would generate an alarm through the ATMS or simply route the image to the video wall, thus notifying the Operator of the incident. These systems are very comprehensive, where the analytics “re-learn” the image every time the CCTV camera is adjusted. A significant drawback to these types of systems is that it requires a substantial amount of additional hardware for processing, typically adding an additional video server for a limited number of CCTV cameras.

The preference for the use of fixed point of view FPOV CCTV cameras for VIVDS is based on international experience where the use of PTZ cameras has caused incorrect readings and or usage. PTZ cameras never exactly return to a home position following use either automatically or manually as the stepper motors are unable to track exact prior position. This results in image ‘drift’ which can be a significant problem for ViVDS most mainstream manufacturers for this reason specify FPOV black and white camera systems for this function.

3.8.4 Magnetometer Detection System (MDS)

The magnetometer sensor is functionally similar to an induction loop and is a type of intrusive induction field sensor that is used for traffic management and vehicle detection. The sensor is designed to detect the passage of a vehicle by measuring the changes of an induced magnetic field and converting them into electronic signals. A portion of the vehicle must pass over the sensor for it to be detected. Depending on battery state and manufacturer Magnetometer sensitivity can vary substantially. Magnetometers come in two versions – typically a free-flow version which is designed for use on motorways and Expressways or a more specific version for detection functions similar to loops at traffic signals. The sensor is placed in the middle of the traffic lane in a core drilled in the roadway surface or in a tube located in a duct under the roadway surface. The detection data is transmitted in near real-time via low-power radio technology to an Access Point (AP) or Repeater Unit (RU), or in the case of duct installed units is transferred over a connecting cable.

Wireless magnetometers have self-contained batteries while connected units obtain power via the cable. The data is forwarded to an ITS enclosure and then sent to the TMC. In some cases software may be located on a server unit in a road side ITS GME, which takes the raw data and pre-processes it prior to forwarding this information to a back office subsystem for further processing.

Magnetometer sensors can be used for a variety of highway and arterial applications. They are used to measure volume, occupancy, speed and advanced detection.

When designing a magnetometer detector location, the designer should pay attention to the following outline steps below.

1. Detector Location

   The location of the detectors is likely to vary based on their use – either data collection or incident detection. All highways and major arterials installations of detectors on roadways throughout Qatar should be designed with consideration being given to provide incident detection.

   - If the detector is used for point data collection, the system needs may require a very specific detection area (e.g., a specific lane or entrance ramp, or a point on the main line). The designer should not place the detector outside of this detection area.
   - If the detectors are part of a corridor data collection system, they should be spaced at consistent distances apart or according to the manufacturer's recommendation.
   - If detectors are part of an incident detection system, the assumption is that they are there to provide granularity on location of issues and therefore they should be spaced consistently and in congested areas relatively closely together. A typical range for these distances between detectors overseas for this function varies between 500m and 300m. When any doubt exists, spacing should be as per standards (National ITS Standards)

2. Detector Quantity

   One or more magnetometers should be placed in each lane of each approach. In typical arterial and highway management applications, a sensor is placed in the middle of a traffic lane to detect the passage of vehicles and provide counts. Vehicle speeds can be more accurately measured by installing two sensors in the same lane. The recommended distance between sensors depends on the range of expected speeds to be measured. For typical highway applications, a separation of approximately 6 to 7 meters is recommended. For typical arterial applications, a separation of 3 to 4 meters is preferred. Exact spacing should be confirmed with manufacturer and venders based on equipment functional requirement and scheme type.

3. Access Points and Repeater Units for Wireless Magnetometers (not required for wired in duct units).

   The number of APs and RUs will be determined by the geometry of the road, mounting height, the number of lanes, and the location of the ITS enclosure. The AP should be placed near the ITS enclosure and to the power source when possible. Note that if the AP/RU structure is located on an embankment or hill, the mounting height may be more or less from the base of the structure, depending on the structure elevation.

Table 3-6 is an example of the offset and height requirements as a function of lanes. This will vary, depending on the actual equipment used and offset from first travel lane, so manufacturer's recommendations should always be considered during the site design.

Mounting Height of AP/RU (Meters)	Maximum Distance to Magnetometer Sensor (Meters)
5	30
6	45
9	50

Table 3-6: Maximum Distance from the AP and RU to Magnetometer Sensor

4. Structure Type

   Wireless Access Points and Repeater Units can be either free-standing on a pole, or collocated with an existing structure such as:

   - Sign structure
   - Overhead truss structure
   - Bridge structure
   - CCTV pole
   - DMS structure

APs/RUs are amenable to mounting configurations that vary from those listed above. The designer should co-locate an AP/RU on any of the above structures where the structures coincide with required detector spacing, and where the structure satisfies the mounting height guidelines.

In the case of wired magnetometers, these parameters are irrelevant and the most important consideration is the distance from the duct installed units back to the road side connection and analysis equipment.

3.8.5 Bluetooth® Device Matching System

Bluetooth® devices have a unique electronic identifier called a Media Access Control (MAC) address, which is transmitted short distances. The system works by having an initial reader pick up the MAC address and then a second reader along the corridor identifying the same MAC address. A vehicle containing a detectable Bluetooth® device is observed at the two stations. The MAC address and time of detection is logged and the information used to obtain a sample travel time for the segment. This information is then processed to approximate the travel time and average speed. Similarly, origin-destination information can also be derived.

Regrettably changes to the Bluetooth specifications in version 4.2, combined with additional changes implemented by vendors such as Apple to improve security in its latest iPhone releases are likely to result in this technology being obsolete as MAC addresses will effectively no longer be either broadcast or may change dynamically at random intervals. These changes will eventually negate the effectiveness of this technology for use in origin-destination information capture. Designers should consider that this technology has an effective life of no more than three to five years.

When designing a Bluetooth® detector location, the designer should consider the steps below.

1. Detector Location

   Bluetooth® detectors are primarily used to provide high level sample link travel times and origin-destination data. The device therefore needs to be positioned along the side of the roadway at a height of approximately 3 to 5 m. Bluetooth® detectors may be considered as an alternative technology in case of conflict or inability to use other more preferred methods or equipment on all highways and major arterials throughout Qatar.

   - On highways, detectors should be located with a general distance of 2km spacing. Additionally, there should be at least one detector located between each interchange.
   - On major arterials, detectors should be located with a maximum of 1km spacing. Additionally, there should be at least one detector located between each signalized intersection or major roundabout.
   - Also, when locating a Bluetooth® site the access for power and communication needs to be taken into consideration. Solar power, Power over Ethernet (PoE), and cellular modem can and should be utilized.

2. Detector Quantity

   Bluetooth® detectors can typically cover approximately a 45m radius, which is equivalent to up to six lanes of traffic. At locations where the roadway exceeds 45m, multiple detectors must be used. When the zone exceeds the detection capabilities of a detector, one detector on either side of the roadway is necessary to capture all travel lanes.

3. Structure Type

   The device can be pole-mounted and does not require an overhead structure. Bluetooth® detectors can be either free-standing on a pole, or collocated on an existing structure such as:

   - Sign structure
   - Overhead truss structure
   - CCTV pole
   - DMS structure
   - Light pole

Bluetooth® detectors are amenable to mounting configurations that vary from those listed above. The designer should co-locate Bluetooth® detectors on any of the above structures where the structures coincide with required detector spacing, and where the structure satisfies the mounting height guidelines.

Mounting Radar Sensors on existing or new wooden poles is technically workable but is not advisable in the State of Qatar as a permanent installation.

3.8.6 License Plate Recognition Systems

License Plate Recognition systems are able to capture and recognize the license plate of vehicles passing through an area of interest. These systems are primarily composed of high resolution, fixed cameras designed specifically for LPR applications accompanied by an Optical Character Recognition (OCR) engine used to extract the license plate characters from the captured images. In newer LPR cameras, the OCR engine is located on-board the camera and the camera is capable of transmitting the text of the license plate to a central system. It is required that all LPR cameras deployed be capable of generating an OCR result directly at the camera and transmitting it to the Master Software.

When a license plate is read in two consecutive locations, it is possible for the central system to create an individual trip for that vehicle and calculate the travel time. This data is aggregated and averaged by the central system to provide useful journey time information.

The use of LPR is for data only and not enforcement. However the use of LPR for OHVDS and WIM can include provisions of data outside of enforcement.

When designing an LPR location, the following factors must be taken into account:

1. Detector Location

   Since LPR systems are used to provide journey time information, they should be strategically placed along key corridors and roadway segments between transfer points to maximize the number of trips that may be built by the central system. Due to the cost and structural requirements, it is not normally practical to deploy LPR systems on local or urban roads. LPR systems should primarily be used on expressway projects unless there is a compelling need to do so otherwise.

2. Detector Quantity

   Typically, a single camera is required to provide complete coverage for each lane. It is common for cameras to provide partial coverage of adjacent lanes as well to ensure capturing of vehicles that are straddling lanes. Moreover, LPR cameras should be positioned to capture the rear-license plate of the vehicle.

3. Structure Type

LPR cameras typically require an overhead structure and are mounted in the center of each lane. Mounting heights and elevation angles vary depending on the manufacturer and are affected by the focal length of the lens, the quality of the OCR engine and the resolution of the camera. Typically, a mounting height between 5 to 7 meters is used depending on the camera manufacturer. It is recommended that for all LPR camera installations, the manufacturer's mounting recommendations be strictly followed to maximize the performance of the system.

Some LPR camera manufacturers also support cantilever structures for LPR camera mounting. In this case, LPR cameras are mounted on one side of the roadway and are oriented towards the lane of interest. The designer should consider the availability of structures and the geographical location when determining the placement of LPR cameras.

4. OCR Engine

The on-board OCR engine of any camera will require a training period to optimize its performance. The training of OCR engines is typically provided by manufacturers as a value added service. It is important to ensure that an identical OCR engine is running on all LPR camera installations within a segment for which journey time is to be calculated to prevent any inconsistencies during license plate recognition.

5. Hard Shoulders

The use of LPR on hard shoulders should be considered by designers and factored into Gantry design for schemes. Taking a pragmatic view of this, if a road has not been designed for hard shoulder running then the positioning of the expensive and high maintenance cost LPR systems on these schemes, is not practical. Designers should ensure that all gantries have the facility to accommodate LPR coverage of shoulders with full connectivity and other capabilities, but for future use.

3.9 ITS Enclosure Placement

When the TDMS system includes devices that will be designed, constructed, and maintained as Ashghal-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes:

- The enclosure for the TDMS controller should be pole-mounted on the TDMS pole or existing structures wherever possible in order to minimize cost.
- If possible, collocate the TDMS enclosure components within another ITS field device enclosure. Verify manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

- The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the enclosure location.
- A maintainer's pad should be provided for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- Designers should avoid placement of enclosures where crossing of active lanes becomes necessary.

When it comes to designing the enclosure, there is no standard size. There are a wide variety of component manufacturers to choose from and this will usually impact the enclosure interior space requirements. In some cases, collocated ITS devices may also share the same enclosure. This will further influence the design of the enclosure size.

Deatils for an ITS enclosure can be found in Ashghal's ITS Specifications. Please note for Local Roads Projects the type and nature of the enclosure may vary from that specified in the National Standards on the basis of space, access and constraints within the roading reserve. In this case, alternative enclosures should be presented to Ashghal for prior inspection and approvals.

4 Closed Circuit Television Cameras

4.1 System Purpose & Design Flow

The primary function of a CCTV camera is _to provide surveillance of the transportation system_ and enhance situational awareness. CCTVs enable operations staff to perform a number of valuable monitoring, detection, verification and response activities for events occurring on the road network.

Typical CCTV camera uses include:

- Detecting and verifying incidents along roadways and within tunnels.
- Monitoring traffic conditions.
- Monitoring incident response and clearance.
- Verifying message displays on DMS.
- Assisting emergency responders.
- Monitoring environmental conditions (visibility distance, wet pavements, etc.).
- Providing information to the public as part of the traveler information services

To maximize the effectiveness of a CCTV camera and to reduce potential threats to driver safety, the camera type and location must be carefully considered when deploying any new camera. The design process is illustrated in Figure 4-1. First, the operational requirements of the camera must be considered. This will determine the camera type and the general camera location required to achieve those requirements. These two factors determine the mounting structure characteristics that are needed.

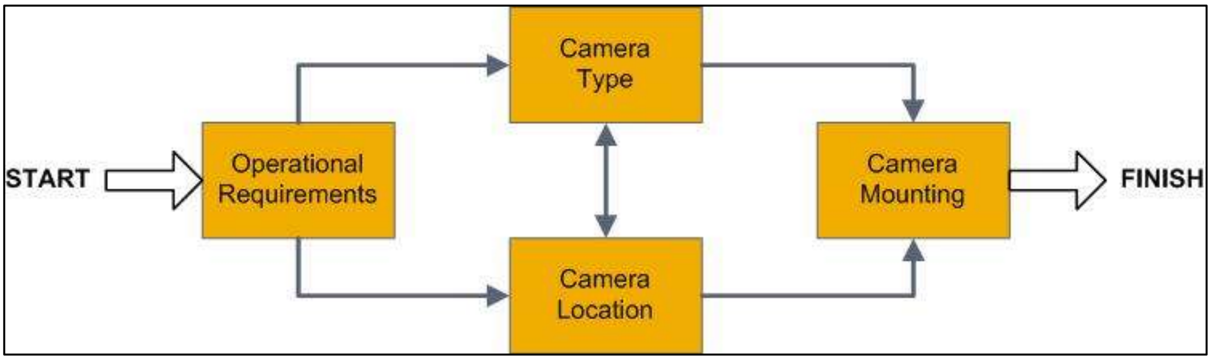

Figure 4-1: CCTV Design Flow Chart

One critical element included in the above image is the communications network. This is factored into the Camera Location decision. Failure to correctly specify a suitable communications network for CCTV will result in failure for the proposed solution. Designers should take significant care around the attachment priorities of CCTV cameras to fiber back bones, MPLS networks and WANS to ensure maximum frame rates and image quality at the Traffic Management Centre.

There are several industry standards/requirements related to CCTV cameras. Table 4-1 highlights some of the more important ones:

Criteria	Relevant Standard
Communication and Software	ONVIF
Structure	Ashghal Civil and Structural Standards for ITS QCS 2010
	Note for CCTV located in Local Roads Projects variations on enclosures, poles and other supporting infrastructure may apply – designers should confirm with Ashghal if they need to depart from Ashghal's ITS Specifications for enclosures and obtain approvals.

Table 4-1: CCTV Standards

4.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the multiple criteria associated with CCTV camera design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific guidance related to the design process for a CCTV camera site are contained in those referenced sections.

The criteria contained in this publication should be considered when designing new CCTV camera sites. It is important to note/clarify that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria, should be detailed by the designer. The goal of this process is to provide practitioners with guidance, as well as to provide consistency with respect to camera installations.

Table 4-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with "needs" outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	
Location/Placement Guidelines	**Section 4.3**
• Has the camera location been chosen/designed with consideration to maximizing visibility? • Has a site for the camera been chosen that considers the available utilities and the cost/constraints associated with connection to those utilities?	

• Has the site been chosen with consideration to protecting the camera structure and ensuring that it will last without undue maintenance necessary to the structure and the surrounding site? • Has a site been chosen that makes the best use of the operational needs of a CCTV camera system (e.g., Incident Management)? • Has a site been chosen that satisfies safety requirements for personnel performing maintenance on the system? • Has the site been chosen so that it will minimize maintenance costs (e.g., there is sufficient shoulder to park a bucket truck without the need for a full lane closure and significant traffic control activities)? • Has the site been chosen where it will not interfere with pedestrian or bicycle movements? • Has the site been chosen that leads to the desired CCTV Camera monitoring coverage of the Qatar Roadway network, including tunnels and the approaches to tunnels and at road works? • Have privacy issues for adjacent land owners and or Government Facilities been addressed? How has this process been conducted and approvals obtained to proceed? • Qatar CAA should be consulted if installing any pole over 9m in the vicinity of an airfield or airport.	
CCTV Type	**Section 4.4**
• Is the camera type (Pan, Tilt & Zoom vs. Fixed) appropriate for the desired location?	
Camera Mount	**Section 4.5**
• Have Ashghal's standards been followed in the design of the mount/structure? Or has a departure been obtained for a variation? • Is a camera lowering system needed? Does this meet requirements? (ie mid hinge pole or pole lowering)	
Enclosure	**Section 4.7**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within the manufacturer's recommended distance to the camera? • Is the enclosure mounted on the camera pole or on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? Has a concrete maintainer's pad been provided at the enclosure's main door?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the camera and all of the system components been	

determined?	
Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the camera site? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 12.2**
• Have any Power Filters/UPS and power back-up options been determined and accounted for?	
Communication	**Section 13**
• Have the communication requirements for the camera been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with Ashghal?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

Table 4-2: CCTV Design Considerations and Section Outline

4.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

4.2.1.1 Communications Interface for CCTV Cameras

The communications interface between the CCTV camera system and the TMC is needed to facilitate the following functions:

- Configure the CCTV Camera System **-** This feature allows an operator to determine the identity of the field device and its capabilities. This feature also allows an operator to configure the presets, pan/tilt/zoom limits, home position, step sizes (for pan/tilt), and timeout parameters.
- Control the CCTV Camera System - This feature allows an operator to control the pan/tilt unit, lens, and camera. It allows an operator to control the zoom, command the camera to preset positions, activate camera features (e.g., wipers, washers, blower, auto iris, auto focus), set and clear alarms and alarm thresholds, and set camera zones and labels and create or set privacy masking for restricted areas

- Monitor the CCTV Camera System Status - This feature allows an operator to monitor the overall status of the field device, the status of each sensor, the output status, and the status of each zone. This feature also allows an operator to determine presets, the position of pan/tilt unit, the status of features supported by the camera (wipers, washers, blower, auto iris, auto focus), and monitor alarms.
- The communications protocol should support all the features that are required for this device.

4.2.1.2 ONVIF for CCTV Cameras (TCP/IP Transport):

The following ONVIF standards may be applicable:

- ONVIF Profile S provides specifications for functions related to controlling and monitoring the status of cameras, lenses, and pan/tilt units. This standard defines data elements specific to the discovery, configuration, control, monitoring and viewing of a CCTV camera control subsystem, which consists of an assembly of a camera, lens, pan/tilt functions and any relay outputs that may be present.

4.3 Location/Placement Guidelines

The selection of CCTV camera locations is based on the operational and maintenance requirements. The desired coverage will often dictate the general camera locations. This should be a primary design consideration. Local topography will also play a major role.

Camera locations should provide a clear line of site with minimal obstructions. The considerations outlined in Table 4-3 below should be taken into account when selecting the site and placement of the camera.

Visibility	• Cameras in low light conditions, such as tunnels, should be located so that the main view is away from bright light. • Near horizontal curves, install on outside of curve. • Near vertical curves, install at the crest. • At the intersection of two major routes or an interchange, place CCTV camera(s) so that secondary roads and ramps can also be monitored. • The blind spot created from the pole should be oriented at a location non-critical to viewing.
Utility Availability	• Consider proximity to power and communications. • If fiber-optic communication is available, try to place the camera on the same side of the roadway to eliminate lateral crossings (this is secondary to visibility regulations).

Safety and Device Protection	• Protect CCTV structure with barrier inside the clear zone, but consider lateral deflection and maintenance vehicle access. • Medians are not the preferred location, but wide medians may be considered if suitable roadside locations are not available. • To reduce site erosion, reduce construction costs, and provide longer device structure life, avoid locating the structure on sections that have a fill slope of greater than one vertical to three horizontal. • Provide working pads where possible
Operational Considerations	• Provide for full visual CCTV coverage of the roadway network on all minor and major arterials and expressways including rural roads. • Provide for full coverage within all tunnels and on the approaches, in compliance with NFPA 502. • Provide full coverage of roadways at road works. • If possible, position cameras to view nearby DMS for message verification. • Large interchanges of two major expressways may require more than one camera to obtain all desired views of roadways and ramps. • If possible, avoid mounting onto bridge structures due to the potential of vibration affecting the image. • Consider the use of fixed cameras for sensitive locations and tunnel-related applications to supplement PTZ coverage. • Provide the appropriate privacy masks and restrict PTZ tours near government locations or residential areas.

Maintenance Considerations	• Where possible, the CCTV camera should be located such that a maintenance vehicle can park in the immediate vicinity without necessitating a lane closure or blocking traffic when possible. • A concrete maintainer pad in front of the enclosure opening should be provided. • The CCTV enclosure should be mounted away from traffic so that the maintainer is facing traffic when looking at the enclosure. This will increase the life of the filter as well as the safety of the maintainer. • Designers should avoid placement of enclosures where crossing of active lanes becomes necessary.

Table 4-3: Camera Site Selection and Placement Considerations

4.3.1 Camera Coverage

Full CCTV camera coverage should be provided for all minor and major arterials, rural roads and all expressways throughout the State of Qatar. Full camera coverage of a roadway results in CCTV camera placement such that an operator can view and monitor the entire corridor, with no breaks in coverage. In order to provide full and continuous coverage of a roadway, cameras should be placed such that 100% coverage is obtained with at least 50m of viewable overlap between cameras depending on the curvature of the roadway. Where there are significant bends, variations in grade or subgrade (underpasses) or tunnels more CCTV units should be used. For all Local Road Projects where there are not existing cameras at signalized intersections PTZ CCTV cameras are to be installed where warranted.

Full CCTV camera coverage within tunnels is also required, in accordance with the requirements of NFPA 502.

When possible utilize a camera-equipped van or bucket truck to validate CCTV camera placements prior to installation.

4.4 Camera Type

Most of the desired CCTV camera features are standard with commonly available commercial products off the shelf. Depending on use, a camera needs to be chosen that meets Ashghal's ITS Specifications.

The following features related to camera type must be considered as part of the design process:

- Pan-tilt-zoom vs. Fixed
- Analog vs. IP

Note that fixed mount cameras should be used on a case-by-case basis, and for very specific applications (such as within tunnels) or in incident black spots for AID/VIDS.

4.4.1 Pan-Tilt-Zoom vs. Fixed

Using a Pan-Tilt-Zoom (PTZ) platform, CCTV system operators can change camera position about the 360-degree 'azimuth' axis and adjust camera elevation up or down (within a 90-degree range) depending on the type of PTZ camera used. Together with a zoom lens, the PTZ camera allows operators to view a scene within any direction about the camera, and within the lens field-of-view and distance ranges. The speed of the pan/tilt mechanism determines the rate of camera coverage, while the horizontal and vertical camera movements determine the coverage area. There are two primary types of PTZ cameras:

1. **Dome PTZ:** Dome-enclosed systems provide much higher PTZ speeds. Dome camera systems have more horizon down capabilities than external units, having the ability to look straight down. This is extremely useful in intersections. It should be noted that dome cameras are "horizon limited" and cannot look up at the sky or up a nearby steep hill very well. However, unless the camera is to be placed in very hilly terrain, this is not a major drawback for roadway traffic monitoring.
2. **Non-Dome PTZ:** Non dome PTZ cameras provide greater versatility in their PTZ motion and do not suffer the reduced sensitivity that tinted domes experience in low light conditions. Non-dome PTZ cameras are also more easily serviced than their dome counterparts, and are generally very good.

For long range use on Expressways – Non Dome external PTZ cameras should be considered. These are more robust than Dome units and have integrated lenses or the capability to install higher resolution lenses with better Telephoto capabilities. These types of CCTV cameras can also have wipers installed and be nitrogen filled which maintains image integrity and camera operations under extreme conditions.

Fixed Point of View (POV) cameras should always be considered for mission critical installations that focus on only one view, and in locations such as tunnels and long underpasses. Fixed POV CCTV cameras are ideal for LPR use, AID and VVIDS use. Designers called upon to consider CCTV for a scheme should be prepared to specify a mix of camera types to meet the functional requirements for that scheme.

4.4.2 Analog vs. IP

New CCTV camera deployments should in general be of the IP type, except in the case where Ashghal requires the camera to be analog-compatible for a particular reason (for special case applications only). This could include the requirement to separate the encoder from the camera for maintenance reasons.

The need to deploy analog cameras is typically due to legacy infrastructure that contains some analog devices or where there is a requirement to separate out the components for maintenance reasons. In general there is no issue with using both types of approach or a hybrid of the two on a case by case basis

4.5 Selection of Camera Mounting Type

The overriding factor in determining a CCTV camera location is the site's fitness for performing the operational role that it is designed for (see Section 4.3). If all other factors are equal, the ITS practitioner may possibly have more than one option on the type of camera mount to design. Additional cameras should be considered to supplement CCTV coverage where it may not be possible to provide complete coverage using a single camera.

The three possible choices are:

- Pole-mounted
- On an existing sign or structure, like a bridge
- Inside a tunnel, on a wall, or an underpass wall

The most prevalent structure for CCTV cameras is a stand-alone pole. The recommended pole height to be used in Qatar for Expressway Projects is 15m, and pole heights of 20 to 25m may be warranted at some locations depending on topography, obstructions, bridges, interchange geometry, etc. The heights that are suitable for Local Roads Projects however are not always about going higher: 6m, 9m, 12m Poles in addition to the 15m through to 25m poles should be considered by Ashghal for use in the State of Qatar for Local Roads Projects. The designs for these if called for by a designer should be submitted for official review and approval as part of the design gateway approval process. The same pragmatic approach needs to be taken on mounting hardware. The standards call for a minimum arrangement. Pragmatically however the number and dimensions of anchor bolts used and the shape of the base plate should be considered on a pole by pole basis. The standards exist to provide guidance but there is no reason why Ashghal should or would refuse to accept an equally robust alternative solution if correctly presented for consideration. For all pole heights, there shall be no more than a 25mm deflection under 50km/hr wind speeds. The pole height and location should be chosen to provide a clear and unobstructed view of the roadway.

However the existing standards for for a 15m CCTV pole can be found in the Ashghal Civil and Structural Standards for ITS.

4.5.1 Camera-Lowering Device

The use of a camera-lowering system is required for most pole-mounted CCTV installations. The inclusion of a camera-lowering system allows for easier access to the camera, in many cases eliminating the need to use a bucket truck or similar vehicle for maintenance, and reducing the need for lane closures. Camera-lowering systems are typically not used for fixed CCTV cameras since those applications involve fixed mounting on tunnel walls, traffic signal mast arms, etc. During the design process, consideration should be given to the possibility of utilizing a camera-lowering system for fixed CCTV cameras wherever practical. This can take the form of a lowering device or a counterweighted split folding pole.

For a pole-mounted winch based lowering enclosure, do not place the enclosure on the same side as the hand hole for a camera lowering winch or under the camera to be lowered.

Standards and specifications for CCTV Camera Lowering Device will be published in due course on Ashghal's website.

Please note that the submission of split folding counterweighted technology based CCTV poles by designers will also be considered even though these are not explicitly covered in the current standards and specifications. Designers wishing to use such poles should submit example designs to Ashghal for approval. Please note a request for trial of any such new proposed pole is highly likely.

4.5.2 Pole mounted enclosures

The ability to use pole enclosure mounted on mid hinge or split folding poles is also available to designers and works well in an expressway environment up to 15 meters. This also then allows pole enclosure mounting abilities at CCTV pole locations. The use mounted enclosures on split pole in local roads projects is also available to designers for lower heights. In general these types of poles are counter weighted. This alows the pole to be lowered with ease for ongoing CCTV maintenance requirements without impact on enclosure access. Example schematics will become available within Ashgal's reference design packages in due course.

4.6 CCTV Cameras in Tunnels

CCTV camera systems for use in tunnels shall ensure compliance with all requirements of NFPA 502 - Standard for Road Tunnels, Bridges, and Other Limited Access Highways. Refer to the NFPA 502 standard for requirements. One hundred percent (100%) CCTV coverage should be provided on the approaches to and inside a tunnel.

4.7 ITS Enclosure Placement

An ITS enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location includes the following:

- The enclosure for the CCTV controller should be ground-mounted.

- In locations where the site has limited space, the enclosure may be pole-mounted.
- A ground-mounted or pole-mounted enclosure should be located at a minimum distance from the barrier, based on the design and type of barrier used. See standard drawings for appropriate minimums.
- The enclosure is to be placed in the safest possible location.
- The enclosure should be oriented so that the maintainer is facing the roadway, while performing maintenance at the enclosure location.
- The enclosure should be at a level where the maintainer doesn't need a step ladder to perform maintenance at the enclosure location.
- The enclosure should be located as close as possible to the location where the camera is installed; however, if site conditions prevent the installation of the enclosure near the camera, the enclosure should be installed up to a maximum distance of 100m. If the distance exceeds 100m, line boosters should be provided for either Ethernet or video signals. If the camera is IP, the absolute maximum distance is 100m for Ethernet CAT5 based on restrictions of the communications cable. In this case single mode fiber optic cable may need to be used to drive signals over distance.
- A leveled maintainer's pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure. Where this is not possible, locate the camera where it is accessible by on-foot maintenance personnel.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

When it comes to designing the enclosure, there are a wide variety of component manufacturers to choose from and this will usually impact the enclosure interior space requirements. In some case, collocated ITS devices may also share the same enclosure. This will further influence the design of the enclosure size.

Details for an ITS enclosure are available in Ashghal's ITS specifications. Should designers wish to vary from the details in the specifications they should present Ashghal with such variations and seek approval to proceed.

5 Roadway Weather Information Systems (RWIS) and Air Quality Monitoring Sites

5.1 System Purpose & Design Flow

The primary function of the Road Weather Information System (RWIS) is to measure and monitor road weather conditions with the use of different sensors. RWIS assists in determining road conditions. This information can be shared with drivers or used internally to assist in scheduling maintenance. RWIS collects atmospheric, pavement surface, and sub-surface information to provide the most accurate weather information available.

The system component that collects weather data is the Environmental Sensing Station (ESS). An ESS consists of a combination of sensors that gather and transmit pavement, temperature, wind speed, visibility, and humidity data. These sensors are controlled by a field controller, called a Remote Processing Unit (RPU), which sends the sensor data to the TMC.

The information can be used to inform drivers of adverse conditions or to determine when to conduct road maintenance operations in a safe manner. RWISs should be used with an information dissemination source such as DMS to reach motorists and reduce weather related traffic accidents. Air Quality Monitoring (AQM) Sites are typically small structures containing electronic instruments used to measure and record the concentration of various air pollutants. The AQM Site purpose is to measure the concentrations of air pollution in a specific area and to determine the source of pollution. If any monitoring station shows pollution levels above a certain threshold, the AQM should notify the TMC.

Any requirement arising from the above raised by a designer for RWIS should be notified to CAA via Ashghal Operations and Maintenance department, in order for CAA to correctly comment on relevance.

Placement of RWIS on specific schemes needs to be conducted in line with consultation with the Civil Aviation Authority (CAA) requirements for placement of this equipment.– Designers should approach Ashghal O&M on obtaining these inputs and to coordinate liaison with CAA in order to correctly place RWIS on Schemes.

With regard to air quality monitoring systems, the placement of these systems is to be determined by Local Roads and Drainage projects in heavily congested areas of the State of Qatar.

There are several industry standards/requirements related to RWIS and AQM Sites. The table below lists a few of the currently available documents:

Criteria	Relevant Standard
Communication and Software	NTCIP
Structure	QCS 2010 Per Manufacturer's Requirements

Table 5-1: RWIS and AQM Site Standards

5.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with RWIS design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a RWIS and/or AQM Site are contained in those referenced sections.

Ashghal requires a system design for each RWIS site which will also include the communications design for that site. The contractor will develop these designs and provide them to Ashghal along with a Communication Test Plan for approval.

All sensors require power to operate. Power is also required for the collection of the data at the RPU and for transmission of the road weather data to its intended users.

Table 5-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with "needs" outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	
Location/Placement Guidelines	**Section 5.5**
• Is this site an RWIS site or an AQM site and why – does the designer expect large numbers of stationary vehicles in the design? Such areas are more prone to AQM issues and include Stadium Car park entrances and exits, heavy vehicle routes and parking areas etc. • Has the RWIS and/or AQM Site location been chosen/designed with consideration to atmospheric conditions? Is the scheme subject to seasonal sand/dust storms, fog or other environmental issues? • Has a site for the RWIS been chosen that considers the available utilities and the cost/constraints associated with connection to those utilities? • Has the site been chosen with consideration to protecting the RWIS and/or AQM Site structure and ensuring that it will last without undue maintenance necessary to the structure and the surrounding site? • Has a site been chosen that makes the best use of the operational needs of a RWIS and/or AQM Site (e.g., low visibility sites)? • Has a site been chosen that satisfies safety requirements for personnel performing maintenance on the system? • Has the site been chosen so that it will minimize maintenance costs and in accordance with QCS 2010, Section 11, Part 1.1.8 (e.g., there is sufficient shoulder to park a bucket truck without the need for a full lane closure and significant maintenance and protection of traffic)?	

Sensor Type	**Section 5.3.1**
• Are the sensor types appropriate for the desired location?	
Sensor Mount	**Section 5.3.1.6**
• Have standards been followed in the design of the mount/structure? • Is the mounting height appropriate?	
Enclosure	**Section 5.6**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure mounted on the RWIS pole or on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? • Has a concrete maintainer's pad been provided at the enclosure's main door?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the RWIS and/or AQM Site components been determined?	
Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the site? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 12.2**
• Have the UPS and power back-up options been determined and accounted for?	
Communication	**Section 13**
• Have the communication requirements for the RWIS and/or the AQM been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with Ashghal?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

Table 5-2: RWIS and AQM Site Design Considerations and Section Outline

5.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

5.2.1.1 Communications Interface for RWIS and AQM

The communications interface between the RWIS sensors and measurements from the AQM Site and the TMC is needed to facilitate the following functions:

- Monitor RWIS Equipment Status. This feature allows an operator to monitor the electrical power for the RWIS equipment to ensure proper operation, and to monitor the movements of a mobile RWIS station.
- Monitor Weather Conditions. This feature allows an operator to monitor the weather conditions that can directly or indirectly affect the transportation system. Weather conditions to be monitored may include wind conditions, temperature, humidity, precipitation, and visibility. This feature also allows an operator to visually inspect and verify reported weather conditions through an image collected at the RWIS equipment location.
- Monitor Pavement Conditions. This feature allows an operator to monitor the road conditions and conditions below the road surface that may adversely affect transportation operations. Roadway conditions to be monitored may include pavement surface temperature, moisture conditions, and surface friction.
- Monitor Water Level. This feature allows an operator to monitor the depth of water at one or more locations, such as over a roadway or in a stream.
- Monitor Air Quality. This feature allows an operator to monitor the current air quality in the vicinity of the RWIS and/or AQM Site, and determine whether there are airborne biohazards in the vicinity. This is the single most important function of the RWIS from a roading management point of view. The state of air quality for both Local Roads and Expressways projects is a critical concern for the State of Qatar as it impacts on public health and safety. Designers should review their schemes from the point of view of probably congestion or impacts resulting in placement of RWIS in consultation with both Ashghal and via them the CAA.

- Upload Event Logs. This feature allows an operator to upload any event logs that are maintained by the RWIS and/or AQM Site.

The communications protocol should support all the features that are desired for RWIS and/or AQM equipment.

5.2.1.2 NTCIP for RWIS

The following NTCIP Information Level standards are applicable.

- NTCIP 1204, Environmental Sensor Station Interface Standard, is a data dictionary standard used to support the functions related to monitoring and collecting environmental sensor data, including weather data, pavement condition data, water level data, and air quality data. This standard defines data elements specific to environmental sensors, which include sensors that monitor weather, roadway surface, water level, and air quality conditions. These sensors are typically connected to a nearby RPU. An environmental sensor station (ESS), in the context of this standard, consists of an RPU plus the suite of sensors connected to it. Typically, the ESS is at a fixed location along the roadway, but ESSs may be portable or even mobile.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

5.3 The RWIS System

The typical RWIS site consists of a pole, enclosure, a RPU, and several environmental sensors. The RWIS outstations are likely to include some or all of the following:

- Road sensors in travel lanes are used to measure surface temperature, sub-surface temperature, and surface condition.
- Atmospheric sensors adjacent to the road measure air temperature, relative humidity, wind speed and direction, air quality, and precipitation.
- A power source supplemented by either a main electricity connection or solar panels.
- A RPU connected to all the sensors translates and records the signals received from the sensors. The RPU transmits data to the server.
- A communication device, such as a modem, to allow remote collection and transfer of data.
- A connection to nearby DMS and/or VSL to provide automated alerts to drivers in hazardous conditions.

5.3.1 Types of Sensors

Most of the sensors on an outstation are installed above the road, affixed to a pole. The sensors that are typically included in a RWIS are the ultrasonic wind speed and direction sensor, precipitation and visibility sensor, air temperature/relative humidity sensor, and passive pavement sensor (PPS). These sensors are typically part of an outstation. However, some sensors are installed either at the road surface or sub-surface.

5.3.1.1 Passive Pavement Sensor (PPS)

The identification of road temperature and condition is crucial for the accuracy of a RWIS. These sensors report the road surface as either wet or dry and usually report the road surface temperature. These sensors are located under or just above the pavement.

5.3.1.2 Air Temperature and Humidity

Air temperature and humidity sensors can provide air temperature, dew point temperature, wet bulb temperature, and relative humidity. Typically, a single sensor provides both air temperature and relative humidity measurements. To minimize errors induced by solar heating, the sensor is typically mounted in a solar radiation shield. These sensors should be mounted approximately 1.5 to 2.0m above ground level and installed towards the predominant wind direction.

5.3.1.3 Precipitation and Visibility Sensor

Visibility sensors measure meteorological optical range, and can be extremely useful in low-visibility or fog-prone areas. The visibility sensor should be capable of detecting fog, mist, smoke, and sand. These sensors typically use infra-red forward scatter technology, with a limitation being that anything in the optical path that attenuates or scatters the infra-red beam, such as dirt, or even spider webs, may cause erroneous readings. To avoid this problem multiple sensors can be used to check and adjust for any contamination errors. These sensors should be installed at a height of approximately 2.0 to 3.0m above the ground.

5.3.1.4 Ultrasonic Wind Speed and Direction

Ultrasonic wind speed and direction measurements will be made either by a combination sensor or by individual sensors. There are a variety of types of anemometers which vary in appearance, but have the same basic principles of operation. This sensor should be positioned approximately 10 m above ground level. Obstructions to the wind flow should be avoided.

5.3.1.5 Barometric Sensor

Barometric pressure sensors are used for determining atmospheric air pressure. These sensors measure the fluctuations in the pressure exerted by the atmosphere. Barometric pressure data is useful to create weather forecasts. The forecasts are used to predict future pavement and weather conditions that will potentially cause road problems.

5.3.1.6 RWIS Structure

The RWIS structure must have a concrete foundation to provide a sturdy platform. The size must be designed for the specific site or according to manufacturer's specifications. The RWIS structure will be a pole. The structure should be sturdy and meet manufacturer's requirements for deflection to reduce contamination of sensor data by turbulence and wind flow.

The pole height should be sufficient to accommodate the sensors. If installing wind sensors, poles should be at least 10m in height. Poles are most frequently installed within a range of 10 to 15m from the edge of the paved surface and if possible at the same elevation as the surface of the road.

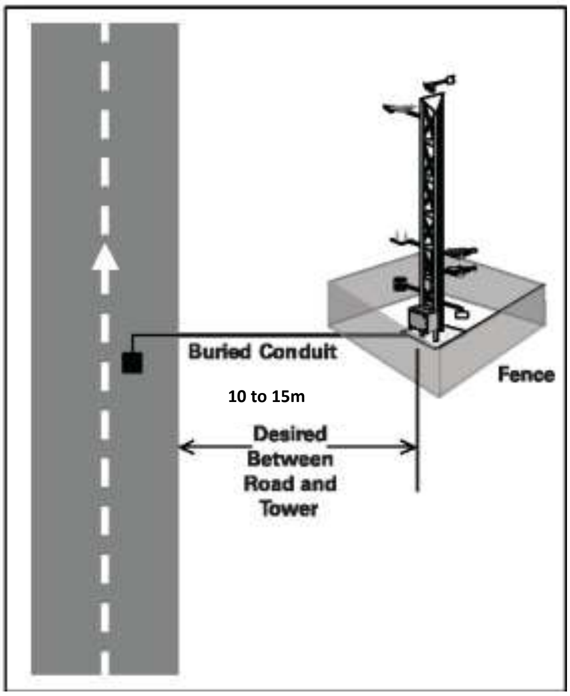

Figure 5-1: RWIS Pole Location

Photo Credit: FHWA The use of these images does not represent any form of endorsement of these products – all images remain the property of their respective owners all rights are reserved.

5.4 AQM Site

The AQM Site is an air quality device that is used to measure common air pollutants including Sulphur Dioxide (SO2), Nitrogen Oxides (NO), Ground Ozone (O3), Carbon Monoxide (CO), Hydrocarbon-Methane and Non-Methane THC, and Particulate Matter (PM10, PM2.5) among others. Air samples are generally collected to observe pollution trends and sources, and activate control procedures. The AQM Site should have a particle monitor module and a gas module to detect the pollutants mentioned above. The mounting assembly and the RPU should follow manufacturer's specifications and Ashghal's ITS Specifications.

5.5 RWIS and AQM Site Selection

A poorly chosen site can result in incorrect readings, service difficulties, or even damage from passing traffic. The site should not be sheltered in such a way that sensor readings give a false impression of the situation closer to the road. At the same time, sensors and the outstation should not be located too close to the road that wind from passing traffic will give inaccurate readings. The height of sensors above the ground, as well as their orientation, can also affect sensor readings and needs to be taken into account when selecting locations and installing equipment.

The use of RWIS and AQM in tunnels needs to be considered on a scheme by scheme basis where such equipment is determined necessary due to tunnel length geometry and position.

The number and placement of sites in the network is dependent upon a variety of factors including; topography, soil type, land use, microclimate zones, proximity to utilities, and road classification. Generally, the greater the variability in these factors, the more sites will be required in the network. RWIS deployments should focus on roadways where sandstorms and/or fog or significant air quality issues are prevalent, (i.e. Souq Waqif due to excessive vehicle emissions). The observation points and pavement sensors should be installed at critical points along the roads. Variations in sensor or structure siting may be unavoidable due to many circumstances, such as limited road right-of way, access for maintenance, geography, and security concerns. The contractor shall install the weather sensors at various pole heights using mounting brackets in accordance Ashghal's ITS Specifications.

AQM sites should be located strategically where pollution needs to be closely monitored or controlled.

The placement and type of mounting of the AQM site should be approved by Ashghal. Also, when locating a RWIS or an AQM site, the access for power and communication needs to be taken into consideration. The use of AQM in Local Roads projects demonstrates commitment to improving Environmental outcomes and public safety in the State of Qatar. Designers are encouraged to identify with Ashghal specific areas of concern on schemes.

5.6 ITS Enclosure Placement

When the RWIS system includes devices that will be designed, constructed, and maintained as Ashghal-owned assets, the enclosure and its associated components must be included in the design process. See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

The RWIS controller system consists of an enclosure, controller, load switches, power distribution unit, and other miscellaneous devices.

The AQM equipment, monitors, sensors, control module, and communications network device should be housed in an enclosure.

6 ITS Enclosures

Standard specifications for ITS enclosures will be published on the the Ashghal website in due course.

7 Over-Height and Over-Weight Detection Systems

7.1 System Purpose & Design Flow

The goal of Over-height and Over-weight Detection Systems is to prevent commercial and non-commercial vehicles from exceeding the legal height and weight limitations established within Qatar. When the limits are violated, damage to the infrastructure could be significant and the operation of the vehicle will be unsafe. These systems should automatically alert the TMC when vehicles that are over the allowed height or weight pass over a Weigh-in-Motion (WIM) sensor or by the Over-height sensor. WIM and over-height detectors are used to monitor the weight and height of vehicles

There are several industry standards/requirements related to Over-height and Over-weight Detection Systems. The table below lists a few of the currently available documents:

Criteria	Relevant Standard
Communication and Software	NTCIP
Mounting Structure	Ashghal Civil and Structural Standards for ITS QCS

Table 7-1: Over-height and Over-weight Detection System Standards

7.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with an Over-height or Over-weight Detection System design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for an Over-height or Over-weight Detection System is contained in those referenced sections.

The criteria contained in this publication must be followed when designing new Over-height and Over-weight Detection Systems. It is important to note/clarify, that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria, should be detailed by the designer. The goal of this process is to provide practitioners with guidance, as well as to provide consistency with respect to Over-height and Over-weight Detection System installations.

Table 7-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with “needs” outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	

Enforcement Purpose	**Section 7.3**
• Has a comprehensive Over-height or Over-weight Detection System Study been performed? • Do the results of the study support continuing with the deployment of the project?	
Enforcement System Location	**Section 7.4**
• Is the sensor placed such that enough space is available to warn drivers and enable them to re-route as necessary? • Has a reserve area been designed for the offending vehicle to safely stop in for WIM systems? • Is the Over-weight detection system installed in a location to ensure coverage for all key Qatar roadway network routes and access routes to/from major generators of truck traffic?	
Enforcement System Signals	**Section 7.4**
• Are the warning signs placed at critical points to allow drivers to stop or exit the road? • Are the signs designed in compliance with QTM and QCS 2010 requirements?	
Enforcement System Sensors	**Section 7.3**
• Does the system design include all of the necessary detectors? • Does the complexity/configuration of the system require additional detection areas and enable them to re-route as necessary? • Are the sensors able to transmit any offences back to the Master Software?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the detector and all of the system components been determined?	
Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from Over-height or Over-weight Detection sites? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 12.2**
• Have the UPS and power back-up requirements been determined and accounted for?	
Communications	**Section 13**
• Have the communication requirements for the detectors been determined?	

• Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • Has the chosen communications option been reviewed? • If using public communications infrastructure, has service been coordinated with Ashghal?
Environmental
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?

Table 7-2: Over-height and Over-weight Detection System Design Considerations

7.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

7.2.1.1 Communications Interface for Over-height and Over-weight Detection Systems

The communications interface between the enforcement systems and the back office processing element in the TMC is needed to facilitate the following functions:

- Configure the over-height and over-weight detection system field devices. This feature allows an operator to determine the identity of each enforcement system device and configure the sensors.
- Control the over-height and over-weight detection system field devices. This feature allows an operator to reset a field device and initiate diagnostics.
- Monitor the over-height and over-weight detection system field device status. This feature allows an operator to monitor the overall status of the field device and the status of each sensor.
- Upload Event Logs. This feature allows an operator to upload any event logs that are maintained by the enforcement system field devices.
- Collect Data from the Field Devices. This feature allows an operator to retrieve the data collected by the enforcement system field devices.
- The communications protocol should support all the features that are desired for enforcement system.

7.2.1.2 NTCIP for Enforcement Systems

The following NTCIP Information Level standards are applicable.

- NTCIP 1206, Object Definitions for Data Collection, is a data dictionary standard used to support the functions related to data collection and monitoring devices within a transportation environment. This standard defines data elements specific to transportation data collection sensors – it supports the collection of information about each vehicle, such as number of axles, vehicle dimensions (such as length, width, and height), vehicle weight, and axle weight. Other information that may be collected includes vehicle headways, vehicle speeds, and vehicle acceleration.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

7.3 Enforcement Purpose

Over-height and over-weight detection systems are deployed to prevent road damage by oversized vehicles. WIM and over-height warning systems can identify those vehicles that do not comply with the limits.

The WIM shall automatically indicate when vehicles are over the permitted weight as they drive over a sensor. Unlike static weigh stations, WIM systems do not require the vehicles to stop; therefore, making them more efficient.

The principle guidance on WIM for designers is that designers should consider the following questions:

1) Is there a source or destination for heavy vehicles on or in scheme? In which case Designers should be considering off route truck weigh stations and over-height detection
2) If operationally the scheme lies on a heavy vehicle route or is located between a source or a destination for heavy vehicles, then WIM on the main line should be considered.
3) If there are structures that fall under or have infrastructure on them that is less than 5.7m in height, then over-height detection, alarms and warning signs are required.

Over-height vehicle detections systems are deployed to warn drivers and the TMC when a vehicle exceeds the maximum height for an upcoming infrastructure or obstacle.

7.3.1 Over-Height Detection System

Over-height detectors are used to identify over-height vehicles and warn drivers of an upcoming obstacle. They can be used in different applications such as bridges, over-road walkways, tunnels, overpasses and parking structures among others. Over-height detectors should be installed prior to a bridge that is lower than the standard height of 5.7m over a roadway before and potentially after any sacrificial beam treatment which should be installed irrespective of any ITS solutions for OHVDs being considered. The system should activate a visual and/or audible alarm, warning signs, flashing lights, or traffic signals to prevent accidents. The system should also send an alarm to the TMC Master Software when activated.

7.3.2 Weigh-in-Motion

WIM devices are designed to capture and record vehicle weights as they drive over a sensor installed under the road pavement. The sensors estimate the load of a moving vehicle without disrupting the traffic flow. WIM systems are used for collection of statistical traffic data, support of commercial vehicle enforcement, and traffic management.

The most common WIM sensors are the quartz piezoelectric sensors. The piezo-quartz sensor is a widely used type of piezoelectric sensor that has a stable response over a large temperature range. The quartz sensors are used for measuring wheel and axle loads of moving vehicles. These sensors consist of a light metal material fitted with quartz discs. When an external force is applied to the surface of the sensor, the load causes the quartz discs to yield an electrical charge proportional to the applied force through the piezoelectric effect. A charge amplifier converts the electric charge into a proportional voltage that can be measured and correlated with the applied force.

Although this sensor offers great accuracy, piezoelectric sensors are not low maintenance items and WIM solutions require frequent calibration. The sensor is embedded in the pavement and produces a charge that is equivalent to the deformation induced by the tire loads on the pavement's surface. The sensor's performance is affected by pavement flatness.

A standard WIM system should cover all lanes of the expressway where oversized are permitted. The travel lanes are instrumented with induction loops and quartz sensors. All vehicles driving through the WIM site are measured. The legal weight and height limits should be determined by Ashghal.

7.4 Deployment Guidelines

This section identifies deployment guidelines and criteria for each detector technology. The designer should use this section as a guide for deployment of the detector or system of detectors.

Enforcement systems provide information on vehicle classification that can be used for regulation and automatic enforcement. The locations and system depend on the characteristics of the roads and their traffic volumes. WIM systems are should have the provision to be supplemented with the use of LPR cameras to capture the offending vehicle details as well as CCTV systems to provide overall coverage of the site in question and DMS to advise offending drivers. Both mainline WIM and Weigh Stations should be installed on all key Qatar roadway network routes and access routes to/from major generators of truck traffic.

7.4.1 Weigh-in-Motion Systems

The installation of WIM includes making the pavement cuts and rehabilitation for the inductive loops and quartz sensors. Loop vehicle detectors and quartz sensors are buried several centimeters beneath the pavement surface of the roadway. For specifics concerning the size and placement of the loop and quartz sensor within the travel lane, the Designer should adhere to the guidelines provided in Ashghal's ITS Specifications.

Weigh-in-Motion systems are typically placed along truck routes to capture any offending vehicles. The systems may comprise of a WIM sensor supplemented by an LPR camera that is triggered if an over-weight vehicle is encountered. Downstream signage (DMS) would instruct the driver to pull into a reserve area in case the vehicle is deemed over-weight and unsafe for travel.

7.4.2 Over-height Vehicle Detector Systems

Over-height detectors consist of a sensor mounted on each side of the road. Over-height vehicle detection systems are deployed to warn drivers if their vehicle exceeds the maximum height for the upcoming infrastructure, whether that is a tunnel entrance, low bridge/overpass, or sign gantry. The location of the over-height detector should provide drivers sufficient warning time to stop prior to the structure or re-route without causing traffic congestion. Typically the Over-height Detector System consists of transmitters and receivers, an electronic warning sign, uninterruptable power supplies, and inductive traffic loops. When designing an Over-height detector or system location, the designer must determine detector location, quantity, height and offsets. The aim of the system is to provide immediate feedback to Truck Drivers to prevent an incident. In some cases, over-height detectors can also be used to support WIM systems. OVDS is typically placed in advance of low bridges or overpasses and tunnel entrances which fall within truck routes.

Structure types for both WIM and OVDS must be approved by Ashghal.

8 Dynamic Message Signs

8.1 System Purpose and Design Flow

The primary function of a DMS is to provide traveler information. The nature of this information is varied, but the goal is to disseminate roadway condition information to travelers so that they can make informed decisions regarding their intended trip and/or route.

Some typical DMS uses include notifying travelers of:

- Full road closure
- Tunnel closure
- Lane closures (Incident, Maintenance/Construction, Events, etc.)
- Weather/Road conditions
- Special events
- Travel times
- Future road work
- Scheduled safety messages (e.g., Public Service Announcements)
- Sign testing

To maximize the effectiveness of a DMS and to reduce potential threats to driver safety, the sign type, placement, and the supporting structure must all be carefully considered when designing and deploying any new sign. First, the operational requirements for what purpose the sign will satisfy must be considered. This will determine the general location and the type of sign. These operational requirements and the location will determine the required support structure. The design process can be simply illustrated in Figure 8-1.

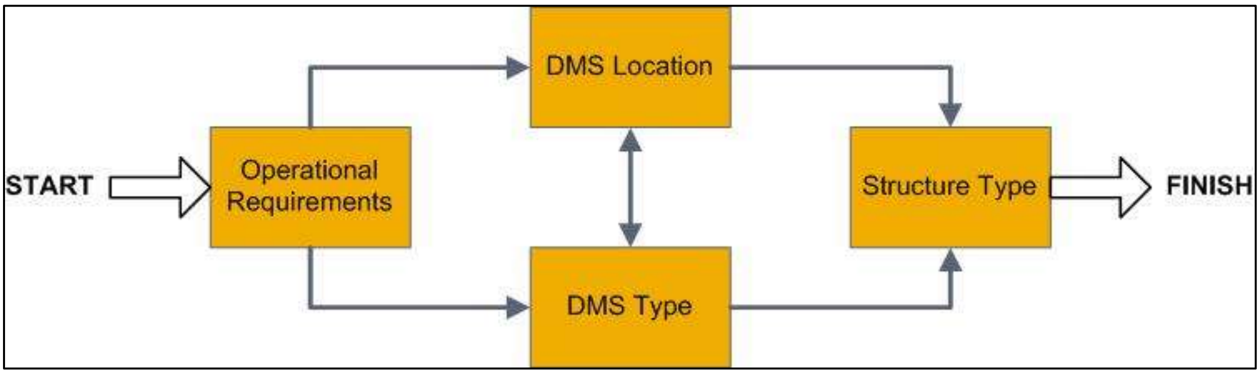

Figure 8-1: DMS Design Flow Chart

There are several industry standards/requirements related to DMS. The table below lists a few of the currently available documents:

Criteria	Relevant Standard
Communication and Software	National Transportation Communications for ITS Protocol
Structures including mounting on existing structures	Ashghal Civil and Structural Standards for ITS QCS

Table 8-1: DMS Standards

8.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with a DMS design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a DMS are contained in those referenced sections.

The criteria contained in this publication should be followed when designing a new DMS. It is important to note/clarify that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria, should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing Ashghal consistency with respect to DMS installations.

Table 8-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with “needs” outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	
Longitudinal Placement	**Section 8.3.1**
• Is the DMS visible and un-obscured? • Is the DMS placed sufficiently in advance of any interchanges that would be used for diversions? • Is the DMS properly spaced away from existing guide signs? • Is the DMS placed to reduce glare/visibility issues from rising/setting sun?	
Lateral Placement	**Section 8.3.2**
• Is the DMS structure located beyond the clear zone or protected by a suitable safety barrier? • Has the lateral offset of the DMS been accounted for when calculating the length of the Reading and Decision Zone?	

Vertical Placement	**Section 8.3.3**
• Is the approaching segment of roadway relatively flat (between 0-4% vertical grade)?	
Sign Matrix Type	**Section 8.4.1**
• Has a sign matrix type been chosen that is consistent with the visibility and message requirements of the roadway being deployed on?	
Sign Viewing Angle	**Section 8.4.2**
• Has a sign viewing angle been chosen that complements the roadway alignment and the DMS structure?	
Sign Access	**Section 8.4.3**
• Are there any traffic, environmental, or safety factors that warrant a specific type of sign access?	
Structure	**Section 8.5**
• Have visibility, road speed/volume, right-of-way, and maintenance/cost issues all been considered when selecting a type of sign structure? • Is there sufficient vertical clearance for the sign and the structure? • Has the structure been designed for the sign, if not then a report from a structural engineer is required.	
Enclosure	**Section 8.7**
• Can personnel safely access the enclosure? • Is the enclosure located within a reasonable distance of the sign? • Is the sign face visible from the enclosure location? • Does the location and orientation provide adequate protection for the enclosure?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the DMS and all of the system components been determined?	
Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the DMS site? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	

Power Conditioning	**Section 12.2**
• Have the UPS and power back-up requirements been determined and accounted for?	
Communication	**Section 13**
• Have the communication requirements for the DMS been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with Ashghal?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

Table 8-2: DMS Design Considerations

8.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

8.2.1.1 Communications Interface for DMS

The communications interface between the DMS systems and the TMC is needed to facilitate the following functions:

- Configure the DMS. This feature allows an operator to determine the identity of the DMS, determine its capability, manage fonts, manage graphics, and manage the brightness.
- Control the DMS. This feature allows an operator to control the message on the sign face of the DMS, control the brightness output, control external devices connected to the DMS, reset the DMS, and perform preventative maintenance. This feature also allows a DMS to be controlled from more than one location.
- Monitor the Status of the DMS. This feature allows an operator to monitor the current message on the DMS, and perform diagnostics.
- Upload Event Logs. This feature allows an operator to upload any event logs that are maintained by the DMS.

The communications protocol should support all the features that are desired for the DMS system.

8.2.1.2 NTCIP for DMS

The following NTCIP Information Level standards are applicable.

- NTCIP 1203, Object Definitions for DMS, is a data dictionary standard used to support the functions of DMS system within a transportation environment. This standard defines data elements that allow for the display of messages and the configuration of DMS. The standard also defines data elements to support fonts, graphics, and message text so that the DMS may accurately render messages on the sign face based on these data elements.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

8.3 Location/Placement Guidelines

DMS should be considered before all key strategic decision making points, variable speed limit gantries, and entries to Expressways. Bespoke DMS signs may also be used on local roads for specific information purposes. Irrespective of location, the site characteristics in the vicinity of the planned DMS must be investigated. These characteristics dictate the amount of information that can be displayed. Relevant characteristics include:

- Operating speed of the roadway (typically the speed limit).
- Presence and characteristics of any vertical curves affecting sight distance.
- Presence of horizontal curves and obstructions such as trees or bridge abutments that constrain sight distance to the DMS around the curve.
- Location of the DMS relative to the position of the sun (for daytime conditions).
- Presence, number, and information on static guide signs in the vicinity.
- Location of the DMS prior to decision points and planned alternate routes.
- Evaluation of possible light nuisance for neighboring properties or other public facilities in urban environments
- Aesthetics, again for local roads implementations
- DMS should be placed in advance of tunnels pragmatically positioned at sufficient distance to provide drivers maximum warning of incidents or issues in the tunnel to maximize safety through early warning and alternative route selection.

8.3.1 Longitudinal Placement

The main considerations related to longitudinal placement of a DMS are to minimize obstructions of and by the DMS, provide for the maximum visibility of the DMS message, and allow the driver ample time in which to read, process, and react to the message.

The approach to a sign can be divided into the following 3 zones:

- Detection Zone
- Reading and Decision Zone
- Out-of-Vision Zone

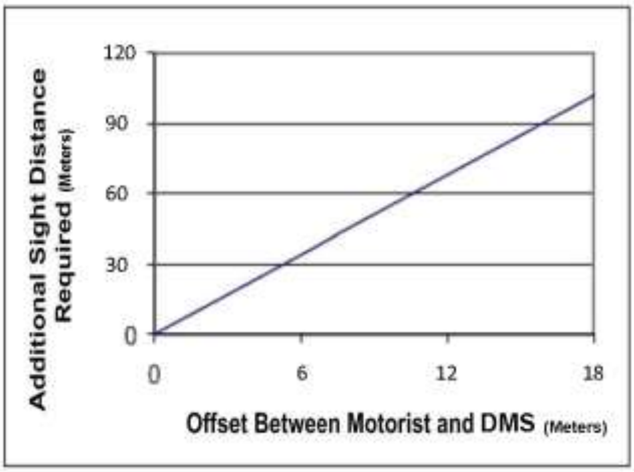

Figure 8-2: Lateral Offset vs. Required Sight Distance

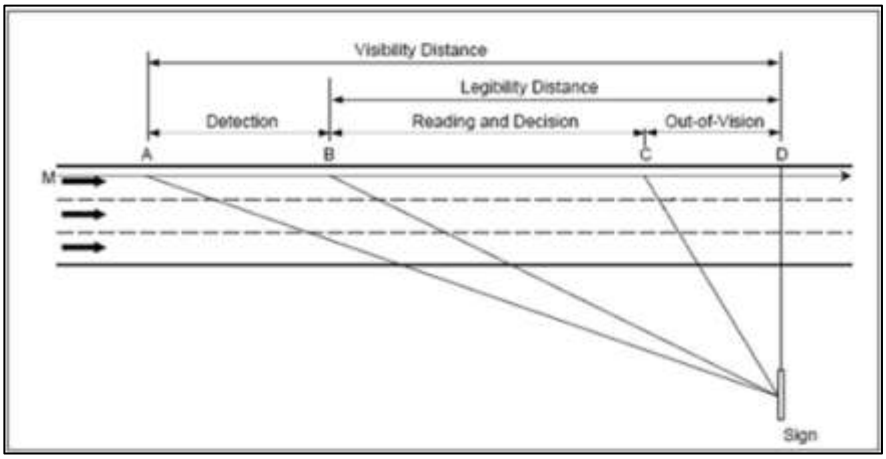

Figure 8-3: DMS Visibility

Detection Distance = AB
Visibility Distance = AD
Legibility Distance = BD
Reading and Decision Distance = BC
Out of Vision Distance = CD

Detection Zone: At expressway speeds (between 80 and 120 km/hr), the DMS should be visible to the approaching driver from approximately 300 to 600m away. The visibility distance should also be increased if the DMS is placed at an offset from the traveling lane, per Figure 8-2 and Figure 8-3.

Reading and Decision Zone: As a general rule, the message panels on an expressway-deployed DMS usually contain room for 3 lines of 21 characters each (see Section 8.4.1).

- For deployment on urban roadways with operating speeds under 80 km/hr, the reading and decision zone should be a minimum of 250m.
- For deployments on roadways with operating speeds greater than 80 km/hr, the reading and decision zone should be a minimum of 300m.
- Individual characters of 30cm in height can be seen from approximately 200m away under normal conditions.
- Individual characters of 45cm in height can be seen from approximately 335m away under normal conditions.

Drivers need approximately one second per word to read and comprehend a message. Travelling at approximately 100 km/hr, this translates into roughly time enough to read and comprehend a 10-word message. The character height, cone of vision, and lateral placement must all be considered when determining the placement of the sign to meet the sight distance requirements.

Out-of-Vision Zone: Once the driver gets close to the sign, they will not be able to read the message. The distance is determined by the viewing angle (Section 8.4.2) of the sign, the structure that the sign is placed on (Section 8.5) and the lateral placement of the sign (Section 8.3.2).

Criteria	Guidance
Visibility	• Location of the sign must provide a viewing distance to drivers of at least 250m, and optimally 300 to 600m. • On expressways, should be placed at least 250 to 300m from a static directional sign. • Should be placed on straight sections of roadway, where/when possible. • If the sign must be located on a curve, should be angled towards the roadway. • The sign should be located/angled to avoid the rising and setting sun from affecting visibility.

Criteria	Guidance
Reaction Time	• In sequence, 2 DMS should be placed no less than 300 m apart; optimally 1.0 km or more. • Should be placed a minimum of 300m away from a lane merge or expansion. • Should be placed 1.50 to 6.0 km in advance (no closer than 1.50 km) of an alternate route or major decision point where possible. • Should not be placed within 60m of a signalized intersection.
Cost	• Should be placed as close to existing communications and power to minimize costs. • Should avoid locating on sections that have a fill slope of greater than one vertical to three horizontal (to reduce site erosion, reduce construction costs, provide longer device structure life),

Table 8-3: DMS Longitudinal Placement Guidance

Legibility Distance Requirements	Expressway	Limited Access Arterial	Major Arterial
Less than 80 km/hr	N/A	200m	200m
80 km/hr to 100 km/hr	250m	250m	250m
Greater than 100 km/hr	300m or more	300m or more	N/A

Table 8-4: DMS Sight Distance vs. Speed Limit vs. Roadway Type

8.3.2 Lateral Placement

Standards regarding lateral placement of signs must be followed when designing DMS. QTM and QCS provide information on the set back distances and vertical clearances:

- QTM
- QCS, Section 6, Part 7 – Vehicle Crash Barriers

The DMS structure must be placed far enough behind a crash barrier or outside the clear zone to comply with the minimum clearances values. Refer to the safety specifications, in QCS, of the particular barrier present at the site or the barrier planned to be installed.

The offset of the DMS (horizontal distance from the sign as a function of travel lane) will require additional sight distance to clearly view and react to the sign.

Criteria	Guidance
All DMS	• All roadside DMS must be placed outside the clear zone or shielded with a crashworthy **barrier** within the clear zone.
	• The distance between the center of a DMS and the driver's forward **line of vision** (offset) must be factored into the DMS placement.
	• For roadways with a speed limit of 100 km/hr and greater, the center of the DMS should be no more than lateral meters from the driver's forward **line of vision.**

Table 8-5: DMS Offset Guidance

8.3.3 Vertical Placement

A roadway's vertical alignment impacts the visibility of the DMS. If there are a limited number of potential locations available, a slight upward grade is desirable.

Criteria	Guidance
All DMS	Where possible, should be placed on roadway segments that are as flat as possible (**grade** of < 1%). Signs may be placed on segments with up to 4% grade.
	Should NOT be placed on roadway segments that have a **grade** of 4% or more (this may be waived if sign is placed on positive grade immediately following a similar negative grade. In these situations, expanded cones of vision should be considered to compensate for the reduction of visibility distance caused by the grade).

Table 8-6: DMS Grade Guidance

8.3.4 Static Signage Considerations

Designers need to ensure that any planned DMS site placement does not conflict with existing directional signage (DS) and advanced directional signage (ADS) on the road corridor. The figure below provides guidelines regarding DMS and LCS placement in conjunction with static signage.

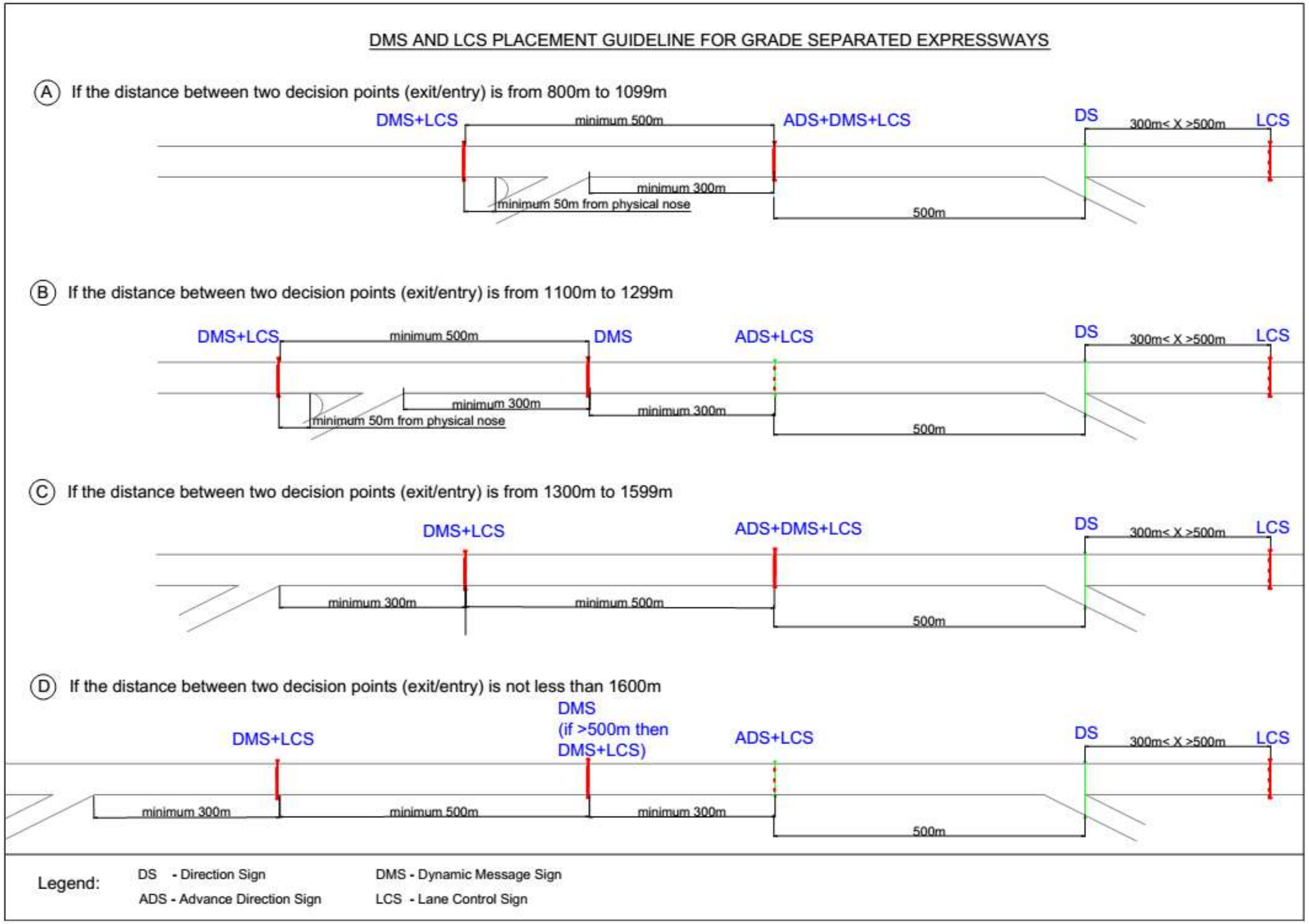

Figure 8-4: DMS+LCS Placement

8.4 Selection of Sign Type

The selection of the sign type, the configuration of the display, and the technology employed all have direct or indirect impacts on the visibility of the message that will be displayed on the DMS.

8.4.1 Matrix Characteristics

DMS display characters and symbols in a matrix format, which are generally designed in one of the following three patterns:

- Character Matrix
- Line Matrix
- Full Matrix

All permanent DMS used in Qatar shall be full color, full matrix. Portable DMS shall be amber color, full matrix. Full matrix DMS displays are important as the use of graphics and symbols become more accepted and used. In this format, the entire display consists of continuous matrix of pixels.

The technology required for all DMS deployed in Qatar is Light-Emitting Diode (LED). LEDs are semiconductors that emit light when current is applied. Typically, several individual LEDs are "clustered" together in order to create each pixel. LEDs have the added benefit of being able to display signs in full color with the appropriate LED type. The reliability of LED lamps is very high.

Criteria	Recommendation
General	• Character height must be between 27 and 45cm. • Sign should be limited to three lines of text. • Each line of text should have between 12 (arterial or local road) and 21 characters (expressways).
On Expressways	• Character height shall be 45cm. • 21 characters per line shall be provided.
All Signs	• Photocell to automatically adjust illumination intensity of display to the ambient light.
Portable	• Character height must be between 28 and 45cm. • Sign should be capable of displaying between one and four lines of text. • Each line of text should have a minimum of 8 characters.

Table 8-7: DMS Display Recommendations

8.4.2 Viewing Angle

Viewing angle depends upon the mounting location of the DMS and the curvature of the roadway. There are three typical angles used in traffic applications: 15 degrees, 30 degrees, and 70 degrees. The 30 degree viewing angle is typical, however, in some cases the designers can consider the use of a 15 degree viewing angle where it does not impede the ability of the sign to be read correctly for the speed environment. Designers should seek Ashghal approval for any viewing angles other than 30 degrees.

8.4.3 Sign Access

Ashghal requires the use of signs that simplify maintenance access. Gantries need to be designed to accommodate sign service and ease of maintenance. What follows is a brief examination of the pros/cons of rear access, walk-in or front-access signs.

Access Type	Pros	Cons	Other Considerations
Walk-In	• Provides safe environment for worker over live traffic.	• Highest installed and recurring costs.	• Catwalk or platform required to access the DMS.
Front Access	• Smaller and lighter sign allows for a smaller structure.	• Sign mounted overhead might require a lane closure.	• A bucket truck is typically used to access the sign • Consider installing catwalk to avoid need for bucket truck and lane closures.

Access Type	Pros	Cons	Other Considerations
Rear Access **(Preferred)**	• Smaller and lighter sign allows for lighter structure • Ease of access from gantry provides safer work environment for service • Signs can be designed to operate without air conditioning and are more cost effective to maintain	• Rear access signs require specific gantry designs to accommodate them however the inconvenience of this is offset by the ease of access and lack of disruption to traffic	• Catwalk or platform required to access the DMS • Removes the requirement for full span cross motorway enclosed signage • No traffic disruption during service • Reduced complexity as most of these signs do not require air-conditioning

Table 8-8: DMS Access Types

8.5 Selection of Structure

The three types of permanent structures that Ashghal allows for mounting DMS are overhead or span, cantilever, and center-mount. All large and medium-size DMS shall be mounted on either overhead or cantilever structures. Center-mount structures will be considered as an exception in urban areas for medium-size/ small signs only; however, they will require specific approval from Ashghal. The lateral placement guidelines in section 8.3.2 and the nature of the roadway are the two main factors in determining the type of structure that the DMS should be mounted on. Portable DMS should not be considered as an acceptable long-term substitution for permanent DMS. Portables should only be deployed as temporary installations.

Support Type	Pros	Cons	Other Considerations
Overhead	• Best for visibility • Has excellent co-location capabilities	• Highest in cost • Due to size is typically more intensive to maintain	• Good alternative if limited ROW available • Can be used on any roadway type • Utilize on high volume roadways

Cantilever	• Less expensive than overhead • Viable alternative to full-span solutions.	• Visibility can be an issue if truck volumes or high sided vehicle traffic is high	• Alternative if limited ROW • Can be used on any roadway type
Portable	• Good **temporary** alternative.	• Smaller display • Maintenance is related to vehicular nature of trailer and battery components	• Suitable for construction activities and temporary emergency measure.

Table 8-9: DMS Support Type Comparison

The width of the roadway (including all lanes and hard shoulders), the speed characteristics, and the available ROW determine the placement and structure type of the DMS.

Center-mount structures will be considered as an exception in urban areas for medium-size signs; however, they will require approval from Ashghal.

Portable DMS should not be considered as an acceptable long-term substitution for permanent DMS. Portables should only be deployed as temporary installations.

8.5.1 Structural Design Guidance

The following outline contains the information which must be submitted for each DMS sign structure. The outline contains aspects of the DMS design required by Ashghal.

Ashghal's sign structure guidelines will be used for all structure types. All design calculations, plans, and details will be in accordance with the Civil and Structural Standards for ITS. Each DMS structure will be assigned its own structure number.

Ashghal's order of preference for DMS support structure types is:

1. Overhead truss
2. Cantilever
3. Center-mount

Center-mount support structures supporting DMS require written justification and approvals. Center-mount support structures are only permitted when it can be demonstrated that an Overhead or Cantilever is not feasible.

<u>Design Calculations will include:</u>

- List of Design Assumptions
    - Sign weight, dimensions, and eccentricity
    - Any non-standard loadings
    - Fatigue Importance Category
    - Design wind speed
- Foundation Design
    - One test boring will be completed at each DMS foundation location. Where exceptions are granted and no borings are completed, use worst-case soil conditions found in the standard drawings. The Ashghal Geotechnical Unit must approve the procedure and assumptions for designing the foundations.
    - Analysis in accordance with QCS will be used for drilled shafts (caissons).
- Additional calculations may be required if the design criteria specified in the Civil and Structural Standards for ITS is not met. The following list of items that may need calculations is not all-inclusive, and may vary by structure type and details:
    - Post/Base Plate connection
    - Base Plate Design
    - Anchor Bolt design
    - Chord Splices
    - Bolted connections
    - Ladder connections
    - Miscellaneous weld checks
    - Catwalk loading and connections

Note: The standard drawings establish minimum plate, bolt, weld sizes, etc. Additional calculations may be required for using larger plate, bolt, weld sizes, etc.

<u>Detailed Design Drawings will include:</u>

- General Notes sheet.
- Drawing sheets shall show DMS enclosure and connection.

  - Drawing sheets shall show, as a minimum, the applicable views and details shown on the ITS standard drawings.
  - Provide panel connection details.
  - Include complete connection details with weld symbols.
  - Unique structure number, provided by Ashghal.
  - Stand-alone drawing package is required for each DMS structure. Multiple structures being presented without detail sheet are not acceptable.

8.6 DMS in Advance of Tunnels

DMS shall be utilized in advance of all tunnels in accordance with all requirements of NFPA 502 - Standard for Road Tunnels, Bridges, and Other Limited Access Highways. These DMS shall be primarily focused on alerting drivers of tunnel closures due to accidents, fires, or other unplanned events and emergencies within a tunnel. DMS should be placed to provide drivers alternative route choice in case of closures. Refer to the NFPA 502 standard for design requirements. Mounting of DMS on Tunnel portals is subject to the viewability and maintainability requirements for signage in this document, approval by the Client, sign off from an accredited civil engineering structures expert and evidence that the tunnel portal has been designed to support the installation of a DMS by design. Designers considering retrofitting DMS to existing structures, irespective of type, must obtain official certification that those existing structures are able to handle all additional loads imposed by the DMS being considered. For maintenance the preferred approach is a rear access DMS, gantry and ladder access.

8.7 ITS Enclosure Placement

When the DMS system includes devices that will be designed, constructed, and maintained as Ashghal-owned assets, the enclosure and its associated components must be included in the design process.

Design criteria for a suitable ITS enclosure location include the following:

- The enclosure should be either adjacent to the structure on the ground in a GME or located on the DMS structure in an attached enclosure.
  - A ground-mounted enclosure should be located at a minimum distance from the barrier, based on the design and type of barrier used. See standard drawings for appropriate minimums.
  - All enclosure types should be oriented so that the maintainer is facing the roadway while performing maintenance at the enclosure location.

- If no suitable location is available for the enclosure to be ground-mounted, or a design requirement exists, the enclosure may be pole-mounted on the DMS (or other existing structure) in order to minimize cost or eliminate ROW takes.
- If ground mounted a concrete pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.
- Where possible, there should be adequate and safe parking conditions present for parking of a maintenance vehicle in the vicinity of the enclosure.
- See manufacturer's specifications to determine the maximum distance between the enclosure and the field device it services.

Standard specifications for ITS enclosures will be available on the Ashghal website in due course. Please note variations from these standards are possible subject to approval by Ashghal. In this case variations will need to demonstrate significant added value to be considered as viable options. Local Roads project requirements will vary from Ashghal's ITS specifications based on available real estate to install signs and will be constrained by existing geometry.

Enclosure types, the use of air-conditioning and/or passive air-management systems will be reviewed in due course. The use of single skinned and double skinned enclosures will also be addressed. The interior and external dimensions, number of acess doors and types of enclosures will also to be examined. Designers are encouraged to propose such enclosures in the interim and to explore non air-conditioned enclosure options. In all such cases, Designers should seek approval from Ashghal for specific non-conforming enclosure designs.

9 Lane Control Signs

9.1 System Purpose & Design Flow

The primary function of the Lane Control Signs (LCS) is to maximize safety. Secondary benefits in line with better driver education and enforced correct lane use behaviors include improvements in roadway capacity. LCS are specific dynamic road traffic signs with a relatively small dimension. Applications for LCS include lane open/close/change, variable traffic restrictions, variable speed limits, travel times, congestion warning, temporary shoulder use, and hazard lane signalization. Signals with a green downward arrow or displaying a mandatory speed limit (preferred) are used to indicate a lane which is open to traffic facing the signal. A red cross indicates that a lane is closed to traffic. Other LCS can show full color graphics or text depending on the intended use.

To maximize the effectiveness of a LCS and to reduce potential threats to driver safety, the sign type, placement, and the supporting structure must all be carefully considered when designing and deploying any new sign. The table below lists a few of the currently available documents:

Criteria	Relevant Standard
Communication and Software	NTCIP /SNMP/TCPIP/ASCII
Mounting Structure	Ashghal Civil and Structural Standards for ITS QCS 2010

Table 9-1: LCS Standards

9.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with a LCS design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a LCS are contained in those referenced sections.

Table 9-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter in general.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with "needs" outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	
Longitudinal Placement	**Section 9.3.1**
• Is the LCS visible and un-obscured?	

• Is the spacing between LCS appropriate where it would give drivers enough time to move from lane?	
Vertical Placement	**Section 9.3.2**
• Is the approaching segment of roadway relatively flat (between 0-4% vertical grade)	
Sign Matrix Type	**Section 9.4**
• Has a sign matrix type been chosen that is consistent with the visibility and message requirements of the roadway being deployed on?	
Structure	**Section 9.5**
• Have visibility, road speed/volume, right-of-way, and maintenance/cost issues all been considered when selecting a type of sign structure? • Is there sufficient vertical clearance for the sign and the structure? • Has the structure been approved for mounting LCS on it?	
Enclosure	**Section 9.6**
• Can personnel safely access the enclosure? • Is the enclosure located within a reasonable distance of the LCS? • Is the sign face visible from the enclosure location? • Does the location and orientation provide adequate protection for the enclosure?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the LCS and all of the system components been determined?	
Power Availability	**Section 12.1.2**
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the LCS site? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 12.2**
• Have the UPS and power back-up requirements been determined and accounted for?	
Communication	**Section 13**
• Have the communication requirements for the LCS been determined? • Has an appropriate communication infrastructure been located and confirmed within a reasonable proximity to the site?	

• If there are multiple communication options, have the pros/cons been studied? • If using public communications infrastructure, has service been coordinated with Ashghal?
Environmental
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?

Table 9-2: LCS Design Considerations

9.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

9.2.1.1 Communications Interface for LCS

The communications interface between the lane control sign systems and the TMC is needed to facilitate the following functions:

- Configure the LCS. This feature allows an operator to determine the identity of the lane control sign, determine its capability, and set its default values.
- Control the LCS. This feature allows an operator to control the sign face of the lane control sign, control external devices connected to the lane control sign system, reset the lane control sign system, and perform preventative maintenance.
- Monitor the Status of the LCS. This feature allows an operator to monitor the current status of the lane control signs and perform diagnostics.
- Upload Event Logs. This feature allows an operator to upload any event logs that are maintained by the lane control sign system.
- The communications protocol should support all the features that are desired for the lane control sign system.

9.2.1.2 NTCIP for LCS

The following NTCIP Information Level standards are applicable.

- NTCIP 1203, Object Definitions for DMS, is a data dictionary standard used to support the functions of a DMS system within a transportation environment. This standard defines data elements that allow for the display of messages and the configuration of DMS. The standard allows addressing LCS by defining each LCS basically as a DMS. Each possible indication (e.g., green downward arrow, mandatory speed, a red cross, etc.) would be defined as a message.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

9.3 Location/Placement Guidelines

The dimensions and weight of most LCS allow easy installation and configuration for different road infrastructures, including tunnels, bridges, expressways, and road interchanges. All messages shall be clearly legible under any lighting conditions. In the case of lane closures, the signs must clearly indicate which lanes are open or closed to avoid driver confusion.

All LCS shall be coordinated so that all the indications along the controlled section of roadway are operated uniformly and consistently. For reversible-lane control signs, the indications must not be simultaneously displayed over the same lane to both directions of travel. All lane-use control signal faces will be located in a straight line across the roadway approximately at right angles to the roadway alignment.

The operation of physical barriers including bollards, boomgates, raising barriers and chain gates can be coordinated with lane closure requirements such as full tunnel closures. The installation, operation and coordination of such systems is subject to official approvals.

9.3.1 Spacing between Signs

The placement should allow drivers to decide in which lane they need to drive, and should provide maximum visibility of the message depending on placement of all existing signage in that location. Levels of congestion should influence spacing based on whether the signage is retrofitted to existing roads or being installed on new schemes. If the latter is the case, a level of service calculation for the roadway shall assist to determine spacing.

At expressway speeds, the LCS should be visible to the approaching driver from 300 to 600m away. The color of LCS indications shall be clearly visible for 600m at all times under normal atmospheric conditions, unless otherwise physically obstructed. LCS are expected to be placed anywhere between 300m-500m-800m apart on all major arterials and expressways where there is high congestion or traffic flow volumes. The use of LCS in remote rural locations is not required unless these are used periodically as reminders for speed limits operating in VSS mode as opposed to lane control mode and their gantries are being used to house additional ITS equipment such as LPR units etc.

Spacing of LCS from congested to non-congested situations may also result in gradual increases in LCS gantry placement from every 300m to 500m to every 800m to every 1.5 km the further away from the center of congestion or traffic the LCS is located. These design considerations need to be checked with Ashghal whom may also wish to review the placement of LCS approaching (currently) remote sports facilities in non-urban areas and tunnels.

9.3.2 Vertical Placement

The sign placement *should not be lower than the required vertical clearance* of the structure where it is attached. QTM and QCS provide information on the vertical clearances. Designers must ensure that placement of LCS does not compromise minimum clearances for vehicle height.

9.4 Selection of Sign Type

LCS are special overhead signs on a street or expressway that indicate whether travel in a lane is prohibited or allowed. Each LCS is independently controlled to indicate the status of each travel lane. LCS signs can also be collocated with a DMS to provide additional information. Colocation of LCS with other signage is acceptable in the State of Qatar except when there is the ability to avoid co-location of LCS with static ADS in which case the LCS should be on its own gantry. Rear access LCS are preferred for maintenance purposes.

9.4.1 Arrow/Cross

Graphic displays placed over individual travel lanes displaying bright color pictograms indicate lane usage as follows:

- Green indication: drivers may travel in the lane under a green signal.
- Steady red indication: drivers shall not enter or travel in any lane where a red signal is shown.
- Or as indicated within QTM (or QTCM).

9.4.2 Graphic Displays

Full matrix, full-color, high-resolution pixels will be used to allow for crisp graphics and easy to read text. Graphics and pictograms should replace text whenever possible to minimize confusion. All lane-use control signal indications will be in units with rectangular signal faces and will have opaque backgrounds. Nominal minimum height and width of each downward symbol will be at least 60cm for typical applications.

9.5 Selection of Structure

LCS shall be placed directly above the lanes they control. They can be attached to a new or existing sign structure. Ashghal's structural engineer must approve the design and the load calculations.

9.5.1 Structural Design Guidelines

LCS can be attached to another type of structure for different road infrastructures like tunnels, bridges, expressways, and static signs. LCS can also be mounted on a new structure depending on the size and the location. The design must be approved by Ashghal prior to installation. Co-location of LCS with ADS is permissible in the State of Qatar but the first preference is to not do so. Where possible electronic sign elements should not be co-located with static sign elements due to differences in maintenance contracts which create demarcation issues. For this reason LCS and DMS should in most cases be located on dedicated gantry structures. Should it not be possible or sensible to not co-locate, permission to co-locate must be sought by designers from both the Ashghal Signage Department and Operations and Maintenance departments.

9.6 ITS Enclosure Placement

The enclosure and its associated components must be included in the design process.

See manufacturer's specifications to determine the maximum distance between the control enclosure and the field device it services.

All LCS controller equipment should be housed in a standard enclosure. (Earlier comments in this Design Guide on variations apply).

10 Ramp Metering Systems

At this time the inclusion of Ramp Metering Systems in any Design for either Local Roads or Expressways should not be included unless at the specific direction of Ashghal. The success of Ramp Metering is dependent on geometry, traffic management systems, detection across an entire network, enforcement and changes in driver behavior (lane disciplines and queueing) which are outside the scope of this document. This section has been included for completeness only. Technical comment in this section is for indicative purposes only and therefore should not be seen as definitive.

10.1 System Purpose & Design Flow

Ramp Metering is the science of controlling flow rates on motorways and expressways by either allowing or denying traffic at a metered rate to enter the road network system, and preserve a higher net average speed on that system. This works by reducing turbulence from un-managed merge behaviors and by ensuring that the overall rate of travel on the network and inter-vehicle spacing is maintained. There are three objectives to consider when looking at Ramp Metering:

- Control the flow of vehicles that are allowed to enter the expressway at metered intervals based on upstream measured flow using vehicle detection every 500m in every lane and on every on-ramp and off-ramp to measure actual road speed and capacity. Note the expression used with Ramp Metering of “managing demand” is incorrect – demand occurs before vehicles enter the system – this needs to be managed with Advanced Traveller Information Systems, vehicles in the system are in “supply.” Ramp Metering manages “supply” and creates space for the vehicles in “supply.”

- Increase Expressway mobility by controlling flow breakdown at motorway on ramp points by managing exact release rates for vehicles entering the system this prevents uncontrolled merge volumes from creating shock waves back through the system and increasing delay. The idea that Ramp Metering increases capacity is incorrect. Capacity is constrained by geometry and design and cannot be increased. Ramp Metering increases efficiency of the network by lowering the overall average speed to an optimum and then only allowing specific numbers of vehicles based on detected saturation and vehicle density to keep the road traffic moving smoothly.

The purpose of the first and second objectives is to ensure that the total traffic entering an expressway section remains at a constant level of performance and speed relative to the overall trip. A secondary objective of ramp metering is to introduce controlled delay to vehicles wishing to enter the expressway, and as a result, reduce the incentive to use the expressway for short trips during rush hour. Ramp Metering is supposed to provide safe and efficient merge operations at the expressway entrance. Ramp metering overseas has been shown to prevent disruptions in expressway operations, which can cause unsafe queuing conditions by significantly decreasing expressway capacity. Prevention of expressway flow disruptions also minimizes chances of rear-end crashes.

However Ramp Metering has a number of significant issues which make it unsuited to the State of Qatar:

1) It pushes storage of vehicles waiting to enter the on ramp back on to local roads – this will create queue barging – multi-lane blockages and aggressive behavior.

2) It requires people to observe the rules for meter rates as enforcement for Ramp Metering to date has been manual and not automated

Most urban expressways are multi-lane facilities that carry heavy traffic during peak periods. Traffic demand at a single on-ramp, however, is usually a small component of the total expressway demand. Metering a single ramp and even a few ramps may not be sufficient to achieve the first objective. In addition, drivers affected by a small ramp metering system perceive such a system to be unduly taxing them, favoring those who have entered the expressway at uncontrolled ramps at upstream expressway sections. Thus, ramp metering with the objective of mitigating downstream congestion should be installed on a sufficiently long section of an expressway if it is to achieve all of these benefits and keep the motorists happy.

When properly installed, ramp metering has the potential to achieve the following benefits:

- Increased expressway productivity
- Increased speeds
- Safer operation on an expressway and its entrances
- Decreased fuel consumption and vehicular emissions

A thorough engineering study should be conducted prior to installing and operating a ramp meter. The typical study process is outlined in Figure 10-1 and fully described later.

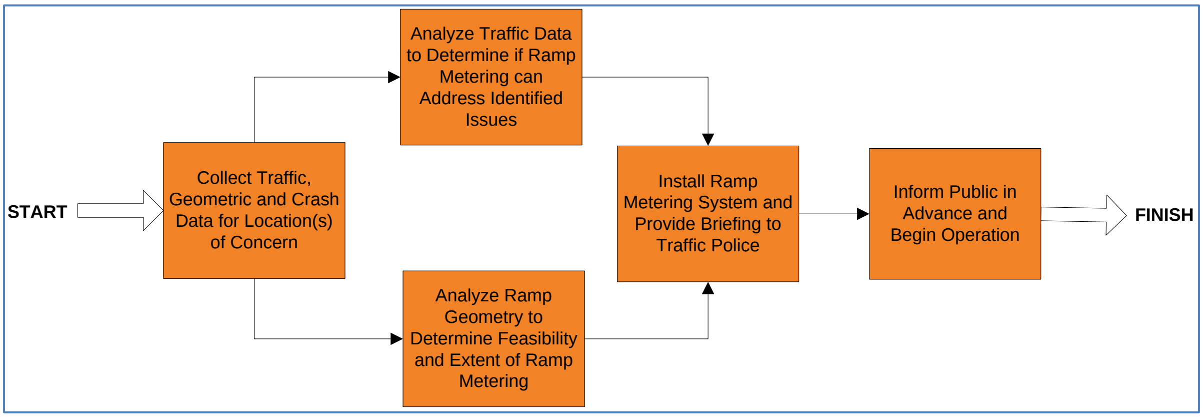

Figure 10-1: Ramp Metering Design and Implementation Process

There are several industry standards/requirements related to Ramp Metering Systems (RMS). The table below lists a few of the currently available documents:

Criteria	Relevant Standard
Signs and Signals	QTM QCS 2010, Section 6, Part 13 - Traffic Signals
Communication and Software	NTCIP
Structure	Ashghal Civil and Structural Standards for ITS QCS 2010

Table 10-1: RMS Standards

10.2 Design Considerations

The following list is intended to be a high-level guide to assist ITS practitioners through the many criteria associated with a RMS design. Each section of the list corresponds to a section of this document chapter. The background, details, and specific regulations or guidance related to the design process for a RMS are contained in those referenced sections.

The criteria contained in this publication should be followed when designing a new RMS. It is important to clarify that there will be instances where all of the criteria in these guidelines cannot be met. Justification for deciding to go through with an installation, despite not being able to meet all criteria, should be detailed by the designer. The goal of this process is to provide practitioners with guidance as well as providing Ashghal consistency with respect to RMS installations.

Table 10-2 contains an overview of the design considerations contained in this chapter and an outline of the chapter.

Pre-Design Planning	**Chapter 2**
• Is this deployment consistent with “needs” outlined in a Concept of Operations? • Is this deployment consistent with the ITS architecture?	
Ramp Meter Study	**Section 10.3**
• Has a comprehensive Ramp Meter Study been performed? • Do the results of the study support continuing with the deployment project?	
Lane Configuration	**Section 10.5.4**
• Do the number of lanes and the vehicles per green design support the projected ramp volume?	

Ramp Meter Location	**Section 10.5.5**
• Is the meter placed such that enough stacking space is available on the ramp to accommodate the queues it will generate? • If the ramp meter consists of more than one lane, does it provide a sufficient distance for the lanes to merge prior to the merge with the mainline? • Does the ramp geometry allow sufficient sight distance to the signal?	
Ramp Meter Signals	**Section 10.5.6**
• Are the signals vertically spaced such that the driver can see the signal heads while parked at or just in front of the stop bar? • Are the signals designed in compliance with QTM and QCS 2010 requirements for Mast Arm Signal Poles, Signal Placement, and Signal Heads?	
Vehicle Detectors	**Section 10.5.7**
• Does the system design include all of the necessary detection areas; Demand, Ramp Queue, and Mainline? • Does the complexity/configuration of the system require the additional detection area; Passage, Exit Ramp, and Entrance Ramp?	
Signing and Pavement Markings	**Section 10.5.7**
• Do the signs and marking meet the QTM and QCS 2010 standards?	
Enclosure Placement	**Section 10.6**
• Is an enclosure required at this location? • Can personnel safely access the enclosure? • Is the enclosure located within the manufacturer's recommended distance to the detectors? • Is it positioned such that maintenance personnel can access the enclosure while viewing ramp meter signal heads? • Is the enclosure mounted on an existing structure (where possible)? • Does the location and orientation provide adequate protection for the enclosure? • Has a concrete maintainer's pad been provided at the enclosure's main door?	
Power Requirements	**Section 12.1.1**
• Have the power requirements for the detector and all of the system components been determined?	

Power Availability	Section 12.1.2
• Has an appropriate power source been located and confirmed with the utility company within a reasonable distance from the detector site? • Have Step-Up/Step-Down transformer requirement calculations been performed? • Have the metering options been determined?	
Power Conditioning	**Section 12.2**
• Have the UPS and power back-up requirements been determined and accounted for?	
Communications	**Section 13**
• Have the communication requirements for the detector been determined? • Has an appropriate communication source been located and confirmed within a reasonable proximity to the site? • If there are multiple communication options, have the pros/cons been studied? • Has the chosen communications option been reviewed? • If using public communications infrastructure, has service been coordinated with Ashghal?	
Environmental	
• Have all the necessary environmental, community, and cultural impact studies, processes and concerns been addressed?	

Table 10-2: Ramp Meter Design Considerations

10.2.1 Communications Interface

The Ashghal ITS Telecommunications Strategy shall be adhered to when considering the communications interface for all ITS device in The State of Qatar.

10.2.1.1 Communications Interface for Ramp Metering

The communications interface between the ramp metering systems and the TMC is needed to facilitate the following functions:

- Configure the Ramp Meters. This feature allows an operator to determine the identity of the ramp meter controller, configure the thresholds, configure the scheduler, and define the lane and sensor configurations for the mainline and ramp.
- Control the Ramp Meters. This feature allows an operator to control the operational mode of the ramp meter and control the ramp metering plans.
- Monitor the Status of the Ramp Meters. This feature allows an operator to monitor the current status of the ramp meters, monitor the current status of the sensors, determine what operational mode or ramp metering plan is currently being implemented, and perform diagnostics.

- Upload Event Logs. This feature allows an operator to upload any event logs that are maintained by the ramp metering system.
- The communications protocol should support all the features that are desired for the ramp metering system.

10.2.1.2 NTCIP for Ramp Metering Systems

The following NTCIP Information Level standards are applicable.

- NTCIP 1207, Object Definitions for Ramp Meter Control (RMC) Units, is a data dictionary standard used to support the functions related to ramp meter control units within a transportation environment. A RMC unit, in the context of this standard, consists of a field controller, its suite of sensors, and the warning signs and signals. This standard defines data elements specific to RMC units – it supports the control and configuration of the RMC units, and allows for the exchange of metering plans to the RMC units.

- NTCIP 1201, Global Object Definitions, is a data dictionary standard to support functions that may be needed by multiple device types. Such functions include device identification and addresses, time management, time schedulers, event logging, and database management.

10.3 Ramp Meter Study

Ramp metering can improve the safety and efficiency of traffic flow at or around expressway bottlenecks under certain conditions. A thorough engineering study should be conducted to determine the applicability of this traffic management strategy.

10.3.1 Data Collection

Detailed data should be collected for the entire expressway section of interest, which may include one or more bottlenecks and adjacent roadway facilities. Preliminary site visits should be performed to assess where and how the data will be collected. Once done, plans should be developed and executed to collect the following types of data:

- When available, crash records for the section of concern for at least the past year, and preferably for three years.

- Traffic data:

    - 15-minute traffic volumes in individual expressway lanes at key locations within the section of interest. For analysis purposes, these volumes should be converted to hourly flow rates.

    - 15-minute volumes of traffic entering and leaving the expressway section at exit and entrance ramps, and converted to hourly flow rates.

    - 15-minute volumes of traffic at surrounding adjacent roadway facilities.

  - Expressway speeds at key locations and speeds of traffic approaching and traveling on the ramp.
  - Observations about formation, dissipation, and impacts of queues on expressway lanes, entrance ramps, and exit ramps.
- Roadway geometry:
  - Number and width of expressway lanes, segment lengths (i.e., distance of on-ramp entrance from upstream intersection, ramp length, length of auxiliary acceleration lane, lengths of tapers, etc.), widths of ramps, locations of physical bottlenecks (i.e., a lane-drop), and other relevant information (i.e., locations of horizontal and vertical cures and any related operational issues.

10.3.2 Data Analysis to Determine Ramp Metering Viability

The first step is to analyze any available crash data to identify the locations, numbers, and severity of crashes in the section, and compare them to other sections of the same expressway or similar roadways. If the number of crashes is higher than the average for other similar locations or the crashes are more severe than similar locations, some countermeasure is needed to minimize the number and severity of crashes. Additional analysis should be conducted to determine the appropriate countermeasures. These countermeasures may include ramp metering at immediately upstream or downstream ramp, active traffic management (advance warning of downstream queues or slow traffic, speed harmonization, etc.), or both. Another countermeasure might be to adjust signal timings to provide more capacity to exiting ramp traffic in cases where queues at the downstream intersection begin to interfere with exiting traffic or spillback into main lanes.

The next stage is to determine if traffic volume/demand levels indicate ramp metering to be a viable option. In this regard, there are two general rules:

1. If the total expressway plus ramp volume is more than the capacity of a downstream bottleneck (a downstream expressway section or the ramp merge area) for a significant part of a peak period, one or more upstream ramps should be considered for metering depending on the amount of excess demand. The reader should note that service volume (count of vehicles) at a location represents traffic demand only when no queuing occurs immediately upstream of that location.
2. Regardless of the above condition, an upstream ramp should not be metered if ramp demand is less than 300 vehicles per hour (vph).

At entrance ramps, merging of entering traffic into the main stream creates bottlenecks under certain conditions. The level of impact depends primarily on the ramp volume, and the volumes in the expressway merge lane and adjacent expressway lane. The graphs in Figure 10-2 and Figure 10-3 can be used to determine if ramp metering can be justified based on two criteria based on these volumes. It should be noted that these two graphs assume typical entrance ramps, which are located on the right side of the expressway. If there is a need, the user can use these plots for on-ramps located on the left-side by using data from the appropriate expressway lanes.

Use the following steps to test the criteria given in these figures:

1. Determine acceleration distance on the ramp. This distance should be measured from the entrance ramp.

2. For each 15-minute flow rate (15-minute volume multiplied by 4), calculate the average expressway volume in the two right-most lanes. Using Figure 10-2, locate the point corresponding to acceleration distance from Step 1 and this value. If the point lies above the solid line, metering is recommended at this ramp during the assessed period. Repeat for other time times.

3. For each 15-minute, add flow rates for the on-ramp and the right-most lane and plot against acceleration distance in Figure 10-2. If the point is located above the solid line, ramp metering would be recommended.

Even if these criteria are not met for a ramp, a meter may be justified based on safety or system-based analysis. For instance, if a ramp meets criteria for metering, but it is not possible to reduce expressway demand by the desired amount by only metering traffic at this ramp, one or more upstream ramps could be metered to achieve the desired results. Also, consideration of the adjacent roadway system should be taken into account to ensure it is not affected by queued traffic from the ramp meter.

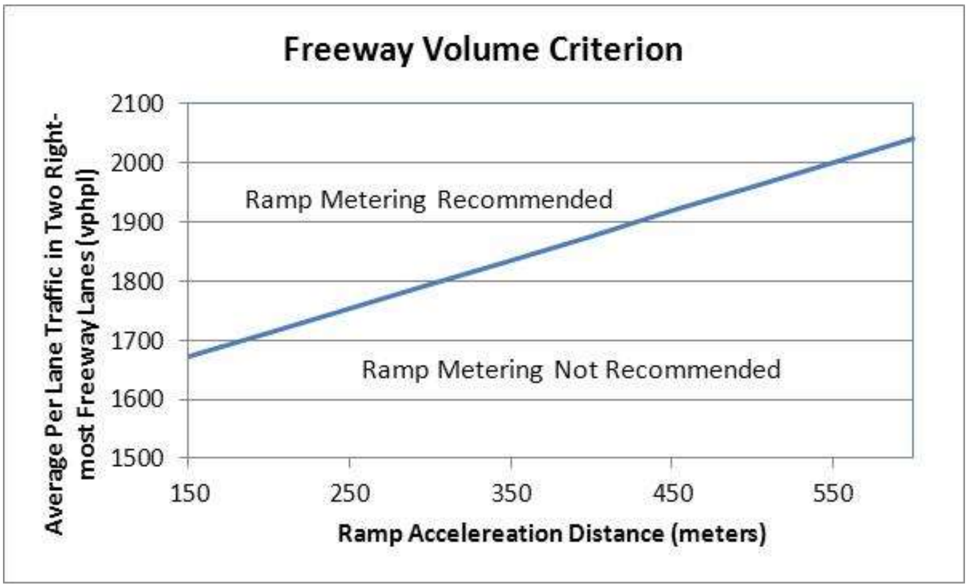

Figure 10-2: Freeway Volume Criterion

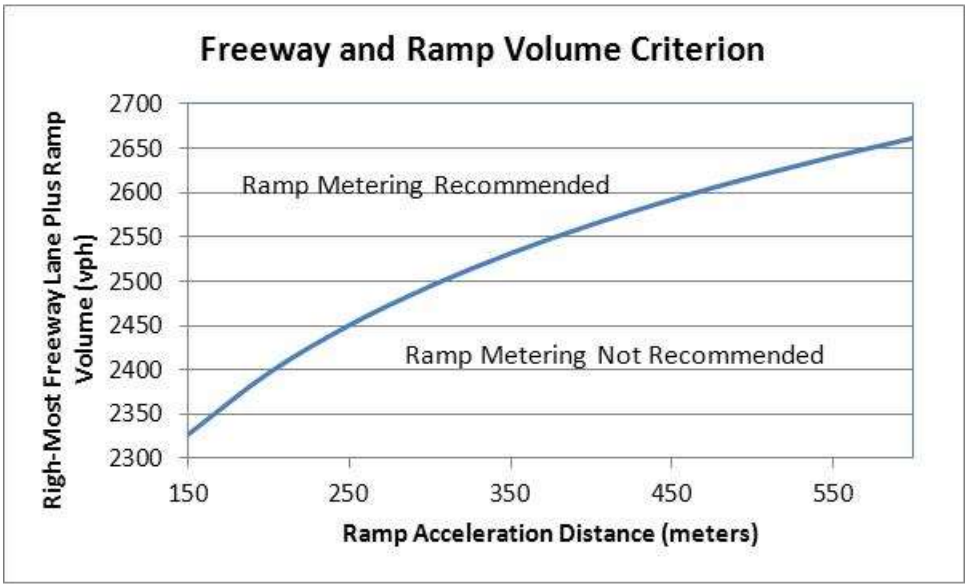

Figure 10-3: Freeway Plus Ramp Volume Criterion

10.3.3 Analysis of Ramp Geometrics

If the analysis shows that safety and/or operational benefits can be achieved by installing a ramp meter, additional analysis should be conducted to ensure that ramp geometry is adequate to support a good ramp metering operation. In some cases, Ashghal may have to make decisions that may compromise some objectives. Using methods (equations and graphs) described earlier, the following tasks are recommended:

- Determine if restrictive or non-restrictive metering should be implemented and determine locations of queue detectors.
- Determine the desired metering rate and select a metering strategy. Note that a dual-lane meter is recommended for metering more than 900 vph. Bulk metering can be used for slightly higher demands, but it compromises a key ramp metering objective.
- Analyze ramp geometrics and signal installation options to determine the ranges of storage and acceleration distances that can be provided.
    - Calculate storage space distance using the formula provided in Section 10.5.3.3.
    - Obtain minimum acceleration distances required from the signal to the merge point. This will be done in two steps. First, use Figure 10-4 to obtain safe merge speeds by selecting prevalent expressway speed and a driver type. Then use this value to obtain acceleration distance from Figure 10-5.
- Determine how many additional ramps, if any, will need to be metered based on a system-based analysis.

- Determine lengths of signal intervals to produce the desired metering rate. Divide 3600 by the sum of green, yellow, and red indications to obtain the metering rate for each metered lane.

10.4 Ramp Meter System Components

10.4.1 Loop Detectors

Several loop detectors can be installed to provide a wide range of operations. Table 10-3 provides a description of these detectors.

Type of Detector	Location/Size	Application
Mainline (Optional)	Located in each expressway lane upstream and/or downstream of the on-ramp ingress point to the expressway. Speed-trap consisting of two 1.8x1.8 m loops.	Provides expressway occupancy, speed, or volume information that is used for traffic responsive control. These detectors also provide measurements for incident detection and other ITS functions in TMCs. Used by nearly all agencies.
Merge (Optional)	Placed upstream of the merge area and downstream of the stop-bar along the on-ramp. Size: 1.8x1.8 m.	Used primarily to provide on-ramp count data.
Passage (Optional)	Positioned immediately downstream of the stop-bar. Size: 1.8x1.8 m.	Used to determine the duration of the green signal display on the specified lane.
Demand (Required)	Placed immediately upstream of the stop-bar in both specified lanes. Size: 6x2 m	Senses vehicle presence at the stop-bar and initiates the green traffic signal display for that specific lane under the selected metering strategy.
Intermediate Queue (Optional)	Placed approximately half-way between the stop-bar and the on-ramp entrance point in both lanes. Size: 1.8x1.8 m	Incrementally increases or decreases metering rate to control queues within the queue storage reservoir.

Primary Queue (Required)	Positioned near the on-ramp entrance area. Size: 20x2 m.	Monitors excessive queues that cannot be contained within the queue storage reservoir. Maximizes the metering discharge rate to clear excessive queues.

Table 10-3: Description of Ramp Meter Detectors

10.4.2 Warning and Regulatory Signs

A series of warning and regulatory signs can be used collectively if needed to convey the intent of the expressway management system.

10.4.3 Traffic Control Devices

The final element of the single-lane or multiple-lane traffic control devices is the traffic signal display. As the motorist nears the ramp meter stop-bar, one of two standard signing and traffic signal display conventions is used to inform the driver of the regulatory requirements of the ramp meter and to indicate when the motorist is allowed to enter the expressway. It should be noted that three-section (three-aspect) signal heads are installed on both sides of the entrance ramp on breakaway posts because they are located within the clear zone. If breakaway poles are not supported by the existing policy, other measures should be used to prevent crashes involving vehicles and signal poles. These measures include curbs and barriers.

Single-lane meters use one signal-head on each side of the ramp. One of these signals is installed at an angle where vehicles stopped at the meter can clearly see the lights. The other is installed at an angle that allows lights to be seen from the ramp entrance. Additionally, a “Stop Here on Red” sign is posted below each signal-head.

For dual-lane meters, two three-section heads are installed on each pole. The top signal head points to vehicles entering the ramp, while the bottom signal head points to vehicles stopped at the meter. Signals on the left side pole are for the left lane and signals on the right side pole are for the right-lane. A “Stop Here on Red” sign is mounted on each pole between the two signal heads. Additionally, a “Left Lane Left Signal” sign is placed below the bottom signal head on the left pole, and a “Right Lane Right Signal” is similarly placed on the right pole.

10.4.4 Pavement Markings

In addition to the standard marking on the ramp to separate travel lanes from the shoulders, dual-lane meters require an additional line to identify the two metered lanes. Typically a solid line is used to convey the message that shifting lanes is prohibited once a vehicle has entered this space. An HOV by-pass lane also requires marking (a diamond) to identify lane restrictions.

10.4.5 Ramp Controller

To be suitable for ramp metering applications, the traffic controller should provide the following functionality:

- As a minimum, support up to two metered lanes without a HOV by-pass lane.
- For each metered lane, allow programming of green, yellow, and red indications in the 1 to 99 second range with 0.1 seconds intervals.
- Support configuration of at least one detector trap per expressway lane for up to a maximum of six lanes. Furthermore, the controller should provide for collection of average speed, volume (separate for passenger cars and trucks), and average occupancy data from these detectors in separate bins. The data should be collected every 0.1 second and aggregated over a user-specified time (e.g., 20 second, 30 second, etc.).
- Collect volume and occupancy data from other detectors on the ramp.
- Support traffic responsive metering.
- Support queue override functionality using occupancy data from primary and intermediate queue detectors.
- Support real-time or manual data uploads.
- Provide separate startup, metering, and shutdown cycles, with separate values for signal intervals during these cycles.
- A startup cycle should provide for activating the advance flashing beacon for a programmable duration before normal metering cycle begins.
- Provide for advance flashing beacon to be active during the normal metering cycles.

Similar to a regular traffic signal, the controller should be installed on a concrete pad meeting the QCS - Traffic Signal requirements.

10.4.6 Miscellaneous Items

Loop detectors should be installed and wired using the QCS requirements and hardware as for traffic signals.

10.5 Ramp Meter Design Considerations

10.5.1 Ramp Meter Operating Philosophies

Ramp metering can be operated in a number of ways depending on the type and level of operation.

10.5.1.1 Local versus System-Based Control

In local metering, the operation at a ramp is independent of adjacent meters. An expressway may have many consecutive ramps operating in local modes. In system-based metering, a group of ramps are operated in a coordinated manner. System-based control may be central or non-central.

10.5.1.2 Pre-Timed versus Traffic Responsive Control

In pre-timed control, ramp metering operation begins and ends at preprogrammed times. In traffic responsive control, meter operation times and metering rates are based on detected traffic conditions. For instance, a meter may be programmed to commence operation if expressway detector occupancy exceeds a certain threshold value or expressway speeds are lower than a corresponding threshold. Traffic responsive operation may also adjust metering rates by either using preprogrammed values or by using a feedback control loop to calculate metering rates in real-time.

10.5.1.3 Restrictive versus Non-Restrictive Control

In restrictive mode, metering rates are set based on expressway conditions. In non-restrictive mode, metering rates are adjusted based on queuing conditions on the ramp. An extreme form of non-restrictive mode shuts-off metering operation when the ramp queue reaches the maximum allowed length. Metering operation resumes when the queue clears.

10.5.1.4 Central versus Non-central Control

In central control, a computer located in the TMC controls ramp meters. Central control is typically used with system-based ramp metering at a group of ramps along a section of the expressway. Non-central control implements ramp metering using only in-field devices, and can be local or system-based.

10.5.2 Types of Ramp Metering

When the merge area of the expressway is not a bottleneck, an uncontrolled single-lane expressway entrance ramp may have a throughput capacity of 1800 to 2200 vph. The same ramp will have lower capacity when metered. The maximum theoretical metering capacity depends on the type of strategy used. There are three ramp-metering strategies. These strategies are described below.

10.5.2.1 Single-Lane One Car per Green

This strategy allows one car to enter the expressway during each signal cycle. To maintain consistency with normal traffic signals, ramp meters use three aspect signal heads with green, yellow, and red signal indications. The length of green plus yellow indications is set to ensure sufficient time for one vehicle to cross the stop line. The length of red interval should be sufficient to ensure that the following vehicle completely stops before proceeding. From a practical point of view, the smallest possible cycle is 4 seconds with 1 second green, 1 second yellow, and 2 seconds red. This produces a meter capacity of 900 vph. However, field observations have shown that a 4-second cycle may be too short to achieve the requirement that each vehicle must stop before proceeding. Also, any hesitation on the part of a passenger-car driver may cause the consumption of two cycles per vehicle. A more reasonable cycle is around 4.5 seconds, obtained by increasing the red time to 2.5 seconds. This increase in red would result in a lower meter capacity of 800 vph.

10.5.2.2 Single-Lane Multiple Cars per Green

Platoon metering, also known as bulk metering, allows for two or more vehicles to enter the expressway during each green indication. The most common form of this strategy is to allow two cars per green. Three or more cars can be allowed; however, this will sacrifice the third objective (breaking up large platoons). Furthermore, contrary to what one might think, bulk metering does not produce a drastic increase in capacity over a single-lane one car per green operation. This is because this strategy requires longer green and yellow times as ramp speed increases, resulting in a longer cycle length. Consequently, there are fewer cycles in one hour. For instance, the two-cars-per-green strategy requires cycle lengths between 6 and 6.5 seconds and results in a metering capacity of 1100 to 1200 vph. This analysis illustrates that bulk metering does not double capacity and this finding should be noted.

10.5.2.3 Dual-Lane Metering

Dual-lane metering requires two lanes be provided on the ramp in the vicinity of the meter, which merges to one lane. In this strategy, the controller displays an independent green-yellow-red cycle for each lane. Signal cycles in the two lanes can be synchronized such that the green indications never occur simultaneously in both lanes. Dual-lane metering can provide a metering capacity of 1600 to 1700 vph. In addition, dual-lane ramps provide more storage space for queued vehicles.

10.5.3 Geometric Design Considerations

Installation of a ramp meter to achieve the desired objectives requires sufficient room at the entrance ramp. The determination of minimum ramp length to provide safe, efficient, and desirable operation requires careful consideration of the elements described below:

- Sufficient room must be provided for a stopped vehicle at the meter to accelerate and attain safe merge speeds.
- Sufficient space must be provided to store the resulting cyclic queue of vehicles without blocking an upstream signalized intersection.
- Sufficient room must be provided for vehicles discharged from any upstream signal to safely stop behind the queue of vehicles being metered.

The placement of signal poles controls the distribution of available ramp length to storage and acceleration distances. If needed, additional acceleration distance may be provided by constructing an auxiliary lane parallel to expressway lanes. Similarly, additional storage may be provided on the frontage road upstream of ramp entrance.

10.5.3.1 Minimum Stopping Distance to the Back of Queue

When a ramp meter is in operation, motorists arriving at the ramp will likely encounter the rear end of a queue. Adequate maneuvering and stopping distances should be provided for vehicles from a location where they are expected to first see the back of the queue. The following equation AASHTO (or equivalent BSEN) stopping sight distance equation can be used to calculate this distance:

$$X = 0.278vT + \frac{v^2}{254\left[\left(\frac{a}{9.81}\right) \pm G\right]}$$

where:

X	=	Stopping sight distance, meters;
v	=	Speed of traffic approaching the on-ramp, km/h;
T	=	Perception-reaction time (2.5 sec), seconds;
a	=	Deceleration rate, m/s^2; and
G	=	Percent grade divided by 100.

Assuming a deceleration rate of 3.5 m/s^2, 60 km/h approach speed, and zero grade, the value of stopping sight distance will be 81.5m. This would be the minimum value for the assumed conditions. If the decision point is an upstream intersection, this calculation should also consider cross-street turning traffic that, even though making the turn maneuver at a slower speed, may need travel distance to allow one or more lane changes.

10.5.3.2 Storage Distance

Storage distance may be calculated using the following generalized model, which assumes a single-lane meter.

$$L = 0.250V - 0.00007422V^2 \qquad V \leq 1600vph$$

In this equation, *L* (in meters) is the required single-lane storage distance on the ramp when the expected peak-hour ramp demand volume is *V* vehicles per hour (vph). Dividing calculated value of *L* by the length of a design vehicle (7.7m) will convert the value to storage requirement in terms of number of vehicles. For a dual-lane ramp meter, storage distance can be calculated by considering the length of dual-lane storage.

10.5.3.3 Distance from Meter to Merge

AASHTO provides speed-distance profiles for various classes of vehicles as they accelerate from a stop to speed for various ramp grades. Figure 10-4 provides similar acceleration distances needed to attain various expressway merging speeds based on AASHTO design criteria. This figure can be used to determine the acceleration distance for any desired merge speed. In the figure, note that the desired distance to merge increases with increasing expressway merge speeds and ramp grade. Because of gaps in the expressway traffic stream, ramp vehicles can safely merge at slightly slower speeds than the expressway free flow speeds. Figure 10-5 provides plots to determine safe merge speeds versus expressway speeds for three types of drivers.

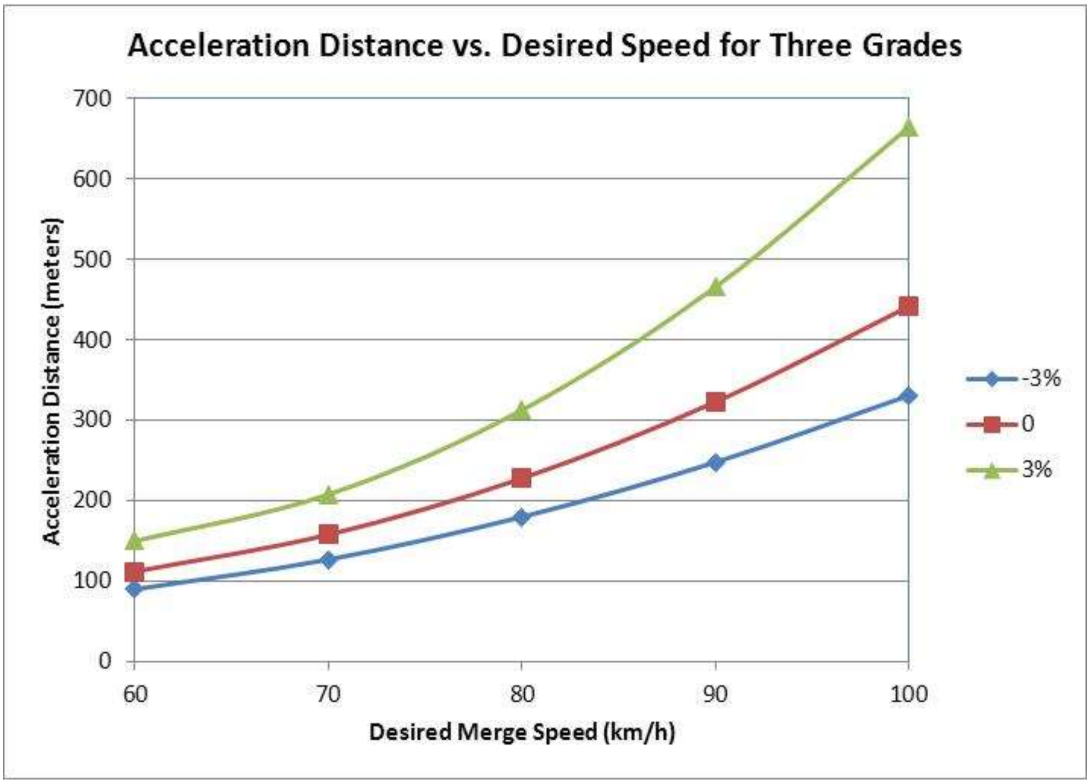

Figure 10-4: Minimum Acceleration Distance for Desired Speeds

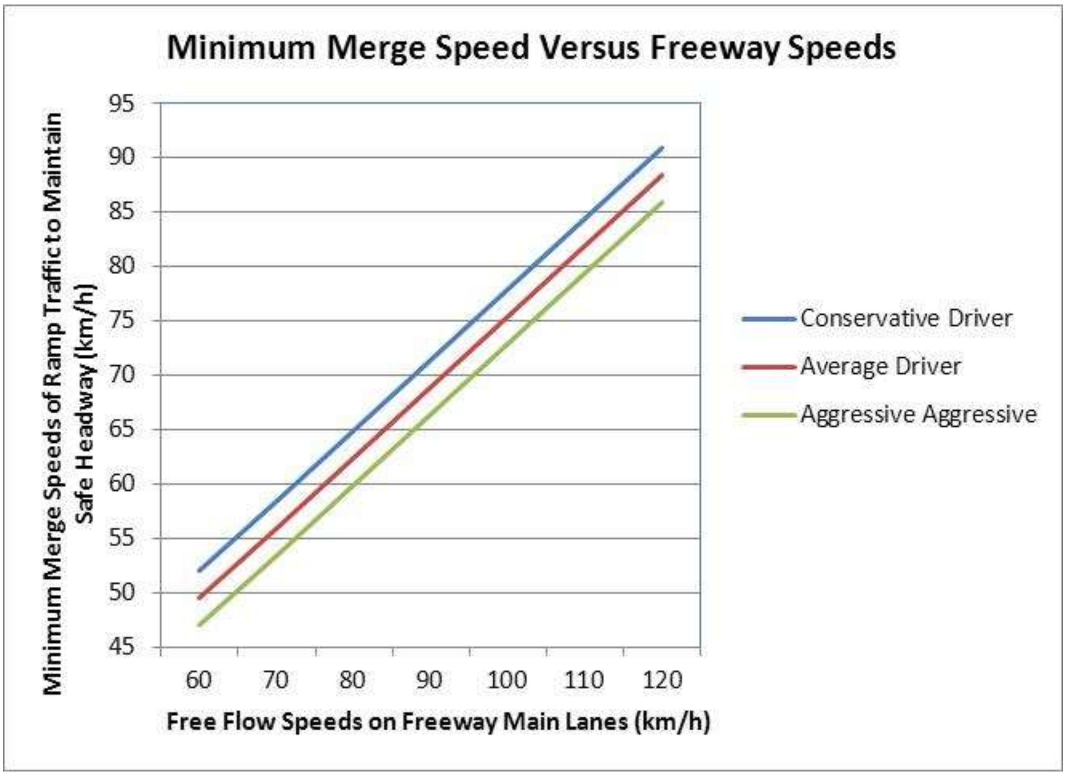

Figure 10-5: Safe Merge Speeds Corresponding to Expressway Free Flow Speeds

10.5.4 Lane Configuration

Ramp metered entrance ramps can be comprised of single or multiple lanes. To determine the number of metered lanes, the designer should take the vehicle volumes and the number of vehicles per green period into account.

The number of lanes must be determined in the ramp metering study.

Table 10-4 indicates when it is appropriate to permit one or two vehicles per green:

Ramp Volumes	Number of Metered Lanes	Vehicles Per Green
<1000 vph	One Lane	Single
900 - 1200 vph	One Lane	Dual
1200 - 1600 vph	Two Lanes	Single
1600 – 1800 vph	Two Lanes	Dual

Table 10-4: Ramp Meter Lane Determination

The FHWA Ramp Management and Control Handbook recommends that ramp lanes have a width of at least 3.6m, an inside shoulder width of approximately 2.0m and an outside shoulder width of 2.0m.

These guidelines should be used when determining the appropriate number of ramp metered lanes. Other considerations such as environmental disturbance, existing structures, and other factors may influence the final design.

10.5.5 Location of Ramp Meter

The ramp meter and stop bar must be placed at a location on the entrance ramp that balances the need for an upstream queuing/stacking area and a downstream acceleration and merge area. The meter must be placed such that enough stacking space is available on the ramp to accommodate the queues it will generate.

The designer should utilize the methods of calculating queue storage requirements. As a rough estimation, queue lengths can be calculated by subtracting the metering rate from ramp volume over a specific period of time.

A commonly utilized rule of thumb is that the ramp should accommodate a queue of 10% of the peak hour volume. For example, if the peak hour volume is 1000 vph, the approximate stacking area should accommodate 100 vehicles.

Special consideration should be given to multi-lane ramp meter locations. Ramp meters consisting of more than one lane must provide a sufficient distance for the ramp lanes to merge prior to its merge with the mainline. This may increase the distance required from the meter to the mainline/ramp merge point to accommodate acceptable acceleration distance.

The exact location of the ramp meter on the entrance ramp will come from the ramp meter study. The rules of thumb included here are to be used to determine general placement areas, but will not address the needs of each unique situation.

10.5.6 Ramp Meter Signals

Single lane ramps should utilize a signal pole (vertical pole) with two mounted signal heads placed on the left side of the stop line. The signals should be vertically spaced such that the driver can see the signal heads while parked at or just in front of the stop bar. A duplicate pole on the right side of the ramp can supplement the left side signal if deemed necessary. For ramp meter applications, signal heads should have red, amber, and green lamps.

Two lane ramps should utilize two signal poles, one on either side of the ramp. For multi-lane ramps using staggered or multi-vehicle green periods, it is recommended that two signal heads be used per lane.

The QTM and QCS provide standards for traffic signal applications. Ramp meter designers must follow Ashghal's ITS Specifications.

The following items should be considered when placing signal supports:

- Signal supports should be placed as far as practical from the edge of the traveled way without adversely affecting the visibility of the signal indications.
- Where supports cannot be located based on the recommended AASHTO (or equivalent BSEN) clearances, consideration should be given to the use of appropriate safety devices as per QCS, Section 6, Part 13 - Traffic Signals.

10.5.7 Vehicle Detectors

Ramp metering systems require a series of vehicle detectors to provide input on various pieces of motorist information. While inductive loops have typically been used as the primary method of detection, other technologies can be used for detection as well, provided they produce all the input information required by the ramp meter controller. Viable technologies for vehicle detection include inductive loops, microwave detection, magnetometers, and VIVDS. Many controller algorithms are designed to incorporate and utilize loop or loop imitator (such as VIVDS system) data. Extra calibration may be required if non-loop detectors are used in the ramp metering system. See Chapter 3 for more information regarding vehicle detection options and installation guidelines.

RMSs employ a series of detectors at key locations. Depending on the complexity of the system, some or all of the detector locations may be deployed. A RMS may utilize some or all of the following types of detectors:

Detector Purpose	Description
Demand Detector	Located at the stop-line. Detects the presence of vehicles at each ramp meter lane. Also referred to as a check-in detector.
Passage Detector	Located just across the stop-line. Detects when vehicles pass the ramp meter. Also referred to as a check-out detector.
Ramp Queue Detector	Located at the intersection of the ramp and the surface street. Detects when the queue is at or exceeding ramp capacity. Intermediate ramp queue detectors may also be utilized.
Mainline Detector	Located at one or more location on the expressway mainline. Detects capacity of mainline, existing congestion, and speeds of each travel lane. Data can be used for data collection, and/or fed into the controller algorithm for traffic-responsive ramp metering systems.
Exit Detector	Located on exit-ramp at the metered interchange. Provides volume information to be used for system-wide, traffic-responsive ramp meter operations.
Entrance Detector	Located on **non-metered** entrance-ramps. Detects volumes entering the mainline of a ramp metered roadway. Volume information is entered into a corridor-wide traffic-responsive ramp metering system.

Table 10-5: Ramp Meter Detector Types

10.5.7.1 Demand Detection Area

The demand detector detects the presence of vehicles at the ramp meter stop-line. These detectors are essential for ramp meter operation because they tell the system when to activate.

The detection area for the demand detector should be approximately 14m, or the length of approximately 2 vehicles. The demand detection area must cover all metered lanes. Figure 10-6 displays a typical inductive loop passage detector/demand detector configuration.

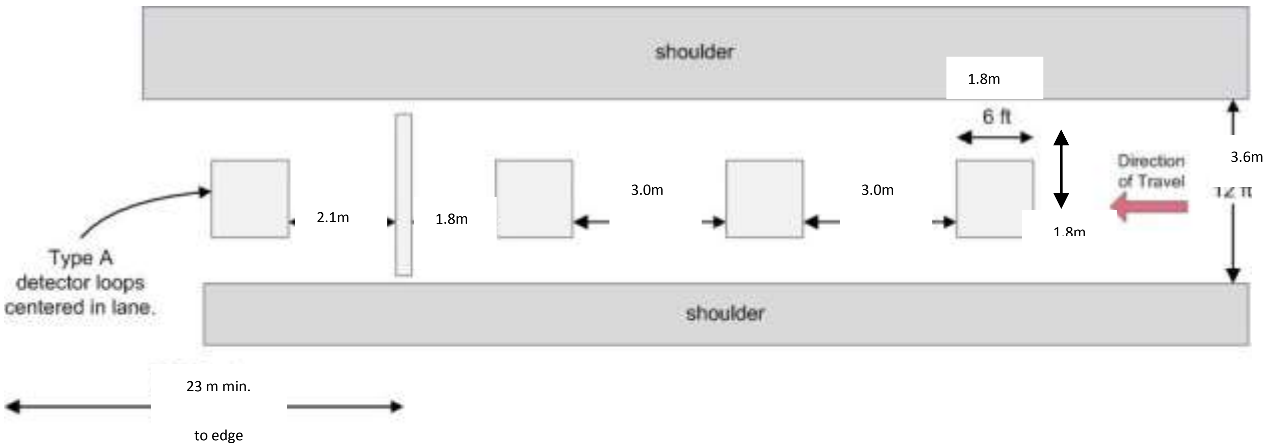

Figure 10-6: Typical Demand and Passage Loop Detector Configuration

10.5.7.2 Passage Detection Area

Passage detection area is used to detect vehicles passing through the ramp meter system. This provides the system with vehicle volumes entering the roadway, and provides confirmation that the vehicles are obeying the ramp meter signals. Depending on the type of system, this detection area may be essential to ramp meter operations.

10.5.7.3 Ramp Queue Detection Area

The ramp queue detection area is essential to a traffic-responsive ramp metering system. The detector is located at the top of the ramp, near the intersection with the surface street. It senses when a ramp is at capacity, and if the queue is in danger of reaching or backing up onto the surface street. Additional detection zones may be set up at midway points on the ramp in order to detect general queue size.

Queue detection is a crucial input for a traffic-responsive system algorithm, and must be included in the ramp meter system.

10.5.7.4 Mainline Detection Area

Mainline detection areas are located on the expressway thru lanes just upstream of the ramp gore area. The zone must include all through lanes. This detection zone provides essential mainline traffic operation data such as speed and volume. These data are inputs to the ramp meter algorithm that are necessary to determine the available capacity of the main line. Available capacity in turn determines the meter rate.

Figure 10-7 displays typical inductive loop mainline detector configuration. If using loops, multiple loops must be installed in sequence in order to accurately detect speeds and vehicle queues.

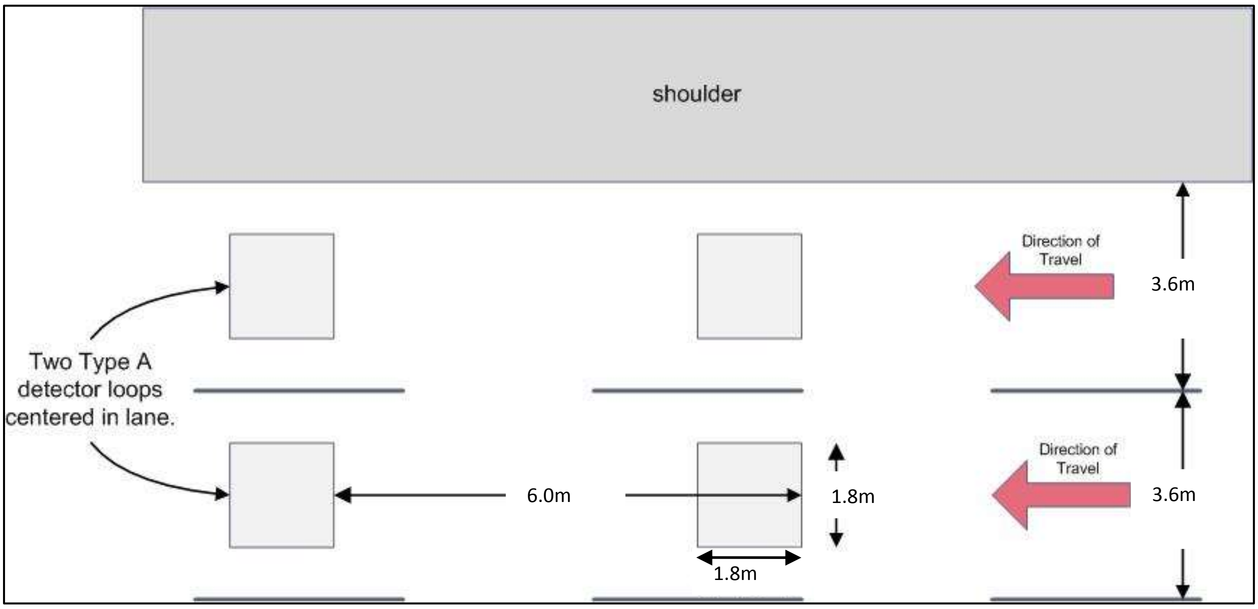

Figure 10-7: Typical Mainline Inductive Loop Detector Layout

10.5.7.5 Exit Ramp Detection Area

Exit ramp detection area is located at some point on the exit ramp of an interchange equipped with a ramp metering system. The intent of this detection area is to collect vehicle volume data which is used in many ramp metering system algorithms. While exit ramp detection is desirable, it may not be a requirement for a functional, traffic-responsive ramp metering system. The need for exit ramp detection will be determined by the ramp metering algorithm selected for the project.

10.5.7.6 Entrance Ramp Detection Areas

Entrance ramp detection areas can be located on ramps that are NOT metered, but are within a ramp metered corridor or system. These detection areas are intended to collect volume data from vehicles entering the mainline, which decrease its available capacity. While these volumes are not required, they are inputs to many ramp meter algorithms.

10.5.7.7 Ramp Meter Signing and Pavement Markings

Ramp meter technology is currently not a typical traffic management method utilized in Qatar. Drivers are generally not yet accustomed to ramp meters, so any installation may cause confusion and dangerous conditions if not properly announced to motorists. If motorists do not know to expect ramp meters, they may swerve, make other erratic motions, or brake abruptly causing hazardous conditions to themselves and drivers around them.

Abundant, well placed, clear signage and pavement markings are critical to effective and safe ramp meter installations. The need for signage increases with the complexity of the system. For example, ramp meters at high-volume or expressway-to-expressway interchanges require a network of signage that includes overhead signs equipped with flashing beacons.

Standard Ramp Meter Signs

Ramp Management and Control Manual signs must adhere to Ashghal's ITS Specifications. These signs may be equipped with flashing beacons that activate upon ramp meter operation to increase the visibility of the sign. The use of flashing beacons should be determined on a project-by-project basis and must be approved by Ashghal.

Pavement Markings

Ramp metering systems should utilize pavement markings consistent with standard signalized intersections and expressway ramp operations, including: stop lines, merge lines, and dashed lane separator lines. Lines may be paint, plastic, or raised pavement markers. All pavement markers should conform to the guidelines set in QCS.

10.6 ITS Enclosure Placement

See manufacturer's specifications to determine the maximum distance between the control enclosure and the field device it services.

The ramp controller system consists of an enclosure, controller, load switches, input files, loop amplifiers, and other miscellaneous devices, very similar to traffic signal systems. The controller must be capable of meeting the needs and functions outlined in the ramp metering study. Many standard controllers are available that meet the general needs of a ramp metering system. The most common controllers are "Type 170s" or "Type 2070s." The Model 170 controllers are becoming obsolete, so new installations should use the Advanced Transportation Controller (ATC) 2070, except in cases where it will conflict with existing systems and/or system software.

All ramp controller equipment should be housed in a standard NEMA or IP enclosure. The enclosure must be positioned at the ramp meter location and must satisfy the following requirements:

- Easily Accessible for Maintenance – access to the controller should not require special vehicles or equipment.
- Positioned such that maintenance personnel can access the enclosure while viewing ramp meter signal heads.
- Does not obstruct vehicle sight distance of the ramp or the ramp meter signal head.
- Protected from errant vehicles – either located outside of "clear zone" or behind a barrier.
- Facilitate a connection to the TMC or remote location that controls and monitors the ramp meter.
- A maintainer's pad should be provided at the front of the enclosure for the maintenance worker to stand on while accessing the enclosure.

11 Ducts and Chambers

The requirements for ducting along roadways and expressways shall be 6 x 100mm High Density Polyethylene (HDPE) ducts running parallel to the expressway in the reserved location within the utilities corridor on both sides of the expressway. In a circumstance whereby ducts cannot be provided on both sides of the expressway due to space restraints or other conflicts, use an 8 x 100mm configuration along one side of the roadway. In 6 way configuration, the top four ducts shall be designated for communications cables of ITS and SCADA, and the bottom two shall be designated for power cabling of ITS and SCADA. In 8 way configuration, the top six ducts shall be designated for communication cables of ITS and SCADA and the bottom two ducts shall be designated for power cabling for ITS and SCADA. Ducts on both sides of the expressway in the 6 x 100mm configuration is the standard requirement and shall be followed on all schemes unless an exception is provided in writing from Ashghal.

In Local Roads projects the ability to run 6 x 100mm ducts in some areas is likely to be impossible to achieve. In this case, the extent of the works at both ends should have facilities to allow for multiple cables from 6 x 100mm ducts to join into a lower number of duct facilities for the duration of the works in question. The number of possible ducts will need to be determined on a case by case basis. Any deviation from the standards however must be approved by Ashghal Design Department, correctly signed off, documented and the as-built drawings must reflect this deviation.

All ducts and chambers are to be sized, spaced and installed in line with the guidelines provided in the Ashghal ITS Telecommunication Strategy.

A chamber shall be installed in the median where there is a planned future need for the provision of communications and power cabling to ITS equipment in the median.

Sufficient drainage shall be allowed for in the area surrounding each chamber, and each chamber shall have a sump to prevent flooding of the ITS network through the conduit system.

For details regarding duct and chamber construction, alignment, location, installation, marker tape, concrete encasement of ducts, duct assignment, and chamber cover labeling, refer to Ashghal's Civil and Structural Standards for ITS.

Chamber dimensions for use in duct works are to be consistent with the standards outlined in Ashghal's Civil and Structural Standards for ITS. Where there are issues with space on road reserves or special circumstances in a design where chamber dimensions are an issue variation from the standards as they apply may be applicable. In this case, designers should present options to Ashghal explaining the need for the variation on their scheme and any impacts that this variation would have on pulling and/or handling of cables during construction.

All duct and chamber materials and works shall be in accordance with Ashghal's Civil and Structural Standards for ITS and QCS. In line with these standards all ducting is expected to be mandrel tested, have hauling ropes installed, be clean and free from debris or other obstructions to cable hauling.

Mandrel testing will be expected to be carried out and documented and signed off. Failure to do so will result in the site not being accepted, for continual fibre or cable installation.

All ducting that is designed to be installed under a Qatar Rail Carriageway must be cleared with Qatar Rail first as to depth and type. Qatar Rail may also have requirements for chamber placements on either side of the rail corridor being crossed. These requirements are to either align with the existing scheme or be met by designers. Designer's shall submit any supporting documentation detailing discussions/agreements that have been carried out with Qatar Rail.

The current market has a number of suppliers whom are able to provide a range of in-expensive, HD plastic chambers and duct management boxes which can be easily handled, buried and have locking lids. Benefits can arise from consistent chamber types and access depths of conduits by the use of preformed HDPE chambers and can give Ashgal greater deployment consistency from this type of approach. Should designers decide to utilize such chambers for projects then they are to approach Ashghal with a proposal to do so outlining the material specifications for these devices and to obtain approval to proceed to use them.

12 Power

12.1 Power Considerations

The key design steps for an ITS device deployment (electric) power system are:

- Determine the total power requirement based on the manufacturer's cut sheets.
- Select a suitable power source based on availability.
- Determine step-up/step-down transformer requirements, where applicable. The need for transformers will be based on voltage drop calculations.
- Determine meter options. Where possible, arrange a flat rate fee with the electric utility provider.

Enclosure types, the use of air-conditioning and/or passive air-management systems will be reviewed in due course. The use of single skinned and double skinned enclosures will also be addressed. The interior and external dimensions, number of acess doors and types of enclosures will also to be examined. Designers are encouraged to propose such enclosures in the interim and to explore non air-conditioned enclosure options. In all such cases, Designers should seek approval from Ashghal for specific non-conforming enclosure designs.

12.1.1 Power Requirements

The total power requirement for any deployed device and/or deployment site is the sum of the power requirements of the following:

- The device(s) (e.g., detectors, CCTV camera, RWIS, LCS, DMS, etc.) powered by the enclosure
- The enclosure components (refer to ITS enclosure specifications in Ashghal's ITS Specifications, QGEWC(E) Regulations for electrical installation, and QGEWC(E) regulations for protective multiple earthing).
- Any convenience outlet(s) as per Kahramaa regulations inside the device enclosure.

Table 12-1 lists typical power requirements for commonly used ITS devices. Listed power loads are for estimation purposes only; actual power loads should be obtained from the related manufacturer(s) of the equipment being specified or provided on each scheme.

DEVICE TYPE	TYPICAL POWER REQUIREMENT
CCTV	~ 30 Watts
SDMS (three 15-character lines)	~ 2000 Watts
MDMS (three 18-character lines)	~ 3000 Watts
LDMS (three 21-character lines)	~ 3500 Watts
LPR	~ 30 Watts
Access Points	~ 30 Watts
LCS	~ 500 Watts
OVDS	~ 50 Watts
WIM	~ 30 Watts
RWIS	~ 50 Watts
PTZ	~ 30 Watts
Convenience Outlet	Maximum of 5A for test equipment or maintenance only
Air conditioning	~ 1000 Watts
Misc. (Lighting, fans, etc.)	~ 250 Watts
Distribution switch	~ 50 Watts
Access switch	~ 50 Watts
Signal Head (LED)	~ 25 Watts
Flashing Beacon (LED)	~ 25 Watts

Table 12-1: Typical Power Requirements

12.1.2 Power Availability

The standard electrical supply in Qatar is 240/415 ± 6%, 3 Phase, 4 Wire at 50 Hz ± 0.1 Hz as per Kahramaa regulations. Occasionally, a higher voltage/ampere service is required when the point of service is located at a significant distance from the ITS device (ie over 200 meters).

Emergency means to disconnect power must be available within a convenient distance from the powered device. In most DMS installations, the power needed to operate the DMS is fed from the related DMS enclosure, and a power disconnect switch is usually installed outside the DMS enclosure. An additional power disconnect switch at the base of the DMS board support structure will not be necessary for such cases.

Once a power supply is made available in the ITS device enclosure, the electric power must be converted to the voltage and format (AC or DC) as appropriate for the used electronic devices.

12.1.3 Voltage Drop

Part of the voltage made available at the point of service is dissipated by the power cable that brings the electrical power to the intended ITS device. This loss of voltage over the supply power cable (voltage drop) is proportional to the distance involved.

Most electrical and electronic devices are designed to operate at the nominal voltage, with varying tolerances above and below the nominal voltage. It is Kahramaa regulation to limit the voltage drop to 2.5% or less.

At ITS deployment sites that may be located a large distance from the intended power source, a significant voltage drop becomes an important consideration.

Given a fixed distance between an ITS deployment site and related power source, a designer has to decide how to keep the related voltage drop within the design limits. The two most common methods are the use of larger power conductors or transmitting the electric power over power cable at a higher voltage. The higher voltage method commonly involves using a step-up transformer near the power source and a step-down transformer at the related ITS deployment site. Step-up/Step-down transformers are not be used within an ITS power supply design due to the shared services nature of the trenches, duct network and chambers being used for the ITS design in Qatar.

All electrical designs for the ITS equipment, including but not limited to, voltage drop calculations, electrical device sizing (e.g. switches, isolators, bus bars, surge suppressors, etc.) and grounding must be done according to Kahramaa regulations.

12.1.4 Metering

When necessary, provide metering for power draw to each ITS deployment site from a power-supply point. In locations that do not use Automatic Meter Reader (AMR) systems, safe and convenient meter reader access for utility personnel is an important consideration in selecting the deployment location. Roadways with small or no shoulders should not be considered for meter location. One way to circumvent this limitation is to arrange for non-metered (flat-rate) electric service through Kahramaa.

Coordinate with the power utility agency early in the design process to determine metering options. Consider the following power metering options:

- Metered, with safe and convenient personnel access.
- Non-metered, flat usage rate.
- Metered with AMR, using a drive-by RF data reader.
- Metered with AMR, using a cellular data service.

12.1.5 Installation of Power Cable

Install power cable(s) in ducts separate from those used for the installation of communications cables. The duct size is 100mm and the maximum duct fill ratio should be 40 percent.

To facilitate cable pulling, chambers should be installed in a manner that the duct center line is aligned with the center line of the chamber. Electrical chambers are typically installed at a maximum separation of 150m to avoid impacting the power cable because of the pulling tension. The chambers should not be installed in carriageways, driveways providing access to properties, drainage ponds, or bottoms of drainage ditches. The cover of the chambers should be labeled in accordance with the Civil and Structural Standards for ITS. In addition, all chambers must be earthed according to the electrical code.

The chambers should match the existing sidewalks elevations or surface level to avoid the potential for pedestrians tripping. Concrete aprons should be provided for all chambers that are not installed in a sidewalk. The concrete apron should be sized according to the size of the chamber. In addition, the concrete apron should be sloped away from the chamber to reduce the intrusion of water into the chamber.

12.2 Power Conditioning

Lightning spikes, transients, and line noise will degrade electronic devices over time. Power conditioning provides protection from these issues as well as regulating against sags (brownouts) and surges, thus reducing premature failure, improving equipment performance, and maintaining the uninterrupted operation of key equipment.

12.2.1 Voltage Surge Suppression

Lightning strikes are the most common cause of power surges to the ITS field devices. The resulting voltage surges can propagate long distances along the cable to the connected devices. In order to protect the related ITS deployment, appropriate surge protection measures must be provided for the ITS devices. These measures can be broken down into four components:

- Lightning rods at the top of or near the support structure.
- Earthing system, usually consisting of one or more earth rod electrodes.
- Surge suppression hardware in the enclosure.
- Earthing conductor bonding the three components described above.

The provision of lightning rods is preferred for deployments involving great heights, such as CCTV cameras and radio antenna at the top of tall poles, or DMS on structures that stand out among the surrounding landscape and vegetation. The use of a lightning rod is usually omitted for deployments involving relatively low heights and where taller structures are present nearby.

In general, surge diverters provide protection from energy (electric) surges by diverting and draining the excess (surge) energy to surrounding soil. It is therefore pertinent to combine the use of surge suppressors with a properly designed earthing conductor and an earthing system bonded to the electrical earth terminal or bar.

The provision of one or more lightning rods over the ITS device, in conjunction with an earthing conductor(s), can often help to divert the lightning discharges away from the field device assembly. Lightning abatement measures such as this are only effective if the lightning rod, related terminations, and the earthing conductors are sufficiently robust to conduct and to survive lightning discharges.

Lightning rods, earthing system, and diversion hardware shall be provided for lightning discharge energy for all installations.

Telecommunications cables and sensor cables from nearby locations, just like the utility power cable, are subject to the same possibility of lightning strikes. The requirement for appropriate surge protection measures must therefore be extended to all cables brought into the enclosure of all ITS deployments.

A proper earthing arrangement must be provided at the support structure, and at the enclosure for the system. Where the enclosure is installed at or close to the base of the support structure, both the support structure and the enclosure may be bonded to the same earthing system.

It is important that the related earthing system is able to disperse the electric charge from the lightning strike to the surrounding earth mass quickly.

Earth rod electrodes, systems, and testing procedures are specified in QCS, Section 21, Part 21 (Lightning Protection). The designer should assess the site environmental conditions to determine if the earthing system identified in QCS is sufficient for the device location. Some devices require more robust earthing requirements, such as CCTV cameras located at the tops of hills and mounted to high structures.

12.2.2 Uninterrupted Power Supply (UPS)

Frequent shutdowns and restarts of the electronic devices generally cause the electronic device to fail prematurely. Intermittent device shutdowns are generally triggered by low power-supply voltage, which are often the result of brief drops in supply voltage (brownouts) lasting seconds, and to lesser degrees complete power outages (blackouts) lasting more than a few minutes.

The provision of a UPS is part of the power-supply arrangement to help bridge periods of short and intermittent drops in power voltages. *Most commercial UPS products* also include other desired features such as power conditioning. Power conditioning helps to filter out unwanted fluctuations in power quality and *delivers "clean" power* to the connected loads.

A UPS providing, at a minimum, 30 minutes of power shall be provided for all ITS field devices and field communications hubs requiring backup power.

13 Communication

All communications for ITS equipment in the State of Qatar are to be installed and designed in line with the aims, directives and processes found within the Ashghal ITS Telecommunications Strategy, as available on the Ashghal website. This document specifies the strategic objectives of the WAN being deployed for ITS equipment in the State of Qatar and should be referred to before any design activity of any kind is undertaken in this area. *All designs are to comply with published standards and specifications.*

The communication protocol for Qatar's roadway ITS devices should be based around those used for wide area network (WAN) via Internet Protocol (IP). At this time, the WAN is to be a fiber Ethernet network (possibly multi-Gigabit (where required)) which is expected to run the length of the roadway connecting the ITS devices and subsystems. It should be constructed as a redundant ring. The data will be carried between nodes on fiber-optic cables and will be converted to a local telecommunications method (e.g., fixed via copper circuits, or wireless Wifi, WIMAX, LTE 4G or higher, dedicated point to point microwave links – MIMO, etc.) in the roadside enclosures.

The Ethernet WAN ring will be used to carry all control, monitoring, and video information. The ring topology will provide redundancy (i.e., closed loop) such that all nodes can be communicated with, even if the ring is cut in a single place.

A telecommunications connection to the TMC for the ITS components implemented as part of this project will also be provided as per the Ashghal ITS Telecommunications Strategy.

All field-to-center (F2C) and center-to-center (C2C) communications associated with the ITS will be designed to maximize interoperability. The designer will require conformance with the AASHTO/ITE/NEMA NTCIP for all F2C and C2C communications. The use of proprietary communication protocols is not permitted.

Remote ITS field devices at far edge locations may use wireless connection to the nearest location containing a fiber drop point. The capacity and security of the wireless connection shall not be inferior to the similar wired connection.

13.1 Communication Design Considerations

Generally, the key design considerations for the F2C communications system for an ITS deployment are:

- Determine the required communications characteristics, mainly the required bandwidth (in Kbps or Mbps).
- Investigate what telecommunication options are available at/near the planned deployment site(s).
- Coordinate with Ashghal to ensure that their requirements are being met.

- If using public infrastructure is required, confirm with telecommunication service providers that the required communications service is available at the deployment location.
- If the WAN is not available, compare the related costs, benefits, and security aspects of different communications options. Select a suitable communications means based on the options available at the deployment site.
- Incorporate the chosen communication means into the overall design and ensure inigration and compliance with the Ashgal ITS Telecomunication Strategy.
- Communications routed through the public internet are acceptable only on a case-by-case basis. Any connection using public internet must be accepted by Ashghal for security reasons.

13.2 Device/System Characteristics and Requirements

Each ITS system brings with it particular communication needs. The communication pattern and bandwidth requirement are the two key factors in evaluating what the system device needs to operate effectively.

Table 13-1 contains the typical bandwidth requirements for various ITS devices. These requirements must be accommodated by the selected communications medium.

System Type	Typical Usage Pattern	Required Bandwidth Range
CCTV Camera	Continuous @ 30 fps and 1080p resolution	Minimum 7 Mbps
DMS	Periodic, intermittent, short bursts	9.6 Kbps to 56 Kbps
Vehicle Detector	Continuous, periodic, intermittent, short bursts	9.6 Kbps to 115 Kbps
Ramp Meter System	Periodic, intermittent, short bursts	9.6 Kbps to 56 Kbps

Table 13-1: Typical ITS System Communication Requirements

13.2.1 Communication Patterns (Intermittent vs. Continuous)

With the exception of CCTV cameras, a typical communications session between an ITS device controller and the TMC usually involves a small amount of data (3 Kilobits or less). Such communications sessions take place only when specific needs arise, or are scheduled on a periodic basis, typically every ten minutes or longer. A communications session with such transmission content, and with such a usage pattern, can easily be supported by low-bandwidth communications means with bandwidth of 9.6 Kbps to 56 Kbps (such as that afforded with voice-grade dial-up telephone services). Due to the long pauses between communications sessions, the communication connection does not need to be engaged all the time or always on; a "dial-up" arrangement will usually suffice.

CCTV cameras, unless being used to transmit strictly still images, will require an always-open, continuous communication session and the means to support the relatively large communications bandwidth is required for the transmission of the video image.

13.3 Availability

Potential F2C communication arrangements that are appropriate for ITS systems are:

- Fiber-optic cable, owned or leased.
- Leased land-line, telephone cable with Frame-relay service at fractional T-1 (E-1) or full T-1(E-1) capacity.
- Broadband radio service, data radio system involving WiMAX, LTE, or proprietary Radio-Frequency (RF) technologies of comparable performances systems (MIMO types).
- Broadband cellular data service, Machine-to-Machine (M2M) data service involving 4G/LTE technologies.
- Satellite internet, data service through commercial service provider.

Availability of a service is not limited to just the availability of existing infrastructure to extend to the deployment sites, but also for an actual usable transmission session when the need for such transmission arises. Commercial communications services which are "shared use" in nature are very much affected by usage surges which are typical during and near places of major events or calamity. In a shared-use arrangement, a potentially large number of users may be sharing a fixed data bandwidth; therefore, a minimum bandwidth cannot be guaranteed unless special priority arrangements are made. Where data service with guaranteed (bandwidth, Quality of Service) performances is offered by the service provider, it is advisable to acquire this type of arrangements for high-bandwidth data streams such as those related to video transmission.

Communication Method	Typical Available Bandwidth
Fiber optic cable	Up to 40 Gbps per carrier light wavelength (Primary choice)
Leased land-line	Fractional (1/4 or 1/2) T-1 (E-1), full T1 (E-1), T-3 (E-3)
Broadband radio	Up to 300 Mbps, depending on technology used
Broadband cellular	Up to 4 Mbps, depending on service plan
Satellite internet	Up to 5 Mbps depending on service plan

Table 13-2: ITS System Communication Capacity

Every potential communication option presents unique capabilities, risks, and limitations. Below is a summary of the major design considerations, advantages, and disadvantages of each.

Unless otherwise specifically stated, use single-mode fiber-optic cable for all communications backbone infrastructure. Use cellular data services for portable ITS deployments and for some stationary DMS installations.

13.3.1 Fiber-Optic Cable

Design Considerations:

- Verify that the cable installation through the intended route is feasible.

Advantages:

- Virtually unlimited bandwidth.
- No danger of voltage surges.

Disadvantages:

- Potential difficulties in achieving clear right-of-way for installation.
- High installation cost of infrastructure for the cable.

13.3.2 Leased Land Lines

Refer to section 12.3.1 for leased fiber-optic cables.

Design Considerations:

- Supports bandwidths limited to T-1 (E-1) over less than 2 km without the use of repeaters.
- Abatement measures against voltage surges are necessary.

Advantages:

- Lower initial investment.

Disadvantages:

- Recurring usage fees.
- Reliance on service provider for repair services.
- Propagation of voltage surges from third-party system are possible.

13.3.3 Broadband Radio Service

Design Considerations:

- Except for short-range paths that can be visually evaluated, a path study, performed by a communications consultant or a system integrator, is recommended for new installations. A path study predicts the signal strength, reliability, and fade margin of a proposed radio link. While terrain, elevation, and distance are the major factors in this process, a path study must also consider antenna gain, feed line loss, transmitter power, and receiver sensitivity to arrive at a final prediction.
- Suitable surface protection and earthing
- Abatement measures against lightning strikes are necessary for outdoor installations.
- Maximum data bandwidth and maximum transmission distance as claimed by manufacturer are singularly achievable, but not both attainable simultaneously.

Advantages:

- High bandwidth (up to 300 Mbps, up to 50 km depending on technology used).
- Point-to-point, multi-point, repeater configurations possible, depending on technology used.
- Low infrastructure costs.

Disadvantages:

- A clear transmission path is not always possible.
- Requires a RF license application/acquisition, unless license-exempt RF bands are used.
- Periodic tree-trimming may be required to maintain clear line-of-sight.

13.3.4 Broadband Cellular Data Service

Design Considerations:

- Cellular system coverage outside of population centers typically is focused along major arterial roads, which coincides roughly with areas where the need for ITS deployments may be the greatest.
- Verify that there is adequate cellular signal strength available at the planned deployment site. This may simply involve using a portable computer equipped with a compatible wireless adaptor module and antenna to measure signal strength and confirm upload bandwidth.
- Verify that Machine-to-Machine (M2M) service, with guaranteed bandwidth, is available in the related deployment area.

Advantages:

- Allows much flexibility in the planning of device deployment sites.
- Available in majority of the regional expressways.
- Antenna height does not have to be very tall.
- Low set-up and infrastructure costs.
- Where available, M2M service provides guaranteed (high) bandwidth.

Disadvantages:

- Availability of data channels is low in/near densely populated areas.
- Where data transmission is routed through public domain, significant security measures are required.
- Recurring costs incurred.

13.3.5 Satellite Internet

Design Considerations:

- Verify that there is adequate satellite data signal strength available at the planned deployment site. This may involve using a portable computer equipped with compatible wireless adaptor module and antenna to measure signal strength and confirm upload bandwidth.

Advantages:

- Available practically everywhere.
- Installation costs are negligible.

Disadvantages:

- Availability affected by usage surges.
- Signal quality affected by weather events.
- Significant security measures necessary.
- Line of sight with satellites required – tree trimming may be necessary.

13.4 Communications Interface

An interface is a shared boundary across which information is passed. It is the hardware or software component that connects two or more other components for the purpose of passing information from one to another.

This section discusses the logical communications interface between a TMC and the roadside devices that the center controls or monitors.

13.4.1 Use of Open Communications Standards

Where available, communications protocols should use open data communications standards. The benefits of adopting open standards include:

- **Interoperability**. Interoperability in this context is the ability of the TMC to exchange information with devices of different types for some common purpose. Interoperability allows system components from different vendors to communicate with each other to provide system functions and to work together as a whole system. Interoperability is desired because it helps to reduce the total costs (procurement, operations and maintenance) of a system over its entire life.

  Open standards support interoperability. If an open standard is adopted, Ashghal will have a choice from several vendors. This decreases the implementation and maintenance costs to Ashghal because there is competition between vendors, not only to provide the field devices, but also to maintain the devices. Operational costs may decrease also because the TMC needs to support only one communications protocol.

  In the future, Ashghal may want to communicate with field devices procured from different vendors. If a closed proprietary communications interface is used, Ashghal will either have to use the same vendor again, or update the TMC software to support a different vendor's communications interface, both of which may be costly. However, with open standards, there are opportunities that new devices can be added onto an existing communications channel and mixed with different types of devices on the same line.

- **Avoiding Early Obsolescence**. By adopting an open standard that is widely used, Ashghal can be confident that its equipment remains useful and compatible long into the future by supporting the open standards even for all future purchases and upgrades. With closed proprietary protocols, maintenance support and options for extending the life of procured equipment is limited to the resources of a few vendors who are familiar with those closed protocols. Thus, support to maintain that equipment can be very expensive, or if those vendors are no longer in business, no support will be available as the system degrades and fails.

13.4.1.1 NTCIP

NTCIP is an example of a family of open standards that will be used in Qatar for remote control and monitoring of roadside equipment from a TMC. NTCIP defines open, consensus-based communications protocols and data definitions for the traffic management industry.

NTCIP has an additional benefit in that it allows a TMC to communicate with a variety of field devices on the same communications channel. This may be a significant cost advantage because the communications network is usually the most expensive component of a transportation management system, and the use of NTCIP maximizes that investment. For example, if a CCTV camera is installed near a DMS, the TMC software could communicate with the CCTV camera using the same communications channel already in place for monitoring and controlling the DMS.

The NTCIP Framework, shown in Figure 13-1, uses a layered or modular approach to communications standards, similar to the layering approach adopted by the Internet and International Organization for Standardization (ISO). The NTCIP family identifies five layers, or levels, for defining the communications interface between the TMC and the field device. The five levels are: information level, application level, transport level, subnetwork level, and plant level.

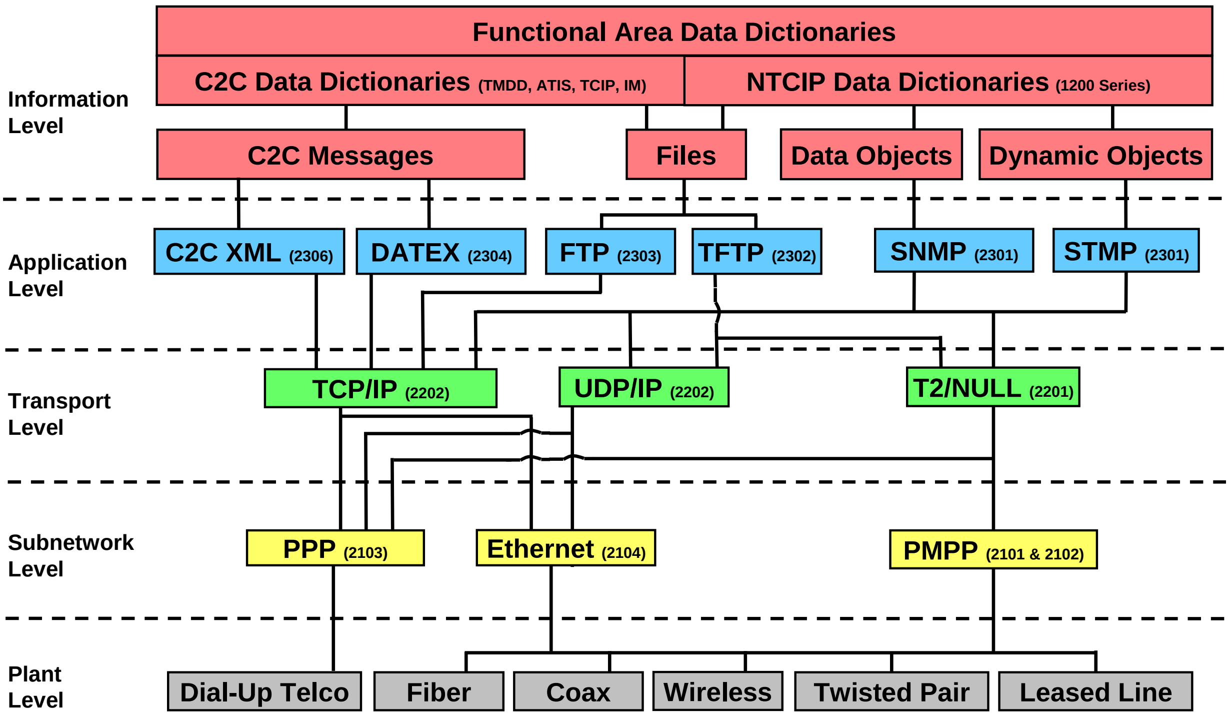

Figure 13-1: NTCIP Framework

For more information about using NTCIP and the NTCIP Framework, the Designer should read The NTCIP Guide, which can be downloaded at www.ntcip.org.

When using NTCIP to define the communications interface for the ramp metering system, the designer should specify which NTCIP standard(s) to use for each level. Multiple profiles may be selected for an implementation. For example, at the subnetwork level, the communications is initially point-to multi point protocol (PMPP), but Ethernet is expected to be used in the future. Standards for NTCIP 2101 for PMPP and NTCIP 2104 for Ethernet should be specified.

The five levels include:

- Information Level – The NTCIP information level defines the data to be used for exchanging information between the TMC and the field devices. It also defines the functions the system is to support.
- Application Level – The application level standards define the rules and procedures for exchanging information data. The NTCIP 2300 series defines the application profiles that can be used. The applicable profiles for managing ramp metering systems are contained in NTCIP 2301, Simple Transportation Management Framework (STMF) Application Profile. NTCIP 2302, Trivial File Transfer Protocol – Application Profile and NTCIP 2303, File Transfer Protocol – Application Profile, which are primarily used to transfer files, may also be applicable.
- Transport Level – The transport level standards define the rules and procedures for exchanging the application data between two points on a network, including any necessary routing and network management functions. The NTCIP 2200 series defines the protocol stacks that can be used in managing the communications network. At least one of the following transport profiles should be included in the specifications if deploying NTCIP:
    - NTCIP 2201, Transportation Transport Profile, which defines the mechanism for exchanging information data when the devices are directly connected to the TMC and do not require network services.
    - NTCIP 2202, Internet (TCIP/IP and UDP/IP) Transport Profile, which defines the mechanism for exchanging information data over a network using the Internet suite of protocols.
- Subnetwork Level – The subnetwork level standards define the rules and procedures for sharing the same communications line with other devices using the same subnetwork profile. At least one subnetwork profile should be included in the specifications if deploying NTCIP. The current applicable NTCIP subnetwork profiles are:
    - NTCIP 2101, PMPP using RS-232 Subnetwork Profile, which defines how to communicate over a multi-drop serial communications link.
    - NTCIP 2103, Point-to-Point Protocol over RS-232 Subnetwork Profile, which defines how to communicate over a dial-up link or a point-to-point serial communications link.
    - NTCIP 2104, Ethernet Subnetwork Profile, which defines how data is transferred over Ethernet links.

- Plant Level – The plant level is shown in the NTCIP Framework only as a means of providing a point of reference to visualize the standards profile when learning about NTCIP.

13.4.1.2 Other Communications Interface

If an open standards-based communications interface is not specified for a roadside system, it is important that the communications interface used and provided by the vendor be thoroughly documented and made available to Ashghal. The proper documentation and licenses provide Ashghal with the ability to better operate, maintain, expand, and upgrade the roadside system. For example, it allows Ashghal to procure a systems integrator to develop a common hardware and software platform from which Ashghal can manage all its transportation resources and assets, such as from a transportation management center. Without the proper documentation and licenses, this systems integration effort will be more costly and difficult.

All of the following conditions should be satisfied, particularly if a non-standards based communications interface is provided:

- The vendor must provide a perpetual, non-exclusive, irrevocable license, at no additional cost to Ashghal to use its communications interface. The license will allow Ashghal (or its employees, agents, or contractors) to reproduce, maintain, and modify the communications interface without restriction for Ashghal's use and benefit; and to use the communications interface on multiple processors utilized by Ashghal or entities affiliated with Ashghal with no additional licensing fee. The communications interface is defined so as to include all the data elements/objects that are exchanged between the TMC and the field devices to perform all the functions described in the specifications.
- The vendor will provide Ashghal with all documentation, including the source and object codes, for the communications interface. The documentation will consist of the source code for the communications interface, and any and all operator's and user's manuals, training materials, guides, listings, design documents, specifications, flow charts, data flow diagrams, commentary, and other materials and documents that explain the performance, function, or operation of the communications interface. The documentation will include a description of the data elements/objects required to perform each function required in the specifications, including the conditions and the sequence of events that the data elements/objects are exchanged between the TMC and the device. The software documentation defining the data elements/objects will be in the form of a management information base (MIB), using Abstract Syntax Notation One (ASN.1).
- Upon providing Ashghal with the communications interface documentation, the vendor will provide and perform test procedures that will demonstrate to Ashghal that the documentation provided is accurate and correct. The test procedures will demonstrate that as each function required in the specifications is performed, that the proper sequence of events, the conditions and the exchange of data elements/objects occur as written in the provided documentation. If the performance of the test procedures demonstrates additional details (or corrections) in the documentation is needed, the vendor will update the documentation and re-submit the documentation to Ashghal.

14 Glossary of Acronyms and Abbreviations

Glossary of Acronyms and Abbreviations	
Term	**Definition**
AMR	Automatic Meter Reader
ATMS	Advanced Traffic Management System
Ashghal	State of Qatar Public Works Authority
CCTV	Closed-Circuit Television
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization of Standards
ITS	Intelligent Transportation System
LAN	Local Area Network
LCS	Lane Control Signs
MDC	Major Desired Capability
MPT	Maintenance and Protection of Traffic
NEC	National Electrical Code
NTCIP	National Transportation Communications for ITS Protocol
O&M	Operations and Maintenance
PDA	Pre-Determined Amount
PMP	Project Management Plan
PTZ	Pan Tilt Zoom
QCS	Qatar Construction Specifications
QGEWC	Qatar General Electricity and Water Corporation

QHDM	Qatar Highway Design Manual
Qtel	Qatar Telecom Q.S.C.
QTM	Qatar Traffic Manual
QTCM	Qatar Traffic Control Manual
RF	Radio Frequency
ROW	Right-of-Way
RWIS	Road Weather Information System
SE	Systems Engineering
SEMP	Systems Engineering Management Plan
TDMS	Traffic Detection and Monitoring Systems
TMC	Traffic Management Center
TVSS	Transient-Voltage Surge Suppressor
WAN	Wide Area Network