System Requirements

prepared for

Minnesota Department of Transportation (MnDOT)

for

Rural Intersection Conflict Warning Systems II Deployment

February 2, 2015

Acknowledgements

These system requirements were originally developed by MnDOT for the statewide Rural Intersection Conflict Warning System (RICWS) project in October 2012. Carver County asked SRF Consulting Group to revise this document to incorporate lessons learned from the RICWS project to enable the installation of additional Intersection Conflict Warning Systems (ICWS) on T.H. 212 in Carver County. MnDOT participated in the development of this project and the associated systems engineering documents. These systems requirements were then revised by SRF Consulting Group for use on MnDOT's second deployment Rural Intersections Conflict Warning Systems II (RICWS II).

Introduction

The primary goal of an ICWS system is to reduce right angle crashes at a stop-controlled intersection. These systems address crashes at stop-controlled intersections by providing drivers with a dynamic warning of other vehicles approaching or entering the intersection. ICWS typically consist of static signing, detection and dynamic elements as illustrated in Figure 1.

Figure 1 Intersection Conflict Warning System Concept
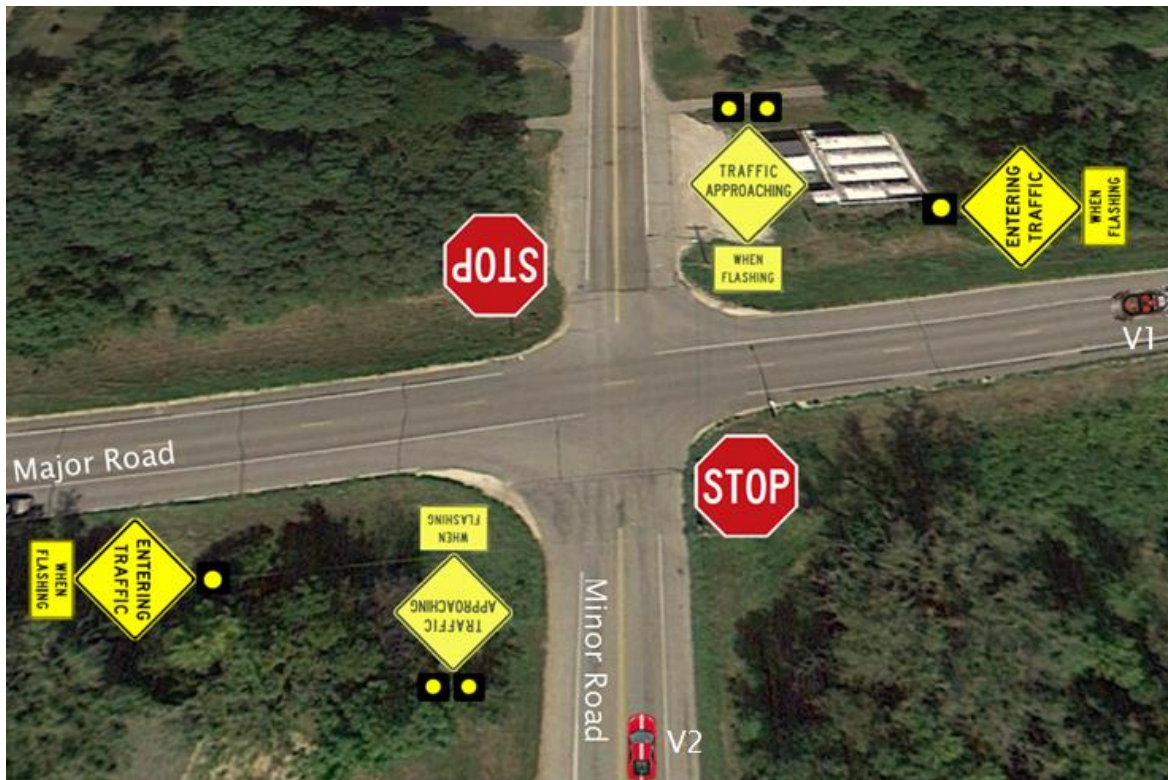
As they are currently conceived, ICWS fit within Minnesota's ITS architecture under the Advanced Vehicle Safety Systems market packages AVSS05-Intersection Safety Warning and AVSS10-Intersection Collision Avoidance.

This document presents detailed system requirements for ICWS systems. These requirements are based on MnDOT experience to-date with ICWS and they will evolve as more is learned.

Definitions

Intersection – as defined in the MUTCD, Part 1. General, Section 1A.13 Definitions of Headings, Words, and Phrases in this Manual:

a) The area embraced within the prolongation or connection of the lateral curb lines, or if not, the lateral boundary lines of the roadways of two highways that join one another at, or approximately at, right angles or the area within which vehicles traveling on different highways that join at any other angle might come into conflict.

b) The junction of an alley or driveway with a roadway or highway shall not constitute an intersection, unless the roadway or highway at said junction is controlled by a traffic control device.

c) If a highway includes two roadways that are 30 feet or more apart (see definition of median), then every crossing of each roadway of such divided highway by an intersection highway shall be a separate intersection.

d) If both intersecting highways include two roadways that are 30 feet or more apart, then every crossing of any two roadways of such highway shall be a separate intersection.

Approaching Vehicle – a motor vehicle that is approaching the intersection which is on:

a) The minor road and at some point was more than time "t" from the intersection.

b) The major road and at some point was more than the major road lag time from the intersection.

Entering Vehicle – a motor vehicle that turns onto the minor road less than the time "t" from the intersection or a motor vehicle that enters the major road less than the major road lag time from the intersection.

Operational Malfunction – component failures and malfunctions of otherwise functional hardware and software that prevents the RICWS system from displaying alerts to any approaching vehicle within parameters defined in these system requirements.

System Availability – is the design life of the system divided by the design life plus the average repair time per year (Design Life/(Design Life+(Repair Time*Average Failures per Year). See Appendix B for system availability discussion.

System Repair Time – is defined as a 72 hour allowable window for response to a reported operational malfunction.

Time "*t*" – a single constant for the intersection and is the largest time computed based on the major road vehicle lag time from 2.5 seconds in advance of the major road warning sign to the intersection at the posted speed limit.

User – Refers to Contractor or Agency field personnel on site.

User-configurable - is the parameter that allows engineering judgment of how best to establish detection and alert activation parameters based on traffic characteristics (gap selection, sight distance, and speed of each approaching vehicle) at a given intersection.

Vehicles – For the purpose of these requirements the term vehicles shall mean motor vehicles as defined in Minnesota Statutes and the Minnesota Manual on Uniform Traffic Control Devices.

Major Road Lag time - the portion of the gap which remains from the major road vehicle to the minor road vehicle at the stop line. This is further defined in NCHRP Report 383, Intersection Sight Distance.

System Requirements

System requirements are verifiable details that define what the intersection conflict warning system will do. They address either functional or performance/operational aspects of the system and are noted as such in the following table. Each of the high level requirements below was originally translated from stakeholder needs identified in the project Concept of Operations. The number references allow for traceability back to those needs and forward to the detailed system requirements. The first number refers to one of three stakeholder need categories – Driver Alerts, Traffic Control or Assessment and Evaluation. The second number refers to the stakeholder needs as they were presented in the Concept of Operations. The third number is used to track high level requirements and the final reference number relates to detailed system requirements, where applicable. Some reference numbers may also be out of sequence because the stakeholder needs that originally prompted them were performance or operationally oriented and therefore more appropriately addressed in project contract documents rather than functional requirements.

Number	High Level Requirements	Number	Detailed System Requirements
1	**Driver Alerts**		
1.1.1	ICWS **shall detect vehicles** approaching and waiting at the stop or yield signs on the minor road.	1.1.1.1	ICWS **shall detect approaching vehicles from both directions on the minor road** as they are approaching the intersection less than time t, from the intersection.
		1.1.1.2	ICWS shall detect any vehicle on the minor road that is waiting at the stop or yield sign on the minor road.
		1.1.1.3	ICWS shall be capable of detecting all entering vehicles on the minor road as they turn onto the minor road. Design considerations for including this detection at specific sites are included in the attached Design Guidelines.
1.1.2	ICWS **shall display alerts** to major road drivers whenever a vehicle is approaching or waiting at the stop or yield sign on the minor road.	1.1.2.1	ICWS **alert shall be active on the major road** whenever any approaching vehicle on the minor road is less than time "t" away from the stop sign.
		1.1.2.2	ICWS alert shall be active on the major road whenever any vehicle on the minor road is waiting at the stop or yield sign.

Number	High Level Requirements	Number	Detailed System Requirements
		1.1.2.3	ICWS alert shall be active on the major road whenever any vehicle from the minor road is within the intersection.
		1.1.2.4	ICWS alert shall be active on the major road whenever any vehicle on the minor road is waiting at the median yield sign.
		1.1.2.5	ICWS alert shall be inactive on the major road whenever: • there are no approaching vehicles on the minor road less than time "t" away from the intersection; • there are no vehicles waiting at the stop sign; • there are no minor road vehicles within the intersection; and • there are no vehicles waiting at the median yield sign.
		1.1.2.6	System activation and de-activation based on time "t" shall be within ± 0.5 seconds of time "t".
		1.1.2.7	ICWS **shall respond with at least 99.95% accuracy** for major road alerts.
1.1.3	ICWS **may display an alert** for major road drivers **even if no major road vehicles are present**.		No further detail required.
1.2.1	ICWS **alerts shall be visible to major road drivers at a distance** that allows them to take corrective action.	1.2.1.1	ICWS **alerts shall be visible** from any approach lanes on the major road.
		1.2.1.2	ICWS alerts shall be placed on the major road according to MN MUTCD Part 2C. Warning Signs and Object Markers, Section 2C.05 Placement of Warning Signs, and using Table 2C-4. Guidelines for Advance Placement of Warning Signs.
1.3.1	ICWS **shall detect** all vehicles as they approach the intersection on the major road.	1.3.1.1	ICWS **shall detect any approaching vehicle from both directions, in all lanes,** as they are approaching the intersection within a user-configurable lag time on the major road.

Number	High Level Requirements	Number	Detailed System Requirements
		1.3.1.2	ICWS shall be capable of detecting all entering vehicles on the major road as they enter the major road. Design considerations for including this detection at specific sites are included in the attached Design Guidelines.
1.3.2	ICWS **shall display alerts** to minor road drivers whenever vehicles approach the intersection on the major road.	1.3.2.1	ICWS **alert shall be active on the minor road** whenever any approaching vehicle on the major road is less than a user-configurable lag time away from the intersection.
		1.3.2.2	ICWS alert shall be active on the minor road whenever any major road approaching vehicle is within the intersection.
		1.3.2.2	ICWS alert shall be inactive on the minor road whenever there are no approaching vehicles less than a user-configurable lag time away from the intersection on the major road.
		1.3.2.3	ICWS **alert shall allow a user-configurable lag time** between 4 and 7.5 seconds, in increments of 0.1 seconds, for any approaching vehicle on the major road. The lag time will define active/inactive parameters for the minor road alert.
		1.3.2.4	ICWS **alert lag-time shall allow for user configuration of lag time** on the major road by changing parameters within the system software and without changes to detector placement, hardware, or firmware/software programing
		1.3.2.5	ICWS **shall meet requirements for user-configurable active and inactive lag timing whenever any approaching vehicle speed is within ±12 MPH of the posted speed** on the major road; excluding vehicles that may be decelerating to execute a turn at the intersection.
		1.3.2.6	System activation and de-activation based on user configurable lag time shall be within +/- 0.5 seconds of the lag time the user has configured.

Number	High Level Requirements	Number	Detailed System Requirements
		1.3.1.2	ICWS **shall respond with at least 99.95% accuracy** for minor road alerts.
1.3.3	ICWS **may display an alert** for minor road drivers **even if no minor road vehicles are present**.		No further detail required.
1.4.1	ICWS **shall display alerts at a location visible** to minor road drivers waiting at the stop sign.	1.4.1.1	ICWS **alert shall be placed** on far right corner of intersection, across from the stop sign, where intersection geometry permits. For those intersections with restricted geometry, ICWS alert may be placed on far left corner of intersection, across from the stop sign.
1.5.1	ICWS design shall include dynamic alerts.		No further detail required.
1.6.2	To the extent possible, ICWS **shall follow recommended design practices** described in "Design and Evaluation Guidance for Intersection Conflict Warning Systems" authored by the ENTERPRISE Transportation Pooled Fund program.	1.6.2.1	ICWS **shall be designed using the placement, sign combinations and message sets described for** Major and Minor Road Alert for 2-Lane/2-Lane (or Multi-Lane) Intersection or for a major road alert only.
1.7.1	ICWS **shall have similar placement, sign combinations and message sets** at each deployment site in Minnesota.	1.7.1.1	ICWS **alert shall use** TRAFFIC APPROACHING WHEN FLASHING (W3-X8b) sign(s) on the minor roadway. The ICWS alert shall use either ENTERING TRAFFIC WHEN FLASHING (W3-X8a and W3-X8aP) on two-lane two-way major roadway or ENTERING TRAFFIC WHEN FLASHING (W3-X8) on multi-lane divided major roadway.
		1.7.1.2	The TRAFFIC APPROACHING WHEN FLASHING (W3-X8b) sign(s) on the minor roadway shall be a blank out sign allowing the sign to be de-energized by the control system or user. This allows a malfunctioning system to appear different than an inactive system.
1.8.1	ICWS **alerts shall be conspicuous**.	1.8.1.1	ICWS **alert shall conform to MN MUTCD 2A.7 Retroreflectivity and Illumination, MN MUTCD 2L.4 Design Characteristics of Changeable Message Signs, and TEM 6-4.05.05 Retroreflective Sheeting Policy** for sign sheeting materials and LED brightness.

Number	High Level Requirements	Number	Detailed System Requirements
2	**Traffic Control**		
2.1.1	ICWS **shall function as a warning sign** as defined in MN MUTCD 2C.1-2C.2.		No further detail required.
2.2.1	ICWS **shall operate continuously 24x7, 365 days per year**, with minimal service interruption.	2.2.1.1	The system shall operate continuously 24 hours per day, 365 days per year during its design life of 10 years (87,600 hours) without the need for restarts, re-initializations for other external interventions.
		2.2.1.2	The system shall have availability over its design life greater than 99.9% as defined in these requirements.
		2.2.1.3	ICWS **components shall conform to NEMA TS 2-2003** environmental requirements.
		2.2.1.4	ICWS **alert shall conform to NEMA TS 4-2005** standards for the hardware and functional characteristics of electronically controlled dynamic message signs, if used.
		2.2.1.5	ICWS **shall be connected to utility power service.**
		2.2.1.6	ICWS **shall detect any detection component malfunction.**
		2.2.1.7	ICWS **system communication components shall comply** with FCC emission requirements. The system shall be able to meet needed FCC approvals when design is complete.
		2.2.1.8	ICWS Control Cabinet shall meet the requirements of UL 508 "Standard for Industrial Control Equipment", January 28th 1999 Edition, and the requirements of the current edition of the National Electrical Code by either being listed by a Nationally Recognized Testing Laboratory (NRTL) or being certified under Minnesota Rule 3801.3620 Subpart 3 D 1, that the ICWS Control Cabinet is safe for its intended purpose.
		2.2.1.9	In the event of a power failure, the ICWS system **shall restart automatically upon restoration of power**.

Number	High Level Requirements	Number	Detailed System Requirements
		2.2.1.10	Restoration of power shall not reset a system malfunction that was previously active.
2.2.2	ICWS **shall not depend on communication with external systems to operate.**		No further detail required.
2.3.1	ICWS **shall display a visible indication of malfunction**.	2.3.1.1	ICWS **shall display indication of malfunction within 1 minute of detection**.
2.3.2	ICWS **indication of malfunction shall be visibly different** than ICWS in any other active or inactive state.	2.3.2.1	ICWS **malfunction indication on the major road alert shall** consist of continuous activation of the flashing beacon, excluding utility power service failure. If utility power service fails, it is acceptable for beacon to just be off.
		2.3.2.2	ICWS malfunction indication on the minor road alert using a blank-out sign shall have no visible legend and flashing beacons shall be de-energized.
2.3.3	ICWS indication of malfunction shall be distinguishable without knowledge of ICWS operations		No further detail required.
2.4.1	ICWS **shall not obstruct any drivers' view** of the roadway, other vehicles or regulatory signs.		No further detail required.
2.5.1	ICWS **shall meet MN MUTCD Section 2A.21 Posts and Mountings standard and AASHTO Specification for Structural Supports for Highway Signs, Luminaires and Traffic Signals** for crashworthiness.		No further detail required.
2.5.2	ICWS **shall consist of materials and be installed** as specified in Section 2564 Traffic Signs and Devices and Section 2565 Traffic Control Signals of the MnDOT Standards Specifications for Construction.		No further detail required.
2.6.1	ICWS design shall be maintainable and fit within Agency maintenance processes.		No further detail required.

Number	High Level Requirements	Number	Detailed System Requirements
2.7.1	ICWS design shall follow design practices that allow maintenance staff familiar with other statewide ICWS systems to operate and maintain the system.		No further detail required.
2.8.1	ICWS **shall have consistent cabinet layout and one central programmable control unit that is the same for each site** to allow major road only, minor road only or major/minor road alerts as defined in Section 17 of Book 2.	2.8.1.1	ICWS **shall allow a minor road only system to be added to a major road system** and provide combined alert to both major and minor road drivers.
		2.8.1.2	ICWS **shall allow a major road only system to be added to a minor road system** and provide combined alerts to both major and minor road drivers.
		2.8.1.3	ICWS **shall allow the minor or major road alert to be removed from a combined major and minor road alert** and provide alerts to only the major or minor road drivers, respectively.
2.9.1	ICWS physical components **shall be physically accessible for maintenance** with one transportation agency vehicle and a 1-2 person crew in the right of way.	2.9.1.1	ICWS control cabinet shall be located in an intersection quadrant that provides easy access by service personnel including proximity to parking of vehicle and easy walking path to cabinet. The control cabinet shall be situated so service personnel can readily see the intersection and related components when standing in front of the cabinet door. The cabinet door shall also be situated to provide easy access during all seasons (e.g. minimal snow and ice during winter, vegetation during summer, etc.) Any pole/post mounted equipment shall be accessible from the shoulder of the roadway, or if no shoulder from the nearest traffic lane, by a bucket truck with a 52 foot maximum reach.
3	**Assessment and Evaluation**		
3.1.1	Systems engineering documentation shall explain		No further detail required.

Number	High Level Requirements	Number	Detailed System Requirements
	safety considerations for ICWS.		
3.2.1	ICWS design shall be compatible with other statewide ICWS systems such that the design, construction, operation and maintenance procedures can be implemented.		No further detail required.
3.3.1	ICWS **shall collect and retain data about system performance** that indicates when and what components have failed or may be operating in less than optimal states.	3.3.1.1	ICWS **shall maintain an internal record of detection and power failures** and a corresponding time/date stamp for when the failure began and ended.
		3.3.1.2	ICWS **shall maintain an internal record of individual system activations** with a time/date stamp during a 96 hour period.
		3.3.1.3	ICWS **shall maintain an internal record of individual vehicle detections** with a time/date stamp during a 96 hour period.
3.3.2	ICWS shall have remote communication and monitoring capabilities that allow for determining if the system is operational or in a failure state.	3.3.2.1	The remote communications monitoring capabilities shall conform to and provide for NTCIP 1202 and include the ability to report detector diagnostics; no activity, maximum presence, and erratic counts (all with settable values).

Appendix A: Design Consideration and Guidance

TIME "T" FOR MAJOR ROAD ALERT

Time "t" – a single constant for the intersection and is the largest time computed based on the major road vehicle lag time from 100 feet in advance of the major road warning sign to the intersection at the posted speed limit. Distances are based on the typical condition for deceleration to the listed advisory speed for the warning of a potential stop situation as defined in MUTCD Table 2C-4. The distances are based on the 2005 AASHTO Policy, Exhibit 3-1, Stopping Sight Distance, providing a PRT (Perception-Response Time) of 2.5 seconds, a deceleration rate of 11.2 feet/second^2, minus the sign legibility distance of 180 feet. The distances shown in Table 2C-4 are provided as an aid for determining the minimum sign location to the intersection. MnDOT's Traffic Engineering Manual Chapter 6, specifically Figures 6.24, 6.25 and 6.26, provides for standard sign location, order, and spacing for the major road warning signs. An illustration of how time t may be applied is provided in Appendix A for ICWS 3 and ICWS 4.

USER CONFIGUABLE LAG TIME FOR MINOR ROAD ALERT

Posted Speed Limit, -12 MPH	Posted Speed Limit	Posted Speed Limit, +12 MPH	Active Alert Timing and Distance (User-Configurable Lag Time)		
			4 Seconds	6.5 Seconds	7.5 Seconds
43 MPH			252'	410'	473'
	55 MPH		323'	524'	605'
		67 MPH	393'	639'	737'

This table illustrates sample calculations initially used by the Minnesota Department of Transportation (MnDOT) to define a user-configurable lag time range for the timing and distance necessary to activate an alert on the minor road. The range for the user-configurable lag time is based on deployment experience in Minnesota. MnDOT established the range by starting with a 6.5 second gap rejection threshold. This threshold is based on research cited in, "Alert and Warning Timing for CICAS-SSA – An Approach Using Macroscopic and Microscopic Data: Cooperative Intersection Collision Avoidance System-Stop Sign Assist Report #1." The research showed that 6.5 seconds represents the average weighted 80% gap rejection threshold in Minnesota and Wisconsin. MnDOT added a +1.0 second/-2.5 second buffer to the gap rejection threshold, considered a 55 MPH posted speed limit, and allowed for vehicles traveling ±12 MPH within the limit. Calculation details are included in the table. The range for the user - configurable lag time may be adjusted as needed for individual deployments, but establishing a range is strongly encouraged to constrain design costs.

DRIVEWAY DETECTION

While most system activations are caused by Approaching Vehicles (vehicles that that enter the Active Zone as they approach the intersection), there may be driveways adjacent to the active zone that require Entering Vehicles (vehicles that enter the Active Zone from adjacent driveways or roads) to be detected. Consideration should be given to detecting and responding to these Entering Vehicles if they are from commercial, retail, industrial and other publically accessed driveways or roads. This consideration should include, among other items, the distance and time to the intersection, volume of traffic, and type of entering vehicles. Detection of Entering Vehicles from residential and other private driveways may be disregarded based on engineering judgment.

TURN ON TEST AND ACCEPTANCE TEST

Project documents shall include requirements for an initial turn on test before systems are "turned-on" and put into service. It is suggested that each system have a 90 day acceptance/break-in period included in the project documents. During this period the Contractor shall be responsible for any and all repairs that are due to workmanship and quality of the equipment and installation. This excludes damage due to vandalism, traffic crashes, or natural disasters that are outside of the control of the Contractor and Manufacturer. At this end of this 90 day acceptance period an acceptance test, similar to, if not identical to the turn on test, should be conducted before turning ownership, maintenance and operation to the road authority.

Appendix B: System Availability and Reliability

Reliability Requirements Overview

Defining system reliability in a consistent and quantifiable way is one of the most difficult aspects of creating functional requirements. The lack of historical data for the overall reliability of newly integrated systems and the limitations of combining mean time to failure (MTTF) figures provided by manufactures make defining reliability in an objective way challenging.

In reliability engineering, one of the most basic specifications is the Inherent Availability (Ai) which is defined as the probability that a system will operate properly under ideal conditions at a given point in time. Ai is calculated by dividing the Mean Time To Failure (MTTF) by the sum of MTTF and the Mean Time To Repair (MTTR). The outage time for a system is then 1/MTTF. This calculation will then produce the equivalent of an "uptime" percentage for a given system.

Applying this approach to the RICWS deployments is somewhat difficult as there is no historical basis for either the MTTF or MTTR. However, using some design assumptions and other allowances it is possible to create a general requirement for system reliability and therefore allowed system failures on a per-year basis.

If, under ideal conditions, the system is expected to operate properly, without interruption, over its design life, the MTTF can be taken to be the design life in years multiplied by 8,760 or 87,600 hours for a 10 year design life. Although repair times will vary based on location of the system and the nature of the malfunction, a maximum of 72 hours to repair any reported malfunction is given as a requirement, and therefore can be taken as a "worst case" MTTR. Using these assumptions, a range of Ai values for different average malfunctions per year can be calculated as shown below.

Inherent Availability Computations					
Avg Failures/year/installation	0.1	0.2	0.5	1.0	2.0
Inherent Availability	99.99%	99.98%	99.96%	99.92%	99.84%
Avg hrs/year outage/installation	7.2	14.4	36.0	72.0	144.0

Application of Reliability to RICWS II System Availability

For an average of one failure per year per installed RICWS, an Ai value of 99.92% is calculated. For a "four nines" (99.99%) level of system availability, only one failure per system over its design life of 10 years is allowed.

The impact of different Ai levels on staffing and resource requirements can be gauged by multiplying the average failures per year per installation by the total number of systems deployed. The results of this computation assuming a total of 55 systems deployed shown in the table below.

Avg Failures/year/installation	0.1	0.2	0.5	1.0	2.0
Avg total failures/year	5.50	11.00	27.50	55.00	110.00

With an Ai value of 99.99%, there will be approximately one failure every 10 weeks that causes a system to be unavailable for up to 72 hours. At 99.92%, the frequency of failures rises to approximately one per week, on an annual average basis.

Based on this analysis, it has been determined to use 99.9 as the reliability requirement for RICWS II. This provides a target reliability that can be assessed over time to determine a measurable and achievable Ai.