Figure 138 represents again more PSM messages received at the APs within MER#2. The overall physiological status for this particular data is 3 or a red/alarm condition. After examining the supporting data you notice the panic flag is set indicating that wearer has pressed the panic button on the CIU box. The PSM system continues to send a alarm condition until the CIU box power is cycled or the batteries run out of energy.

PSM S/N# 4 - G. Schwartz - RED Indication

SN	0x40000004	AP	4003	5/24/01	12	19	22.421	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	0	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	19	37.322	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	0	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	22.42	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	0	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	37.422	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	0	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	44.522	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	45.523	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	46.468	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	46.525	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	47.47	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	47.516	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	48.471	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	48.518	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	49.473	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	51.475	CST	0	IST	0	PST	0	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	52.567	CST	0	IST	0	PST	3	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	53.515	CST	0	IST	0	PST	3	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	53.568	CST	0	IST	0	PST	3	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4003	5/24/01	12	54	54.516	CST	0	IST	0	PST	3	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0
SN	0x40000004	AP	4002	5/24/01	12	54	54.57	CST	0	IST	0	PST	3	ORIENT	0	WET	0	Motion	0	MEMFail	0	PANIC	1	ELE	0

12:54:44.522 Panic button pressed
12:54:52.567 PSM issues an alarm

Why the 8 second delay? The PSM physiological status algorithm is executed every 15 seconds. The button was pressed in the middle of the sleep period.

Figure 138 PSM Red Indication

5.2.3.5 Personnel Tracking

The ability to determine a sailor's location within the ship has been identified as a desired feature especially in a minimally manned ship. The majority of the compartments are small enough that just knowing the a sailor is in a given compartment is sufficient enough. However in larger compartment such as MER#2 you'd like to know more detail as to the location of the sailor. Figure 139 represents the output of a compartment level algorithm that is trying to determine the location of a sailor within MER#2. The data that was used to generate the plot was gathered during the VIP demonstration held on May 24 onboard the USS MONTEREY. The wearer was assigned the duty of escorting the VIPs from the one demonstration station to another demonstration station that was located in MER#2. For the most part the wearer was standing near AP1 (noted 4001 in the plot) but when the demonstration was completed the escort navigated through the compartment to the next station and then returned to the original AP1 station. The "navigation" period of time is captured in the plot by the APs #2 and #3 having the greater signal strength.

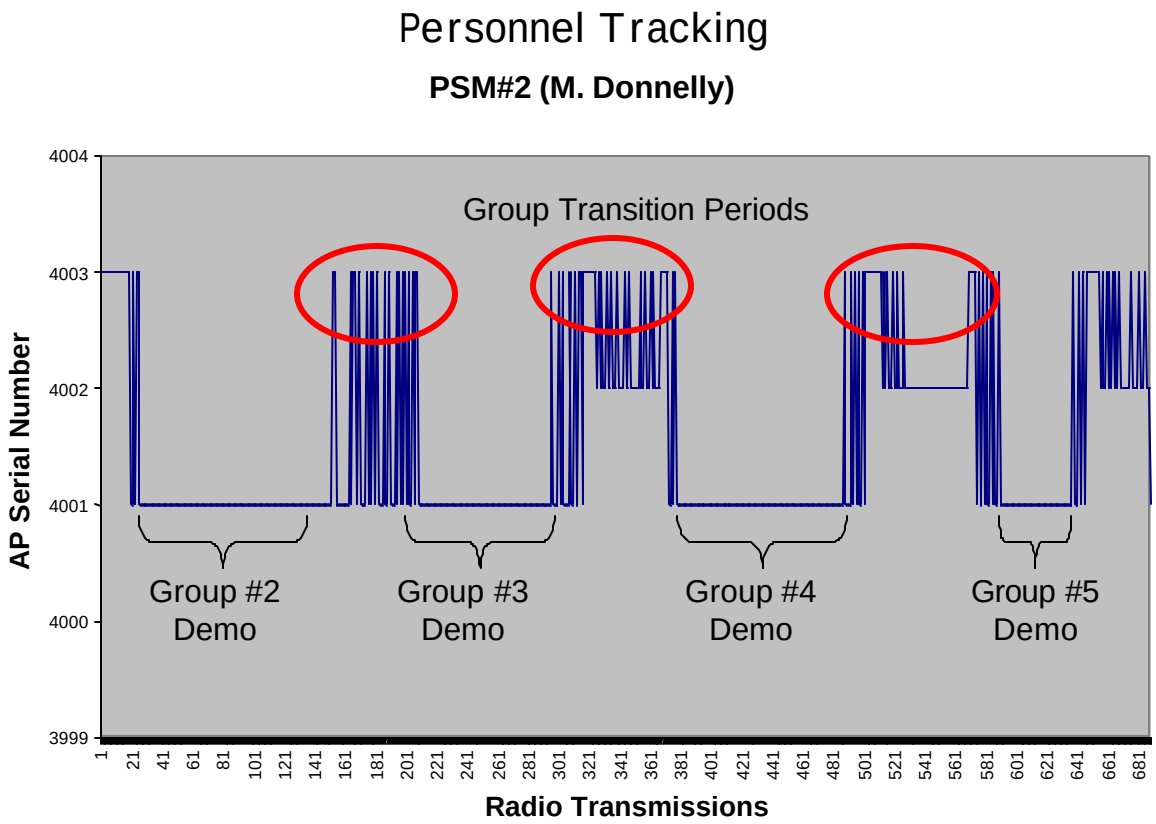


Figure 139 Location Determination Within MER#2

One of the key attributes that the RSVP team wanted to capture during the USS MONTEREY demonstration was the overall performance of the low-power RF network architecture. Included in the AP as part of the data logging feature is the ability to determine the bit error rate (BER) of a particular sensor cluster unit. Figure 140 is a screen capture of sensor cluster data messages received at the AP during one of the at–sea tests. What the data is telling us is that for sensor cluster s/n 111 a BER of 2% is being realized. The RSVP BER is 1% so a 2% BER is very close and acceptable.

Bit Error Rate (BER)

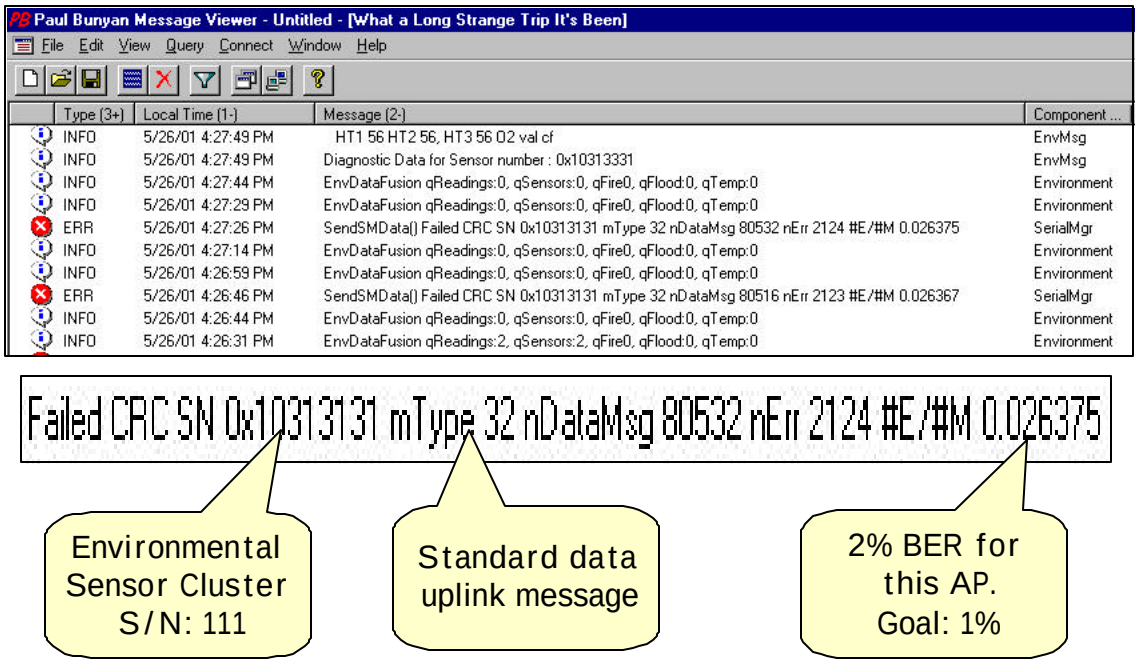


Figure 140 Bit Error Rate (BER)

5.2.3.6 Power Harvesting

5.2.3.6.1 Power Management Module (PMM)

The PMM was connected with Sensor Cluster #02 of Figure 141. A Photovoltaic Array and the Thermo-Electric Energy Harvesting Generator (Figure 142) were connected to the PMM and supplied harvested power to the sensor cluster as battery augmentation.

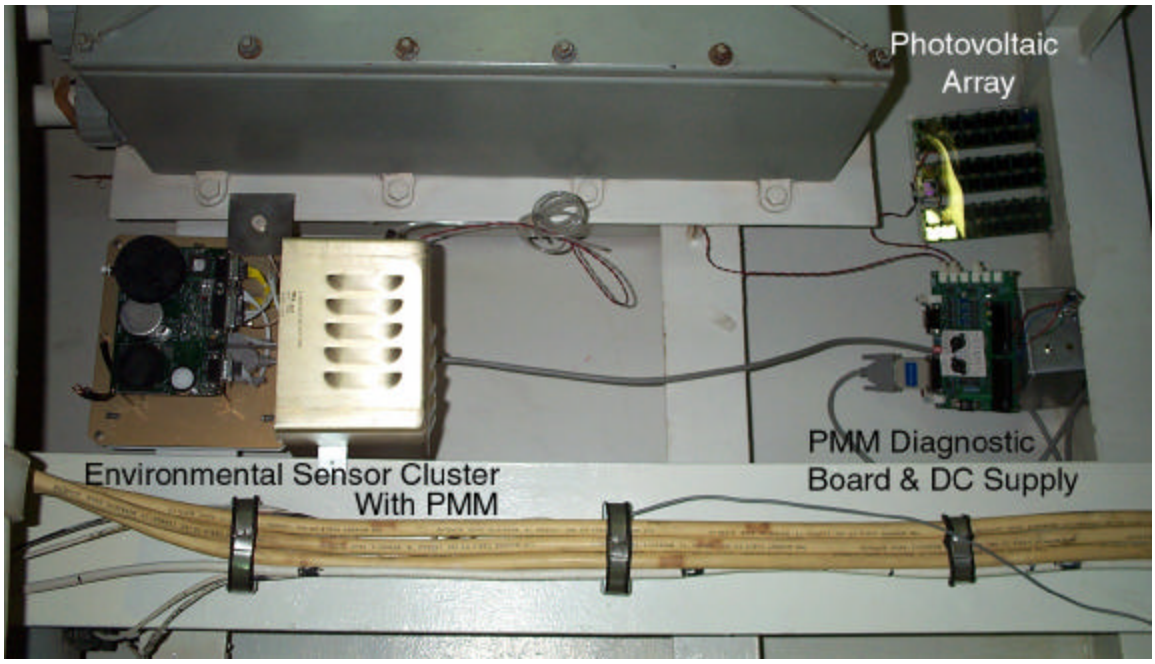


Figure 141 Sensor Cluster with PMM and Diagnostic Board

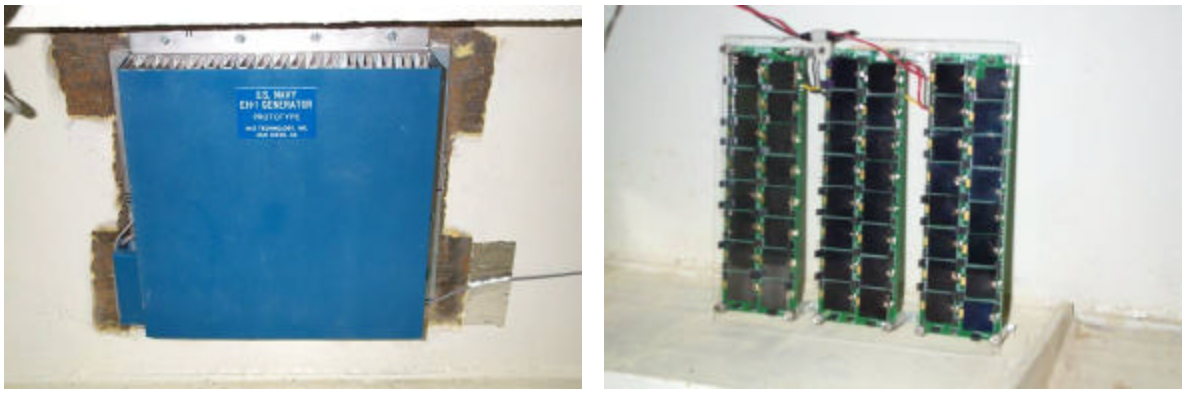


Figure 142 Thermo-Electric Harvesting Generator and Photovoltaic Array

5.2.3.6.2 Photovoltaic Input

If the photovoltaic array were placed directly under a lighting fixture, it could produce the required amount of power; however, if it were placed above the fixture where the top is typically totally shielded, then it would produce no power. Power from the Photovoltaic array was not measured during this evaluation because it was determined during risk mitigation testing that there would be no measurable current in the ambient lighting conditions from this particular array. The array was connected to demonstrate the interface. A more efficient array, and one that would have been cost prohibitive for RSVP, could be acquired to power the PMM.

5.2.3.6.3 Vibration-to-Electric Input

The technology developed for RSVP vibrational power harvesting is too immature and undeveloped to be a viable power source even under the most favorable conditions at this time. However, it may become a viable power source in the future. The Vibration-to-Electric power harvesting device was not connected to the cluster because an interface to the PMM board was not developed. The Vibration-to-Electric power harvesting device was brought to the CG-61 for display.

5.2.3.6.4 Thermo-Electric Input

Tests were run in controlled conditions at 35, 20, 10 and 5 degrees delta T with loads of open, 1M, 500K, 200K, 150K and 100K. Measurement stopped when the voltage dropped below 3.3 volts because it is unusable at that point.

35 Degrees Delta T : Cold=90F Hot=125F

open	5.3 volts	.000 mA
1M	4.65	.004
500K	3.96	.007
200K	3.35	.016
150K	3.15	.020

20 Degrees Delta T : Cold=90F Hot=110F

open	5.13 volts	.000 mA
1M	4.50	.004
500K	3.80	.007
200K	2.78	.013

10 Degrees Delta T : Cold=90F Hot=100F

open	5.03 volts		.000 mA
1M	4.26		.004
500K	3.52	.006	
200K	2.3		.011

5 Degrees Delta T Cold=95F Hot=100F

open	4.85 volts		.000 mA
1M	4.14		.004
500K	3.40	.006	
200K	2.18	.010	

As the results indicate, the Thermo-Electric generator did not develop enough current in any of the tests to power the cluster.

5.2.3.6.5 Summary

The PMM was designed to handle 1ma at 3.3 volts average power with 100ma at 3.3 volts peak demand. How much power that could have been drawn from the power harvesting devices is very dependent upon the specific location in the environment in which they are placed. Inappropriate placement could yield no power at all. This evaluation revealed that power harvesting was most technologically immature of the RSVP components. There are no COTS products currently available and cost effective that meet RSVP design goals. More development is required to provide the anticipated power loads for wireless sensors in these areas. RSVP expects commercial development to continue, and expects maturation of these technologies.

5.3 Ex-USS Shadwell

5.3.1 Introduction

The objective for the RSVP ex-USS SHADWELL Demonstration is to exercise and demonstrate environmental and personnel monitoring capabilities in an integrated environment. The RSVP ex-USS SHADWELL demonstration will be a collaborative effort between the Damage Control – Automation for Reduced Manning (DC-ARM) program and the RSVP program. RSVP sailor status and location information will be exchanged via the SHADWELL LAN to the two supervisory control systems being demonstrated during the September FY01 demonstrations.
The following is a sample of RSVP performance requirements that were established at the beginning of the program by a number of government and industry experts. A complete listing can be found in the RSVP Systems Engineering Study.

- RSVP will alert an operator that there is a fire in a compartment.
- Goal for probability of missed detection: 0.2% of actual fires.
- Goal for time to detection of a Class A fire (due to combustibles on the ship, not an external event): 5 min.
- Goal for probability of false alarm: 2/year per ship 1 (approximately 500 compartments).
- RSVP will alert an operator that there is an incipient fire in a compartment.
- Goal for alert time prior to ignition: 5 min. An alert will be given *prior* to ignition?
- RSVP will alert an operator that a crew member is undergoing extreme fatigue.
- RSVP will allow an operator to continuously track the location (to the compartment level) of crew members over the range of motion from stationary to running.
- RSVP will allow an operator to track crew members' vital signs with a maximum latency of 0.5 minute.

Prior to the FY01 demonstration, workup tests were conducted on board the ex-USS SHADWELL. The workup tests reflected the fire and flood scenarios that were executed during the formal test phase of the demonstrations. The workup tests were executed during the same time period as the DC-ARM workup tests and in many cases were the same test scenario identified in the DC-ARM FY01 Test Plan. Workup tests were held between August 1 through August 31, 2001. The purpose of the work-ups was to refine the fire scenarios and to exercise the supervisory control systems. The FY01 Peacetime Demonstrations were held during September 10 through 14 and the FY01 Wartime Demonstrations were held during September 24 through 28, 2001. The RSVP remained onboard the SHADWELL because of ONR desire to have a second VIP demonstration onboard SHADWELL in February 2002.

5.3.2 Equipment Locations

The RSVP team provided 72 environmental sensor clusters, 1 structural sensor cluster and 10 PSM units and the RSVP watchstation. The HMS was installed on the SHADWELL's fire pump #2 but was not part of the formal testing. Depicted in Figure 143, Figure 144, and Figure 145 are the locations of the RSVP equipment onboard SHADWELL.

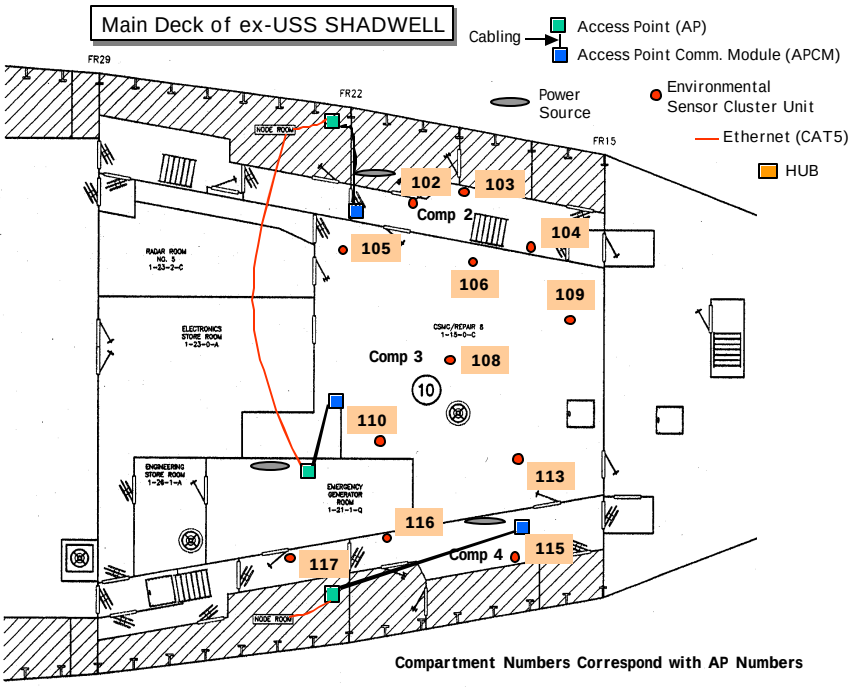


Figure 143 Main deck RSVP equipment locations

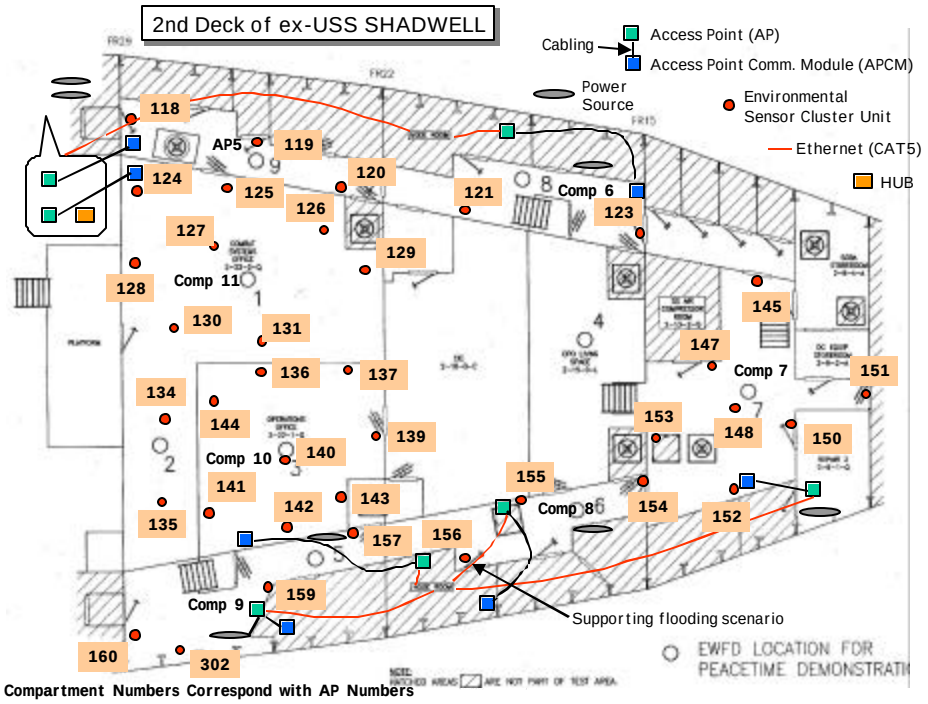


Figure 144 2nd Deck RSVP Equipment Locations

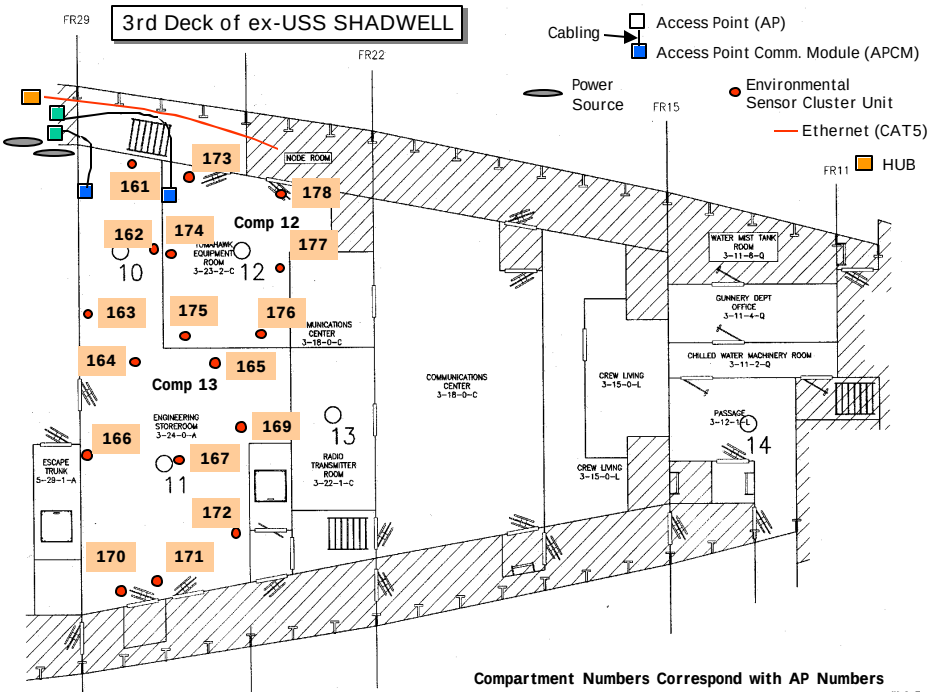


Figure 145 3rd Deck RSVP Equipment Locations

As mentioned previously the SHADWELL demonstration was broken into two phases, peacetime and wartime scenarios.

5.3.3 Peacetime Scenarios

The RSVP peacetime scenarios were a subset of the DC-ARM peacetime scenarios because the RSVP system was not installed in all of the compartments the DC-ARM equipment was installed in. For RSVP the peacetime scenarios included a computer monitor fire, a diesel engine exhaust, a smoldering electrical cables, a bedding fire and the grinding of metal. Over the next few pages the results from the various peacetime scenarios will be discussed.

Figure 146 and Figure 147 represent the test configuration and test results for the computer monitor fire. The location of all the RSVP equipment is identified as well as the location of the source. The observations that were made are included the table. Specific sensor cluster fire detection indexes are plotted also to illustrate what the sensor cluster "saw" during the test.

Computer Monitor w/ Cal Rod

Test Activity	Time	RSVP Information
Ignition	12:50	
Fire Announced; Rapid Response Team dispatched	12:54:19	Alert SC140
	12:55:14	Alarm SC140 & SC142
Fire Extinguished by Rapid Response Team	12:56	
	12:56:05	Alarm SC140, SC141 & SC142

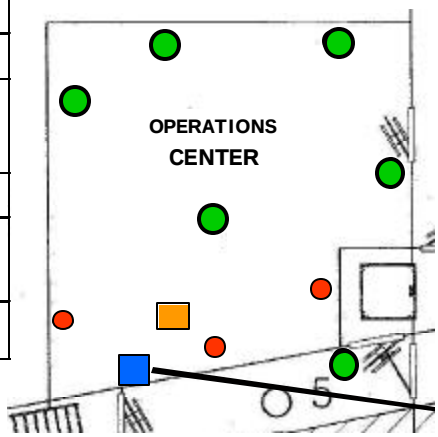


Figure 146 Computer Monitoring Fire Test Setup

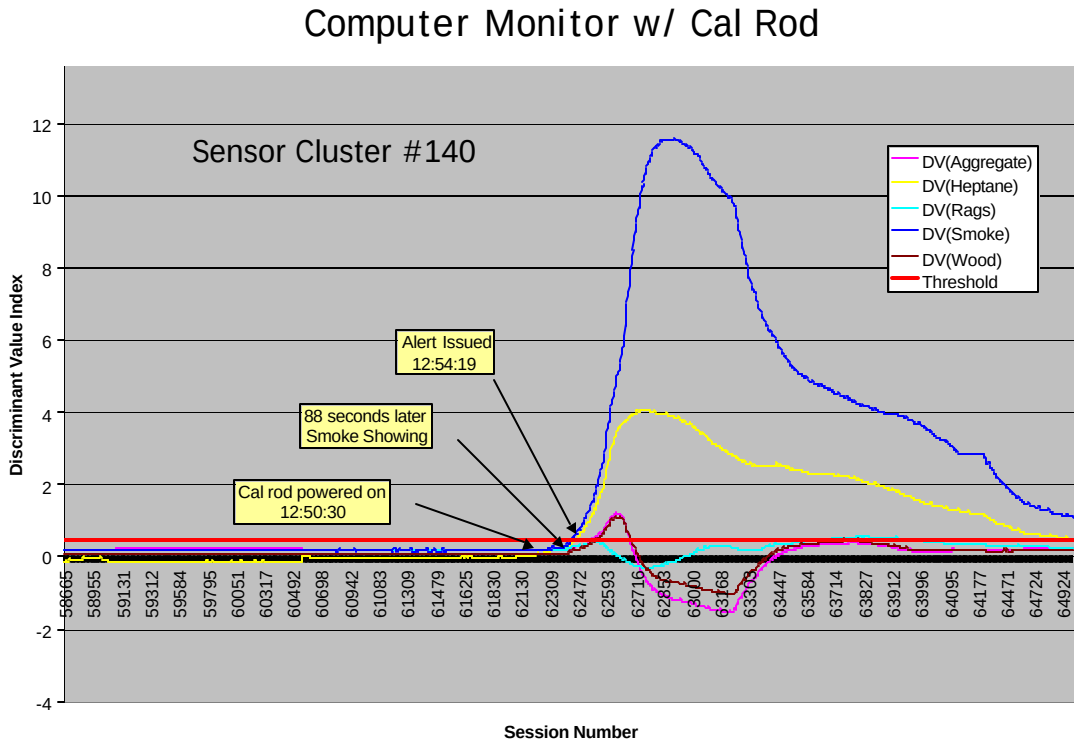


Figure 147 Sensor Cluster #140 Fire Detection Indexes

During the test the voltage to the cal rod had to be increased due to the minimal effect the lower voltage had at starting the fire. Because of his the detection time was rather long but still within the 5 minute detection requirement.

Figure 148 and Figure 149 represent the test configuration and test results for the diesel engine exhaust scenario. The location of all the RSVP equipment is identified as well as the location of the source. The observations that were made are included the table. Specific sensor cluster fire detection indexes are plotted also to illustrate what the sensor cluster “saw” during the test.

Diesel Engine Exhaust

Test Activity	Time	RSVP Information
Initiate	12:50	
	12:54:20	TBD
	12:57:28	Alert SC172
	12:58:33	Alarm SC166 & SC172
Terminate	TBD	

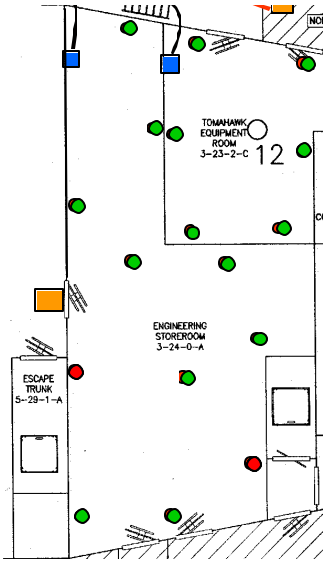


Figure 148 Diesel Engine Exhaust Test Setup

Diesel Engine Exhaust

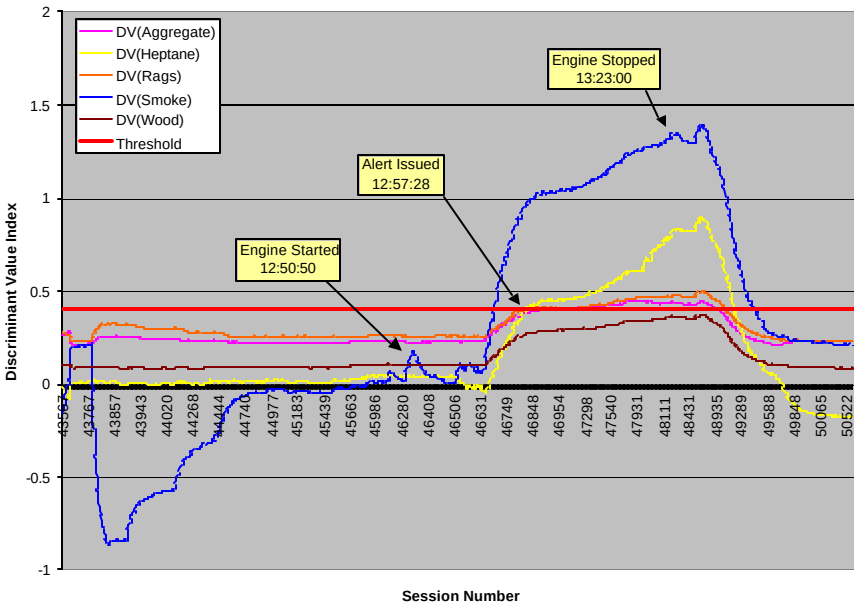


Figure 149 Sensor Cluster #172 Fire Detection Indexes

After seven minutes of run time the compartment was fully engulfed with a light smoke from the generator, which is what lead the sensor cluster alert condition. Even tough the there was no actual fire the detection algorithm did detected a dangerous condition and notified the watchstander.

Figure 150 and Figure 151 represent the test configuration and test results for the smoldering electrical cable scenario. The location of all the RSVP equipment is identified as well as the location of the source. The observations that were made are included the table. Specific sensor cluster fire detection indexes are plotted to illustrate what the sensor cluster "saw" during the test.

Smoldering Electrical Cable

Test Activity	Time	RSVP Information
Cal rod set to 50 V	13:55	
Cal rod set to 60 V	14:05	
Visible smoke	14:17	
	14:20:43	Alert SC178
Fire reported	14:32:45	
Extinguished	14:34:30	

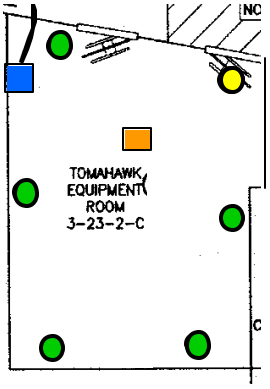


Figure 150 Smoldering Electrical Cable Test Setup

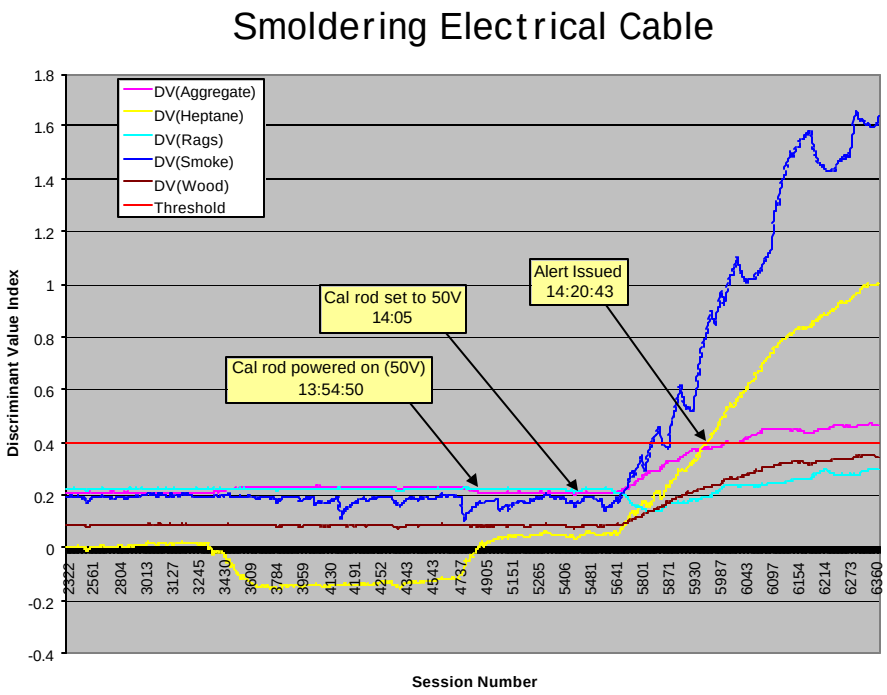


Figure 151 Sensor Cluster #178 Fire Detection Indexes

Similar to the computer monitor fire test, the cal rod was set a low voltage, which basically heated up the cable. The cal rod voltage was increased which resulted in smoke coming from the cable bundle, within 3 minute the sensor cluster issued an alert which is within the RSVP requirement of 5 minutes.

Figure 152 and Figure 153 represent the test configuration and test results for the bedding fire. The location of all the RSVP equipment is identified as well as the location of the source. The observations that were made are included the table. Specific sensor cluster fire detection indexes are plotted to illustrate what the sensor cluster “saw” during the test.

Bedding Fire

Test Activity	Time	RSVP Information
Ignition	13:03	
Visible Flame, smoke	13:04	
	13:03:21	Alert SC140
	13:04:51	Alarm SC136, SC139 & SC140
	13:05:26	Alarm SC142
	13:06	Another Alarm SC142

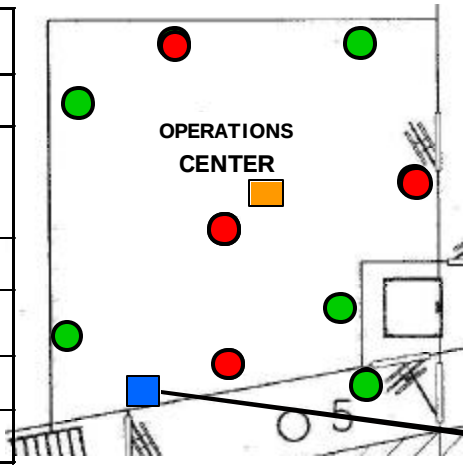


Figure 152 Bedding Fire Test Setup

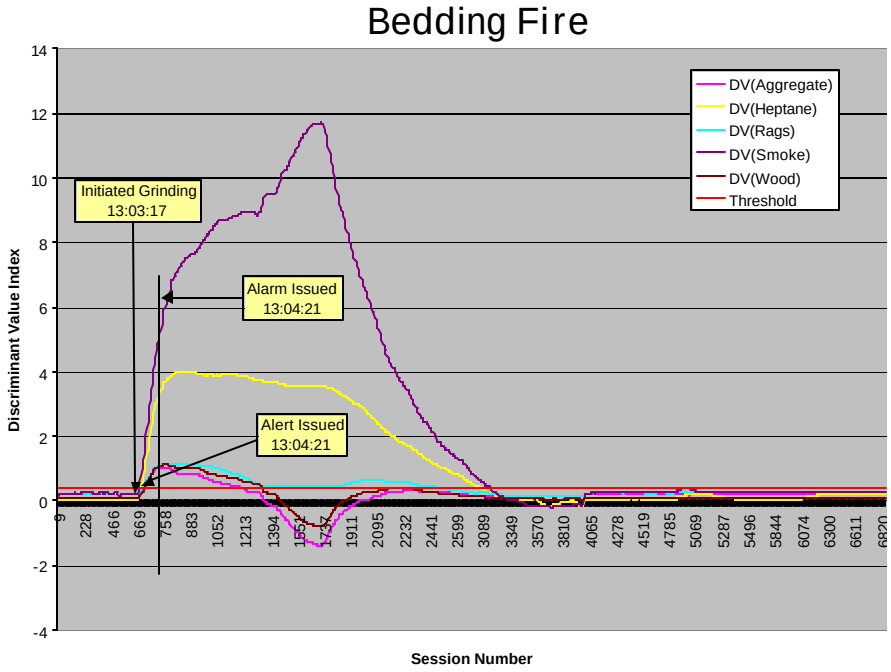


Figure 153 Sensor cluster #140 fire detection indexes

Within 21 seconds a sensor cluster issued an alert condition and within 110 seconds three sensor clusters issued alerts. All of which was within the RSVP requirement of 5 minutes.

Figure 154 and Figure 155 represent the test configuration and test results for the grinding of metal scenario. The location of all the RSVP equipment is identified as well as the location of the source. The observations that were made are included the table. Specific sensor cluster fire detection indexes are plotted to illustrate what the sensor cluster "saw" during the test.

Grinding

Test Activity	Time	RSVP Information
Initiate	13:03	
	13:06	Alert SC169
	13:08:43	Alarm SC169 & SC172
	13:10	Another Alarm SC167
Terminate	13:11	

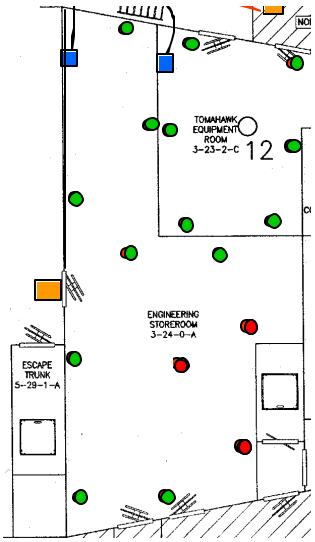


Figure 154 Grinding Test Setup

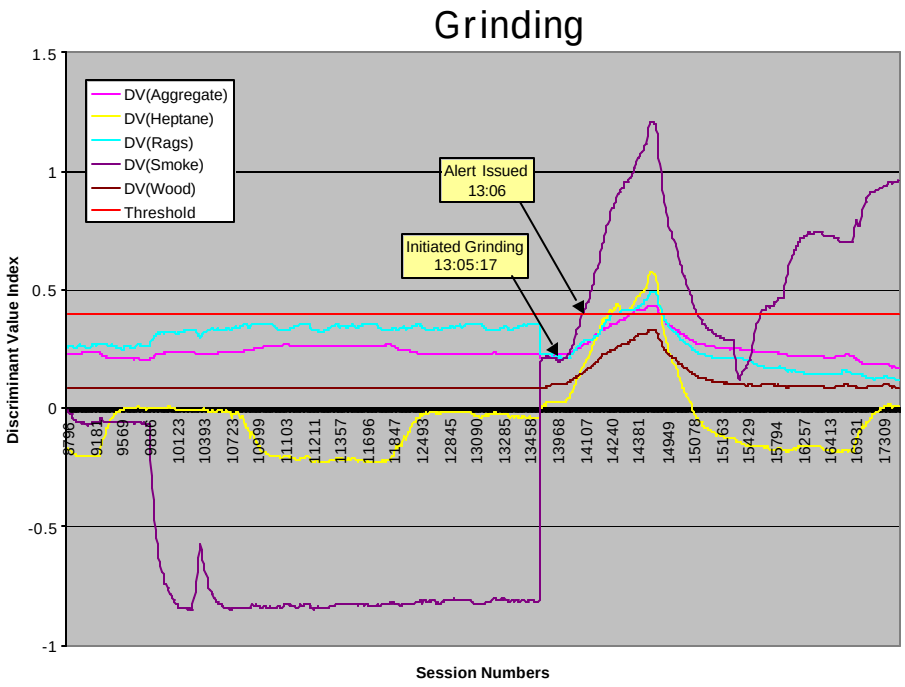


Figure 155 Sensor Cluster #169 Fire Detection Indexes

The grinding of metal was most difficult situation to discriminate against. After close to 4 minutes of grinding on metal the compartment environmental conditions were very close to the conditions that seen by a real fire. The significant amount of sparks and smoke made the grinding resembled a bedding of wood type of fire.

5.3.4 Wartime Scenarios

RSVP will leveraged the wartime fire scenarios identified in Section 4.3 of the DC-ARM FY01 Test Plan. RSVP will monitor a subset of the fire fighting team(s) for physiological adversity and location within the port and starboard passageways between frames 15 and 29 on the main and second decks. Even though the RSVP equipment is not high temperature tolerant a certain subset of the RSVP equipment were located in some of compartments during the wartime scenarios. The compartments had “adjacent to primary damage area” type fires where the temperature would be less likely to reach 65°C, the threshold for the water mist system. Steps were taken to mitigate the impact of the water mist system if it were to be activated in these specific compartments.

Figure 156 describes the layout of the Tomahawk Equipment room. Identified are the locations of the RSVP equipment and the source location. The situation that will be discussed now was part of the VIP demonstration scenario that was held on September 26, 2001. Similar result exist for the other similar RSVP compartments.

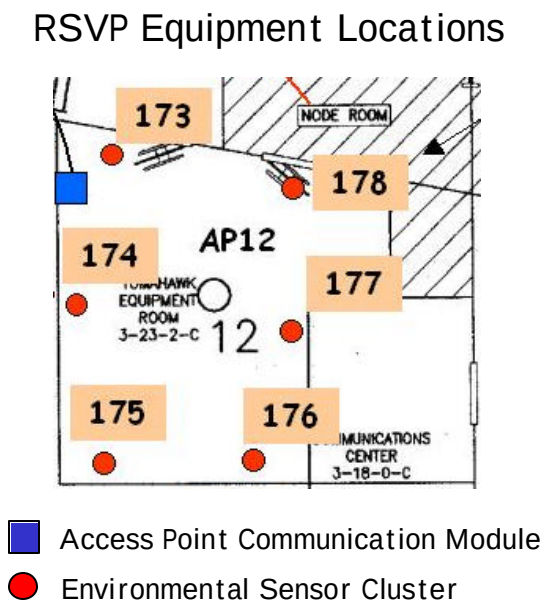


Figure 156 Tomahawk Equipment Room Layout

Figure 157 represents the messages being sent to the RSVP watchstation. The messages are being generated based on the output of the compartment-level fire detection

algorithm. As you can see the duration of the situation and whose contributing to the detection of the situation is being sent to the watchstation.

Tomahawk Equipment Room Messages

```
09/26 13:26:45.928 Comp: 3 Inst: 30000 Type: 2 Dur:  1:22 Min Fire alarm 106 108 109
09/26 13:26:50.620 Comp:13 Inst:130000 Type: 2 Dur: 11:14 Min Fire alarm 162 170 171 172
09/26 13:26:55.810 Comp:11 Inst:110000 Type: 1 Dur:  0.0 Sec Fire alert 125
09/26 13:27:01.443 Comp:12 Inst:120000 Type: 1 Dur:  0.0 Sec Fire alert 176
09/26 13:27:05.622 Comp:13 Inst:130000 Type: 2 Dur: 11:29 Min Fire alarm 162 170 171 172
09/26 13:27:09.872 Comp: 3 Inst: 30000 Type: 2 Dur:  1:46 Min Fire alarm 106 108 109
09/26 13:27:10.812 Comp:11 Inst:110000 Type: 1 Dur: 16.0 Sec Fire alert 125
09/26 13:27:16.443 Comp:12 Inst:120000 Type: 2 Dur: 15.0 Sec Fire alarm 174 176 178
09/26 13:27:20.622 Comp:13 Inst:130000 Type: 2 Dur: 11:44 Min Fire alarm 162 170 171 172
09/26 13:27:24.874 Comp: 3 Inst: 30000 Type: 2 Dur:  2:01 Min Fire alarm 106 108 109
09/26 13:27:30.811 Comp:11 Inst:110000 Type: 2 Dur: 36.0 Sec Fire alarm 124 125
09/26 13:27:36.443 Comp:12 Inst:120000 Type: 2 Dur: 35.0 Sec Fire alarm 174 175 176 178
09/26 13:27:39.876 Comp: 3 Inst: 30000 Type: 2 Dur:  2:16 Min Fire alarm 106 108 109
09/26 13:27:40.622 Comp:13 Inst:130000 Type: 2 Dur: 12:04 Min Fire alarm 162 170 171 172
09/26 13:27:45.812 Comp:11 Inst:110000 Type: 2 Dur: 51.0 Sec Fire alarm 124 125
09/26 13:27:54.878 Comp: 3 Inst: 30000 Type: 2 Dur:  2:31 Min Fire alarm 106 108 109
```

Note: All messages being published from there respective compartments.

Figure 157 Compartment-Level Messages Being Sent To The RSVP Watchstation

Specific sensor cluster fire detection indexes for Sensor Cluster #176 can be found in Figure 158. The plot illustrates what the sensor cluster "saw" during the test.

Sensor Cluster Fire Detection Models

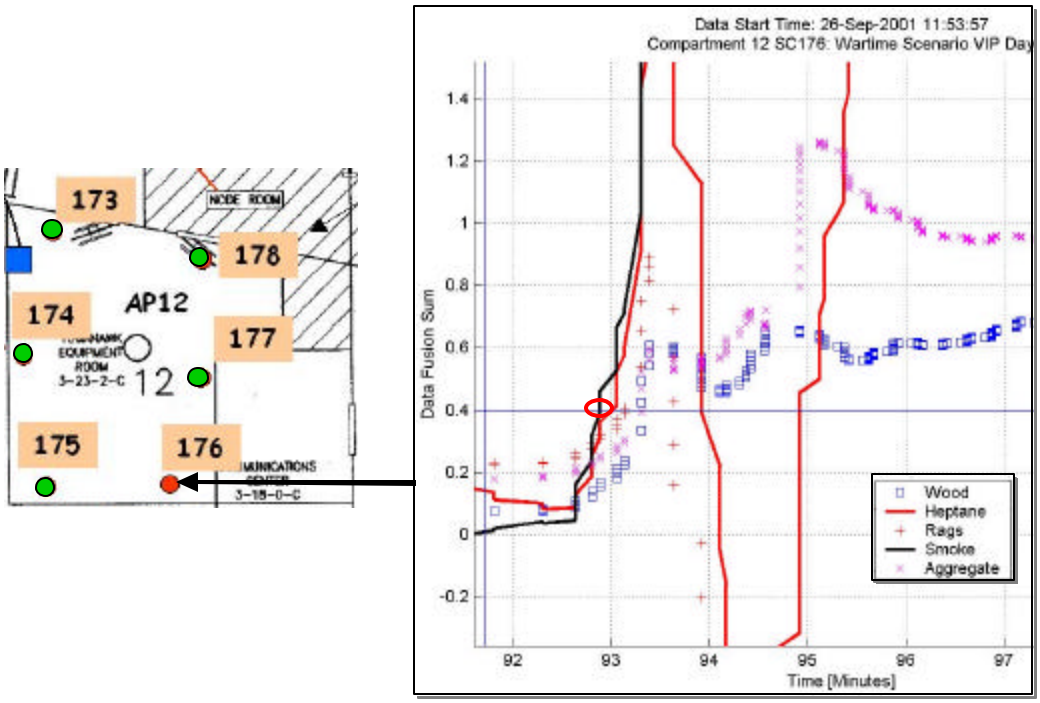


Figure 158 Sensor Cluster S/N #176 Fire Detection Indexes

Figure 159 illustrates the evolution of the fire that took place in the Tomahawk Equipment room.

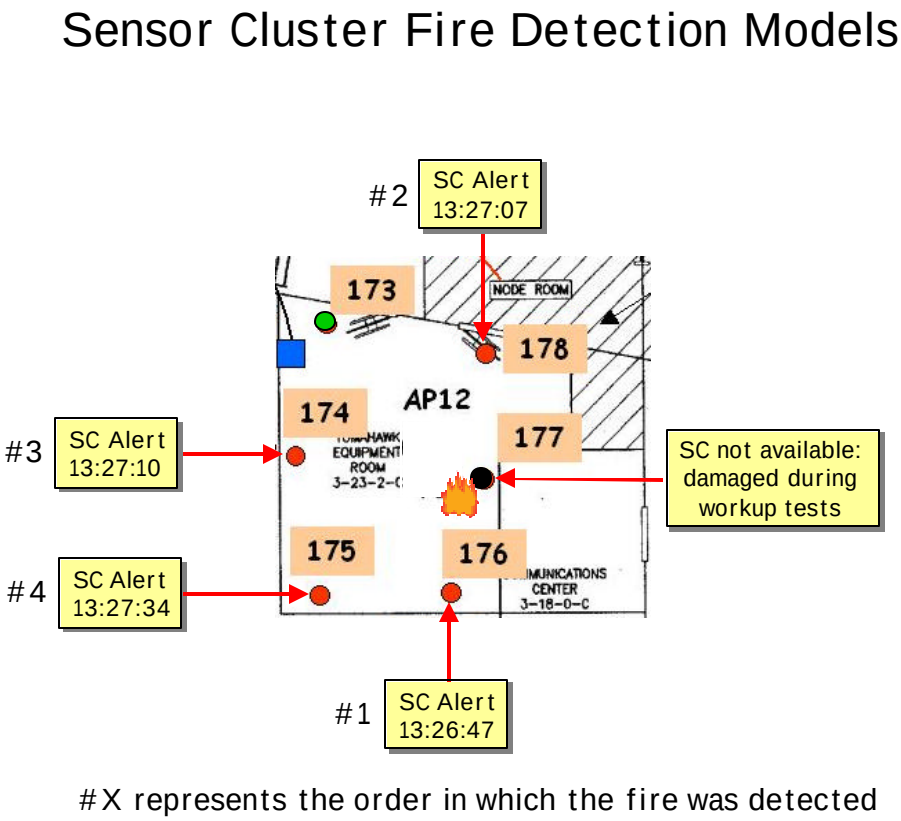


Figure 159 Fire Evolution Illustration

5.3.4.1 Personnel – Physiological Status

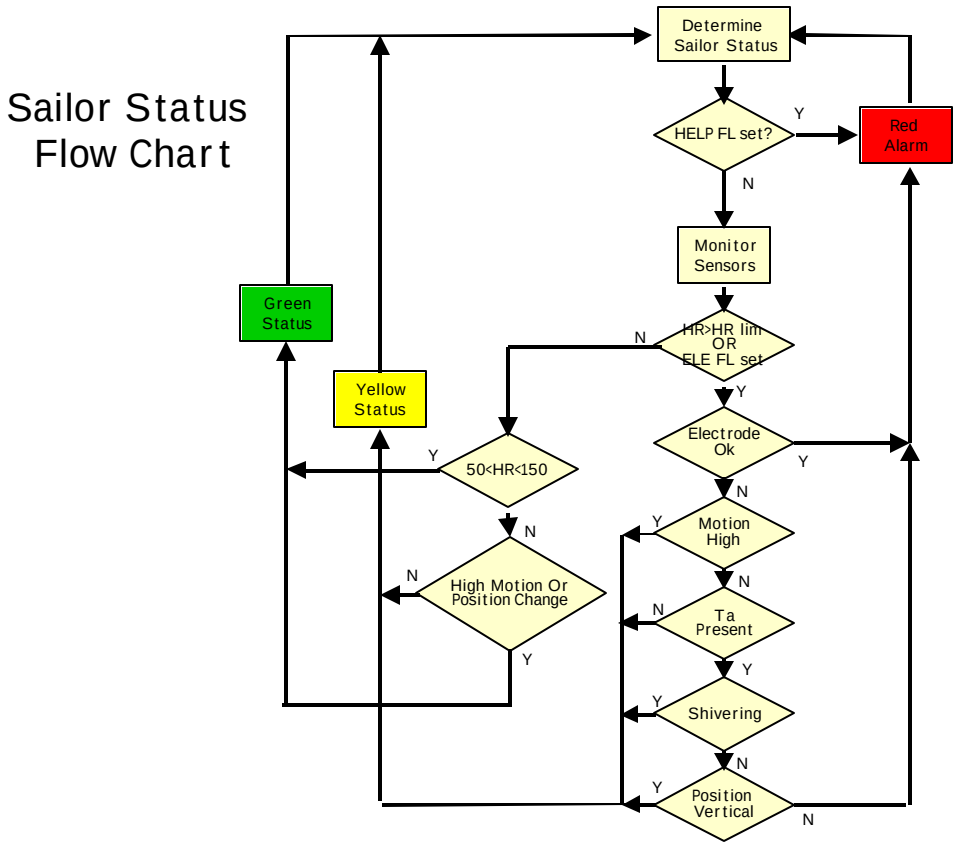


Figure 160 PSM's physiological Status Algorithm

PSM RED Alarm

```
SN 0x40000004 AP 4012 COMP c 12 28 27.5 CST 0 IST 0 PST 3 ORIENT 0 Motion 1 PANIC 1 ELE 0 SHIVER 0 PULSE 162 ATemp 46
SN 0x40000004 AP 4012 COMP c 12 28 39.8 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 80 ATemp 30
SN 0x40000004 AP 4012 COMP c 12 28 47.4 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 80 ATemp 30
SN 0x40000004 AP 4012 COMP c 12 28 48.4 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 80 ATemp 30
SN 0x40000004 AP 4012 COMP c 12 28 54.8 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 84 ATemp 35
SN 0x40000004 AP 4012 COMP c 12 28 54.8 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 84 ATemp 35
SN 0x40000004 AP 4012 COMP c 12 28 54.8 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 84 ATemp 35
SN 0x40000004 AP 4012 COMP c 12 32 29.5 CST 0 IST 0 PST 3 ORIENT 0 Motion 0 PANIC 1 ELE 0 SHIVER 0 PULSE 90 ATemp 31
```

CIU Panic button pressed resulting in a RED alarm

Figure 161 PSM Red Alarm

PSM YELLOW Alert

```
SN 0x40000002 AP 4009 COMP 9 14 5 27.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 34
SN 0x40000002 AP 4009 COMP 9 14 5 42.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 34
SN 0x40000002 AP 4009 COMP 9 14 5 57.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 34
SN 0x40000002 AP 4009 COMP 9 14 6 27.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 34
SN 0x40000002 AP 4009 COMP 9 14 6 42.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 34
SN 0x40000002 AP 4009 COMP 9 14 14 27.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 35
SN 0x40000002 AP 4009 COMP 9 14 14 42.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 36
SN 0x40000002 AP 4009 COMP 9 14 14 57.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 36
SN 0x40000002 AP 4009 COMP 9 14 21 27.2 CST 0 IST 0 PST 2 ORIENT 0 Motion 0 PANIC 0 ELE 1 SHIVER 0 PULSE 210 ATemp 36
```

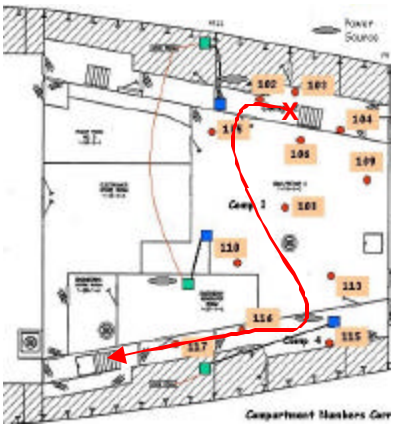
Improper ISU electrode contact resulting in a YELLOW alert

Figure 162 PSM Yellow Alert

5.3.4.2 Personnel – Location Determination

As in the MONTEREY demonstration the ability to determine a sailor's location within the ship has been identified as a desired feature especially in a minimally manned ship. For SHADWELL we are interest in tracking the sailor has he moves from compartment to compartment in the RSVP test area. Over the next few pages the results of the location determination algorithm will be presented. It should be noted that a ship survey was required to calibrate the algorithm so that the algorithm could discriminate from one compartment from the adjacent compartment.

Location Determination on the Main Deck



Location Determination Algorithm at Watchstation

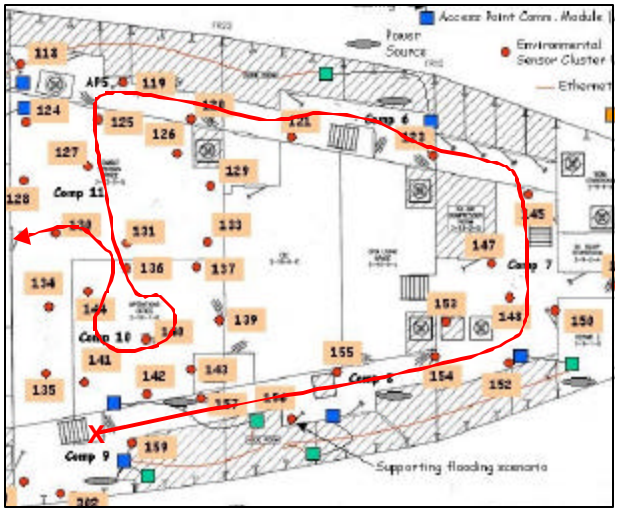
```
==>Compartment:2 (SN:2, Green , RSSI:79)
09/14 11:58:27.810 Sailor: 2 Msg:  5 RSSI: 77 AP:02
09/14 11:58:27.744 Sailor: 2 Msg:  5 RSSI: 92 AP:04
09/14 11:54:33.020 Sailor: 2 Msg:  5 RSSI: 79 AP:03
09/14 11:58:27.874 Sailor: 2 Msg:  5 RSSI: 65 AP:07
==>Compartment:3 (SN:2, Green , RSSI:94)
==>Compartment:3 (SN:2, Green , RSSI:94)
==>Compartment:3 (SN:2, Green , RSSI:94)
09/14 11:58:42.845 Sailor: 2 Msg:  6 RSSI:105 AP:04
==>Compartment:4 (SN:2, Green , RSSI:105)
==>Compartment:4 (SN:2, Green , RSSI:105)
==>Compartment:4 (SN:2, Green , RSSI:105)
09/14 11:54:58.617 Sailor: 2 Msg:  7 RSSI: 80 AP:03
```

Test Summary

PSM Test 9/14/01 Route Comp	Time	Deck
2	11:57:10	Main
3	11:57:50	Main
4	11:58:35	Main
9	11:59:45	2nd
8	12:00:20	2nd
7	12:02:00	2nd
6	????????	2nd
5	12:03:08	2nd
11	12:03:50	2nd
10	12:05:45	2nd
11	12:06:36	2nd
13	12:07:15	3rd
12	12:08:03	3rd
13	12:08:46	3rd
Exit	12:09:30	3rd

Figure 163 Results Of Sailor Tracking On The Main Deck

Location Determination on the 2nd Deck



Test Summary

PSM Test 9/14/01
Route

Comp	Time	Deck
2	11:57:10	Main
3	11:57:50	Main
4	11:58:35	Main
9	11:59:45	2nd
8	12:00:20	2nd
7	12:02:00	2nd
6	????????	2nd
5	12:03:08	2nd
11	12:03:50	2nd
10	12:05:45	2nd
11	12:06:36	2nd
13	12:07:15	3rd
12	12:08:03	3rd
13	12:08:46	3rd
Exit	12:09:30	3rd

Figure 164 Results Of Sailor Tracking On The 2nd Deck

Location Determination on the 2nd Deck

```
==>Compartment:9 (SN:2, Green , RSSI:97)
==>Compartment:9 (SN:2, Green , RSSI:97)
==>Compartment:9 (SN:2, Green , RSSI:112)
==>Compartment:9 (SN:2, Green , RSSI:112)
==>Compartment:9 (SN:2, Green , RSSI:112)
==>Compartment:8 (SN:2, Red   , RSSI:115)
==>Compartment:8 (SN:2, Red   , RSSI:110)
==>Compartment:8 (SN:2, Red   , RSSI:96)
==>Compartment:8 (SN:2, Red   , RSSI:93)
==>Compartment:7 (SN:2, Green , RSSI:108)
==>Compartment:7 (SN:2, Green , RSSI:108)
==>Compartment:7 (SN:2, Green , RSSI:108)
==>Compartment:7 (SN:2, Green , RSSI:69)
==>Compartment:7 (SN:2, Green , RSSI:69)
==>Compartment:7 (SN:2, Green , RSSI:69)
==>Compartment:5 (SN:2, Green , RSSI:96)
==>Compartment:5 (SN:2, Green , RSSI:96)
==>Compartment:5 (SN:2, Green , RSSI:96)
==>Compartment:5 (SN:2, Green , RSSI:96)
==>Compartment:10 (SN:2, Green , RSSI:97)
==>Compartment:10 (SN:2, Red   , RSSI:92)
==>Compartment:10 (SN:2, Red   , RSSI:100)
==>Compartment:11 (SN:2, Red   , RSSI:150)
==>Compartment:11 (SN:2, Red   , RSSI:151)
==>Compartment:10 (SN:2, Red   , RSSI:72)
==>Compartment:11 (SN:2, Red   , RSSI:150)
==>Compartment:10 (SN:2, Red   , RSSI:93)
==>Compartment:10 (SN:2, Red   , RSSI:91)
==>Compartment:11 (SN:2, Red   , RSSI:151)
==>Compartment:11 (SN:2, Red   , RSSI:151)
==>Compartment:11 (SN:2, Red   , RSSI:151)
==>Compartment:10 (SN:2, Green , RSSI:105)
==>Compartment:10 (SN:2, Green , RSSI:105)
==>Compartment:10 (SN:2, Green , RSSI:105)
==>Compartment:11 (SN:2, Green , RSSI:150)
==>Compartment:11 (SN:2, Green , RSSI:150)
```

Panic button pressed and then reset

Compartment 6 was not picked up.
- Possibly:
  - Sailor moving quickly
  - Blocked CUI communication
  - AP/APCM not working

Panic button pressed and then reset

Figure 165 Graphic of sailor tracking on the 2nd Deck

Location Determination on the 3rd Deck

Test Summary

PSM Test 9/14/01
Route

Comp	Time	Deck
2	11:57:10	Main
3	11:57:50	Main
4	11:58:35	Main
9	11:59:45	2nd
8	12:00:20	2nd
7	12:02:00	2nd
6	????????	2nd
5	12:03:08	2nd
11	12:03:50	2nd
10	12:05:45	2nd
11	12:06:36	2nd
13	12:07:15	3rd
12	12:08:03	3rd
13	12:08:46	3rd
Exit	12:09:30	3rd

Location Determination Algorithm at Watchstation

```
==>Compartment:13 (SN:2, Green , RSSI:84)
==>Compartment:13 (SN:2, Green , RSSI:98)
==>Compartment:13 (SN:2, Green , RSSI:100)
==>Compartment:13 (SN:2, Green , RSSI:95)
==>Compartment:13 (SN:2, Green , RSSI:99)
==>Compartment:13 (SN:2, Green , RSSI:99)
==>Compartment:13 (SN:2, Green , RSSI:99)
==>Compartment:12 (SN:2, Green , RSSI:93)
==>Compartment:12 (SN:2, Green , RSSI:82)
==>Compartment:12 (SN:2, Green , RSSI:82)
==>Compartment:13 (SN:2, Green , RSSI:102)
==>Compartment:13 (SN:2, Green , RSSI:102)
==>Compartment:13 (SN:2, Green , RSSI:0)
```

Left Compartment #13

Figure 166 Results Of Sailor Tracking On The 3rd Deck

5.3.4.3 Flood Detection

The flood detection algorithm was demonstrated in starboard passageway on the 2nd deck. Sensor Cluster #156's pipette was used to measure the water depth. The flooding was a result of a simulated pipe burst. The flooding alert threshold was set to 1" of water. Due to the fact I only one pipette was used in the test the RSVP system is only going to issue an alert condition, had a second pipette been used then an ALARM conditions would have been issued once both reading were over the 1" level. The results from the flooding scenario are shown in Figure 167.

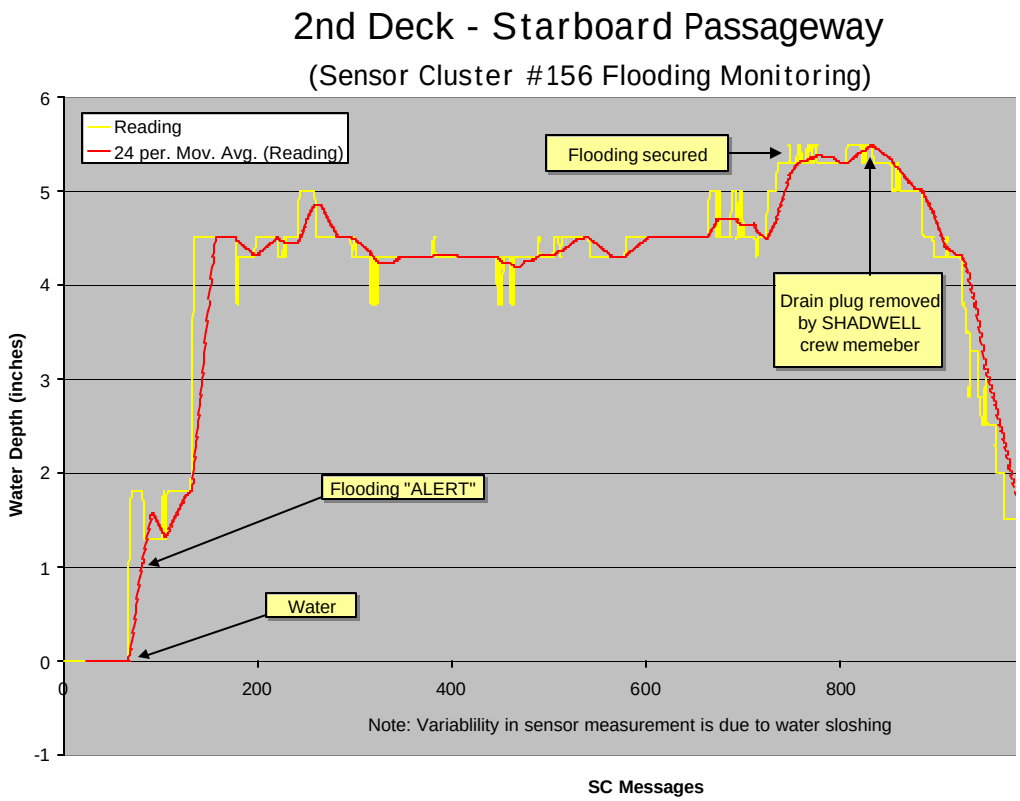


Figure 167 Sensor Cluster #156 Flooding Data

6.0 Additional Results

6.1 Manning Analysis

6.1.1 Manning Reductions

RSVP tasked Carlow, Inc to conduct a third phase of the Manning Analysis for RSVP. The objective of the effort was to address workload/manpower reduction issues, and apply Human Systems Integration (HSI) methods to assess usability of the RSVP operator interface.

In a previous Carlow report, "RSVP Manning Functional Analysis Study (MFAS)"[ref 3], baseline workload data for engineering control watchstanders under Condition III steaming and for damage control personnel during a fire and flood scenario were used to estimate workload reduction due to introduction of RSVP. In both cases, previous analyses of workload associated with the existing designs were reviewed and work load redistributed according to the functionality of RSVP and its ability to perform extensive ship monitoring, data analysis and fusion. The results included estimated workload reductions of:

- *73% for the Damage Control Administrator/DC team located in Damage Control Central for a fire and flood scenario aboard the DDG-51*

- *47% for personnel tasks performed in the machinery spaces aboard DDG-51 for each four-hour watch under condition III steaming.*

A considerable portion of the engineering control workload reduction noted above was due to assumed elimination of the need for roving equipment monitors to manually record machinery and environmental parameters during hourly or semi-hourly rounds in the engineering spaces. The capability of RSVP to automate this data collection effort was investigated.

The estimated workload/manpower reduction potential of RSVP assumed that much of the data recording workload currently performed by roving monitors in the machinery spaces could be eliminated using RSVP sensors, data collection and archiving. Roving monitors currently read local displays of machinery and environmental parameters and record these observations on standard data sheets during rounds in the engineering spaces. The issue was investigated of the engineering complexity involved in these observations and measurements.

In connection with RSVP usability testing aboard the USS MONTEREY (CG-61), copies of data collection sheets were obtained that were used by the roving monitors to record machinery parameters during rounds in the engineering spaces. The parameters recorded by roving monitors are listed in Appendix A. These were classified as follows:

- Visual observation of fluid level or condition using a sight glass
- Moisture
- Fluid level
- Discrete mode (e.g. ID of the pump currently on line where more than on is available)
- Air flow
- Time (e.g. cumulative run time for a component)
- Electrical current
- Pressure
- Temperature

Figure 168 shows the cumulative frequencies of the parameter types in ascending order of the estimated complexity of automatically measuring the parameter via sensors. Most of the parameter types present no problem and, in fact, are currently measured by the prototype RSVP system. Fluid level measurements in general are somewhat more complicated than are temperature, pressure, etc. Moisture determination would require assessment of water content. Measurements that currently use human observation of a sight glass would require analysis of the exact target property. Such observations often involve fluid level or fluid quality (e.g. contaminants in fuel or lubricating oil) and might be obtained by level or chemical analysis.

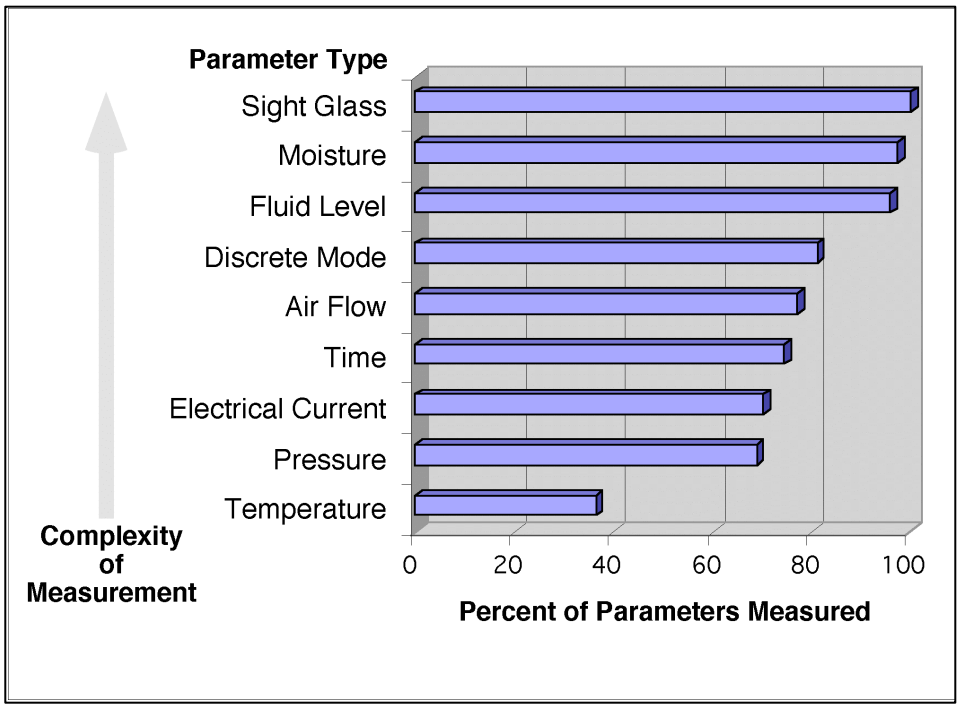


Figure 168 Roving Monitor Parameters

Figure 168 indicates the cumulative percent of all parameters that could be accommodated if the type in question and all less complex types could be measured. Measurements of temperature alone would accommodate about 35 percent of all parameters. Measurements of temperature and pressure would accommodate about 67 percent of all parameters. Measurements of parameters up and including fluid level would accommodate over 90 percent of all parameters and would very nearly obviate the need for hourly rounds by roving monitors. For complete results, refer to the "RSVP Manning Functional Analysis Phase III Report" [ref 15].

6.1.1.1 Usability Testing

Usability testing was conducted during the RSVP land-based and at at-sea demonstrations and test programs. Ship personnel who were familiar with engineering control activities used the RSVP watch station to step through the graphic user interface (GUI) and their comments were recorded. Walkthroughs/talkthroughs were conducted for the screens that were applicable to tasks and user comments, questions and issues were recorded. During the at-sea test, two participants commented on the screens. The test participants were Navy personnel who were familiar with engineering control activities.

User computer interface issues and recommendations were developed using the test participant comments and reviews of the screens by Carlow project personnel applying UCI design guidelines from the HSI and human factors literature. For the RSVP demonstrations and tests, the watchstation presented a stand alone RSVP GUI. This will probably not be the mode of implementation used when RSVP technology is integrated aboard future ships. The prototype RSVP GUI used for this project did not contain provisions for machinery control since RSVP was conceived and designed to fill a health monitoring function - not to support machinery control. Nevertheless, the GUI approach to navigation to screens associated with compartments, machines, etc. was considered to be quite effective.

An ideal engineering control or damage control workstation might include:

- The navigation facilities of RSVP as a top layer

- A second machinery control layer with screens similar to the RSVP overview data screens having buttons, pop-up menus, sliders and other interface widgets to control components

- RSVP detailed data screens, such as parameter time histories, as a third health monitoring and diagnosis layer

For complete results, refer to the "Manning Functional Analysis Phase III Report" [ref 15].

6.2 Value Analysis using the Process Analysis Toolkit for Affordability (PATA) – IPPD Analysis

6.2.1 Introduction

RSVP tasked James Gregory Associates to provide a Value Analysis RSVP based on the IPPD methodology. This analysis was conducted using test data collected during the demonstrations of the system. The following is an essential summary of the results. For the complete Value Analysis, refer to the "Value Analysis using the Process Analysis Toolkit for Affordability (PATA) Report on the Reduced Ship's-crew by Virtual Presence (RSVP) ATD" [ref 16].

Value is measured using two fundamental metrics, *desirability* and *risk*. It is assessed across all of the relevant areas (e.g. performance, cost, and schedule). All of these factors are weighted and brought simultaneously into the assessment. A *Value Analysis* requires that we quantitatively estimate the desirability and risk of one or more technologies, processes, or design concepts. As suggested by the nature of the desirability curve, it is driven by the customer's perspective. Risk is measured with respect to customer thresholds. The process itself involves building up various estimates using underlying requirements matrices and technology worksheets. The result is a *Value Scorecard* that contains values for desirability and risk that are traceable back to the original requirements, thresholds, and desirability curves.

6.2.2 Scope

Although requirements were collected for the production system to be fielded in CY 2008, we only focused on evaluating the requirements as defined for the ATD Demonstration. From this information we can now quantitatively estimate what it will take to transition the RSVP technology into the production system.

6.2.3 Objectives

The objectives of this Value Analysis were to:

- Evaluate the RSVP ATD Demonstration system in terms of desirability and risk.
- Identify cost drivers, technology shortfalls, and risk areas.
- Use the results of the value analysis to build the business case for transitioning the RSVP technology.

6.2.4 Approach

The RSVP Integrated Product Team (IPT) applied the Science and Technology (S&T) Integrated Product and Process Development (IPPD) Process on the RSVP ATD. (See Figure 169.)

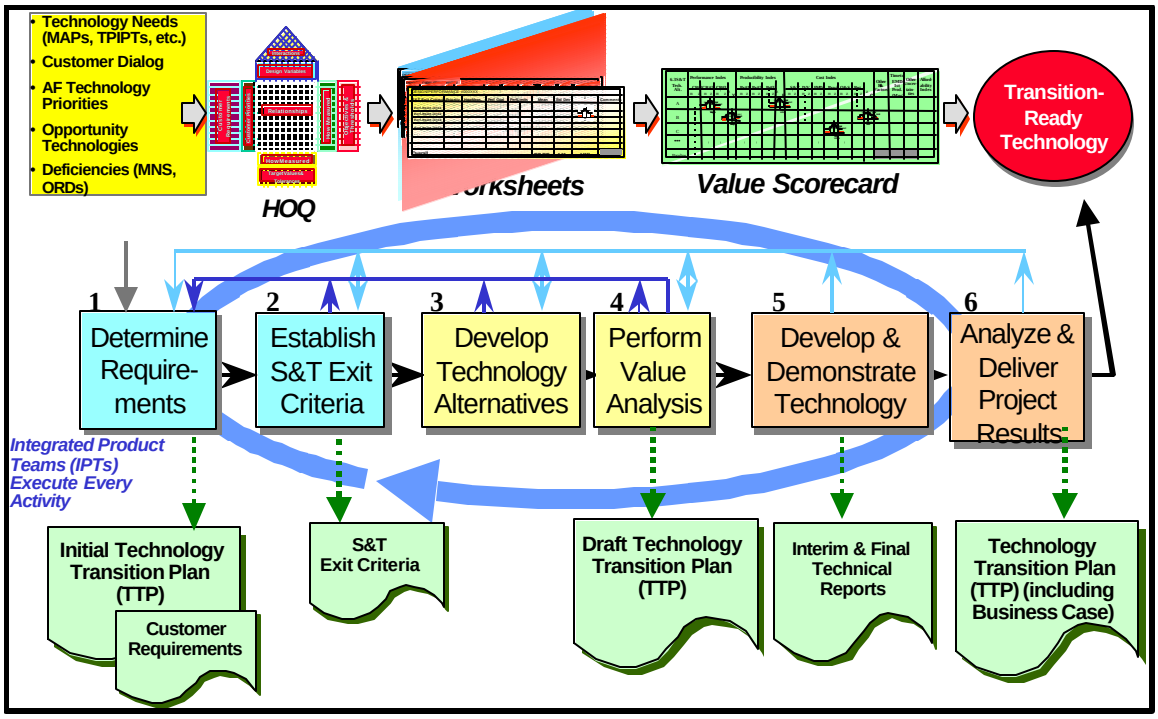


Figure 169 S&T IPPD Process

6.2.4.1 Requirements Determination

The IPT held several working sessions early in the program to accomplish the first activity of the IPPD process--Determine Requirements. IPPD begins with defining user requirements. The essential ingredient in any system design is the identification of complete, precise, unambiguous, and measurable user requirements, and that such an analysis is critical if the system design is to provide the *functionality* users demand and expect. Given a controlled set of user requirements to identify the essential system behavior that is required, one can design an optimal system, more quickly, and at less cost. The requirements gathering process is described in Section 2.2. To capture and manage the requirements for the RSVP ATD, the IPT used the Process Analysis Toolkit for Affordability (PATA). The complete IPPD Requirements are found in Table 1.

6.2.4.2 Desirability Functions

One of the most powerful tools used in the S&T IPPD Process is the desirability function. One of the important benefits of thinking about requirements in terms of desirability is that it promotes discussion with the customer concerning threshold negotiation. Thus, it helps the team reach consensus on the real requirement—the “must have” rather than the “nice to have.” Figure 170 shows an example RSVP desirability curve from the PATA toolkit. Notice that desirability ranges from 0 to 1 (or 0 to 100%) and is a function of the response to a given requirement. In this case, the response is "Fire Detection" and it is measured in "Percentage Detection w/in 5 mins." For the requirement shown in Figure 170, the RSVP IPT decided that they would be extremely pleased with a 100% detection rate, and that a system that has a detection rate less than 95% is undesirable.
The RSVP IPT constructed desirability curves for each requirement. We used these curves and the associated requirement weights to calculate the desirability of the RSVP Technology.

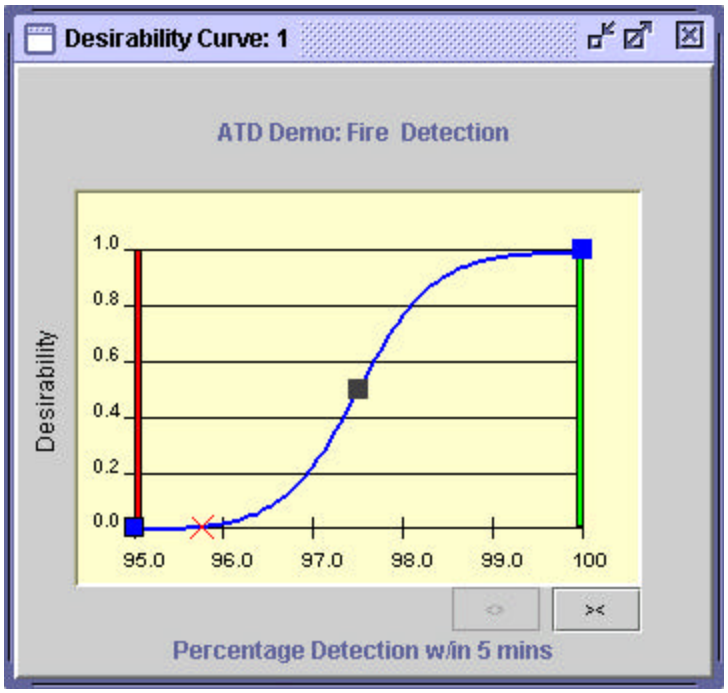


Figure 170 Sample RSVP Desirability Curve

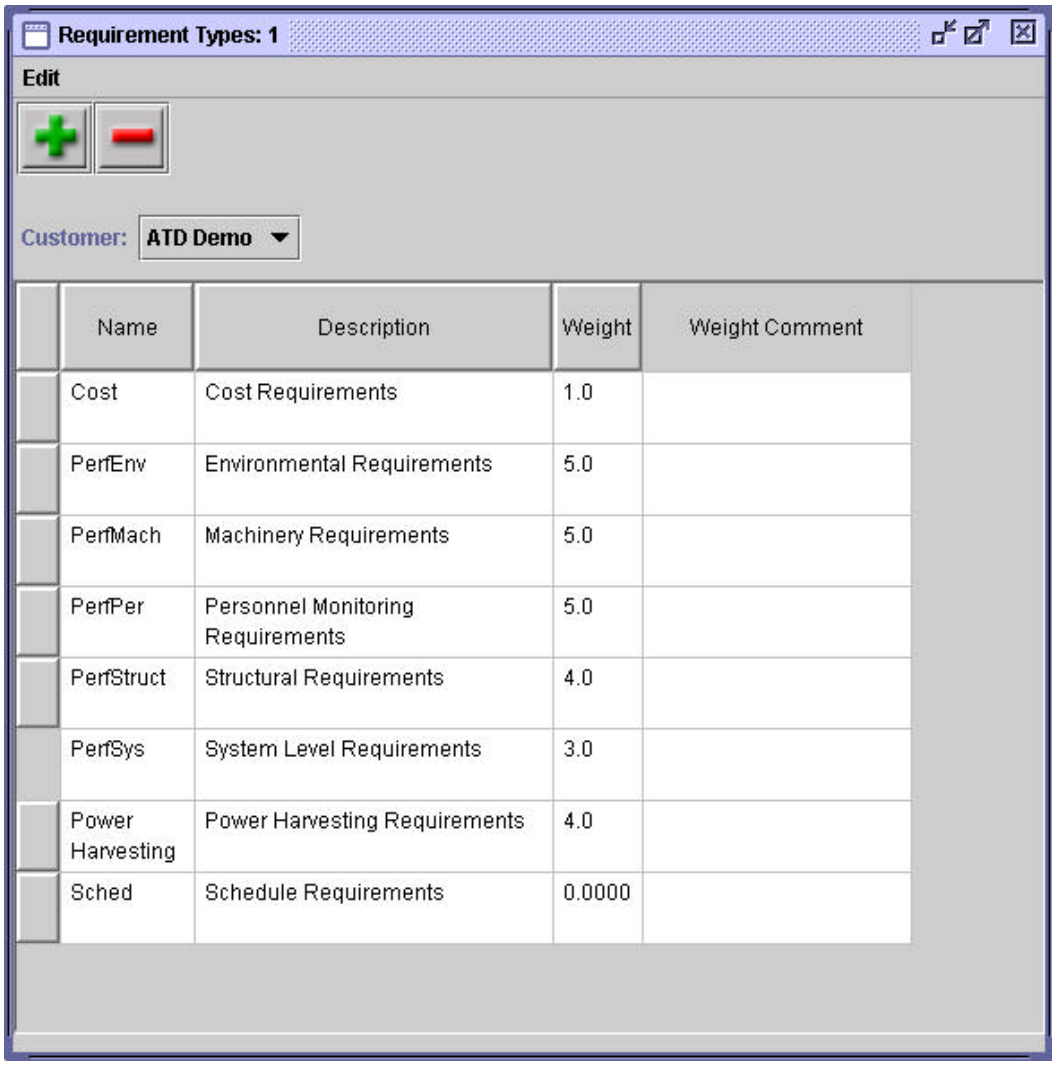
6.2.4.3 Demonstration and Data Collection

The RSVP IPT conducted a series of demonstrations of the RSVP technology. Data was collected according to the test plan. We used this data to assess the RSVP technology against the exit criteria in terms of desirability and risk.

6.2.4.4 Value Analysis

RSVP performed a Value Analysis and conducted an assessment of how well the RSVP technology had met the requirements for the ATD Demo customer.

Value analysis involves the systematic assessment of the relative value of a technology or design concept. The assessment is performed using *Value Analysis Worksheets.* For RSVP, we populated seven worksheets, one for each of the requirement types shown in Figure 171, except "Schedule." The only requirement in this type was to conduct the RSVP ATD Demo by the end of 2001. This requirement was met and was therefore not a discriminator in the analysis.



Name	Description	Weight	Weight Comment
Cost	Cost Requirements	1.0	
PerfEnv	Environmental Requirements	5.0	
PerfMach	Machinery Requirements	5.0	
PerfPer	Personnel Monitoring Requirements	5.0	
PerfStruct	Structural Requirements	4.0	
PerfSys	System Level Requirements	3.0	
Power Harvesting	Power Harvesting Requirements	4.0	
Sched	Schedule Requirements	0.0000	

Figure 171 RSVP Requirement Types and Weights

We used the PATA worksheets to capture the assessment of the RSVP technology against the ATD Demo requirements. Once the data was entered into PATA, the weighted geometric mean was used to compute the desirability of the RSVP technology. Desirability was first computed for each requirement, then for each requirement type, and finally rolled into the overall desirability, known as the Customer Satisfaction Index (CSI). Risk was measured with respect to the ATD Demo thresholds. For each requirement we computed the probability of failing to meet the established threshold. We then computed the overall risk of failing to meet at least one of the thresholds for all of the requirements of a particular type.

For each requirement, an expected value and a standard deviation were captured. The expected value and standard deviation were obtained from actual RSVP Demo test data and/or expert opinion. Once entered into the worksheet, the PATA calculated the risk for each requirement based on the threshold, expected value, and standard deviation. The

PATA also calculated the desirability for each requirement based on the expected value and customer-defined desirability curve.

The information in the worksheets was then used to generate a Value Scorecard. The scorecard contains all of the results of the value analysis in terms of the RSVP technology answered the ATD Demo requirements. The remainder of this section presents the results of the Value Analysis.

6.2.4.5 Technology Worksheets

The seven Technology Worksheets are presented and discussed in the following sections. To become familiar with the content and format of the worksheet, refer to Figure 172 below. Note the column headings for the worksheet. The "Requirement", "How Measured", "Objective", Threshold", and "Weight" columns were populated early in the program during requirements determination. We entered "Expected Value" and "Standard Deviation" values that were obtained from actual RSVP demonstration test data and /or expert opinion. The individual "Zeta" and "Desirability" values were computed by the PATA after we entered the expected values and standard deviations. The last row in the worksheet shows the total Zeta and total Desirability. Zeta and Desirability are computed in the PATA using equations 1 - 3 shown above.

Note that desirability ranges from 0 to 1 with values closer to 1 being preferable. Risk also ranges from 0 to 1 but values closer to 0 are preferable since we view risk as the probability of not meeting a threshold value.

6.2.4.6 Cost Worksheet

Figure 172 shows the ATD Demo Cost Worksheet. The total Zeta is 0.06494 and the total desirability is 0.49. This Zeta is not high, but the desirability is somewhat low. By looking at the individual requirements in the worksheet, we see that three of them are contributing to the low desirability--Reduce Manhours, O&S Costs (Crew), and O&S Cost of RSVP. Notice that these three are weighted as the most important cost requirements and their individual desirabilities were the lowest of all the requirements. When the overall desirability for cost was computed using the weighted geometric mean, these high weights coupled with the low desirabilities caused the overall desirability to go down. It should be noted that the RSVP technology is still desirable from a cost perspective since it is meeting all of the thresholds. But there is room for improvement and the analysis points to these three requirements as place to look to make improvements.

Worksheet: 1

Risk Estimation

Type: Cost

Customer: ATD Demo

Technology: Wireless

Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability	Comments
38: Reduce Manhours	Percent Manhours/year/ship	10.0	5.0		7.0	1.0	0.02272	5.0	0.40	
39: Installation Costs	Dollars (M)	5.0		25.0	4.5	2.2	0.00000	2.0	1.00	
40: System Acquisition Costs	Dollars (M)	24.0		45.0	10.8	3.2	0.00000	3.0	1.00	
41: O&S Costs (Crew)	Dollars (M)	2.5	1.5		2.0	0.25	0.02070	5.0	0.52	
42: Development Costs	Dollars (M)	5.0		10.0	6.0	2.0	0.02278	1.0	0.95	
43: Time to Break-even Point	Years	3.0		15.0	7.5	1.2	0.00000	4.0	0.97	
48: O&S Cost of RSVP	Dollars (M)	25.0		100	54.0	13.0	0.00020	5.0	0.14	
Total							0.06494	25.0	0.49	

Figure 172 Cost Worksheet

6.2.4.7 Environmental Monitoring (PerfEnv) Worksheet

The Environmental Monitoring is shown in Figure 173. The "Monitor Humidity" requirement was removed from the analysis by setting its weight to zero5 since this data was not collected during testing. The total Zeta was .00196 and the total Desirability is .92. The only individual desirability that seems low is on the "Fire Detection" requirement measured in "Time to Detection (mins)." The lower desirability on this requirement is due to the shape of the desirability curve. (See Figure 174.) Even with an expected value of 2 minutes (which is very close to the objective of 1 minute), the shape of the curve determines that the desirability is only .54 -- leaving room for improvement. It is interesting to observe that on ten out of the fourteen requirements, the RSVP technology met or exceeded the objective value. Sensitivity analysis showed that the total desirability is unchanged if all weights are set to 1.0. This result was expected since the individual desirabilities on most requirements were large.

Worksheet: 1

Risk Estimation

Type: PerfEnv
Customer: ATD Demo
Technology: Wireless

Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability	Comments
1: Fire Detection	Percentage Detection w/in 5 min	100	95.0		100	0.0000	0.00000	5.0	1.00	
2: Fire Detection	Number False Alarms during de	0.0000		1.0	1.0	0.0000	0.00000	5.0	0.61	
3: Fire Detection	Time to Detection (min)	1.0		5.0	2.0	1.0	0.00135	4.0	0.56	
5: Monitor Temperature Set Point	Percentage Detection w/in 30 se	100	99.0		100	0.0000	0.00000	4.0	1.00	
6: Monitor Temperature Set Point	Number False Alarms during de	0.0000		1.0	0.0000	0.0000	0.00000	5.0	1.00	
7: Monitor Temperature Rate of	Percentage Detection	100	99.0		100	0.0000	0.00000	3.0	1.00	
7.1: Monitor Temperature Rate of	Measurement sensitivity: Delta T	1.0		10.0	0.50	0.100	0.00000	5.0	1.00	
8: Monitor Temperature Rate of	Number False Alarms during de	0.0000		1.0	0.0000	0.0000	0.00000	2.0	1.00	
15: Monitor Humidity	Measurement Accuracy (percent	1.0		5.0	2.0	1.0	0.00149	0.0	0.75	
16: Monitor Temperature	Measurement Accuracy (degrees	1.0		5.0	0.50	0.25	0.00000	2.0	1.00	
17: Monitor Pressure	Measurement Accuracy (psi)	0.25		1.0	0.013	0.0039	0.00000	2.0	1.00	
22: Detect Gas Composition (non	Measurement Accuracy (percent	1.0		5.0	1.9	0.95	0.00061	3.0	0.77	
23: Remote Visual	Coverage (percent compartment	80.0	60.0		80.0	0.0000	0.00000	5.0	1.00	80% remote vi
25: Detect Noise Event (clang)	Percentage Over Background (%	3.0		10.0	3.0	0.0000	0.00000	3.0	1.00	
Total							0.00196	49.0	0.92	

Figure 173 Environmental Monitoring Worksheet

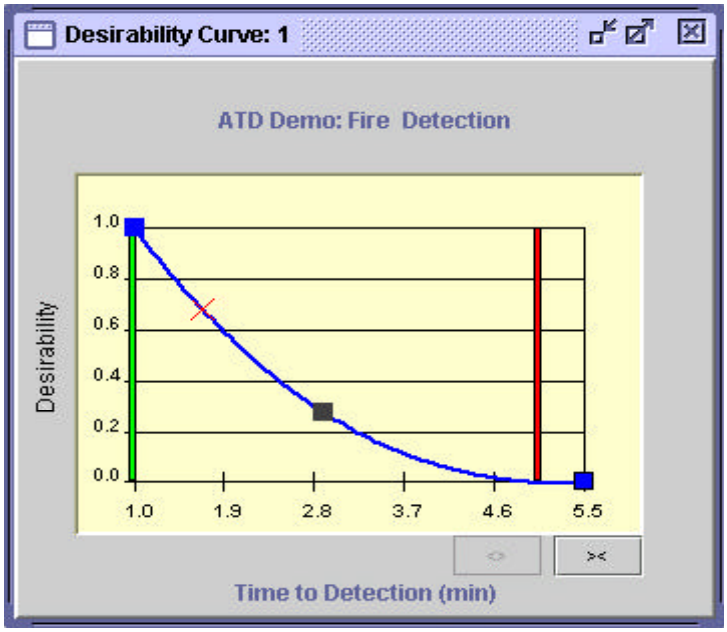


Figure 174 Fire Detection Desirability Curve

6.2.4.8 Machinery Monitoring (PerfMach) Worksheet

Figure 175 shows the Machinery Monitoring Worksheet. The analysis for this category closely follows that of the Environmental Monitoring. The total Zeta was .00008 and the total Desirability is .93. The only individual desirability that seems low is on the "Determine Operating State" requirement measured in "Seconds." One reason the desirability is somewhat low is that the test data results yielded an expected value of 10 seconds. (The upper threshold is 60 seconds and the objective is 1 second.) Collection and analysis of high bandwidth data at equipment delayed response time for on demand data requests by an operator. These results identify the need for two data collection schemes 1) to support near real time data collection for presentation to the operator and 2) to support capturing high bandwidth data locally, processing it, and sending the operator messages regarding system status. The lower desirability on this requirement is also due to the shape of the desirability curve. (See Figure 176.) The shape of the curve determines that the desirability is only .45-- leaving room for improvement. Sensitivity analysis showed that the total desirability is unchanged if all weights are set to 1.0. This result was expected since the individual desirabilities on most requirements were large.

Worksheet: 1

Risk Estimation

Type: PerfMach
Customer: ATD Demo
Technology: Wireless

Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability
29: Notification of Adverse Condition (In context)	% of alarms detected out of number simulated dur	100	96.0		100	0.0000	0.00000	5.0	1.00
30: Notification of Adverse Condition (In context)	Percentage Detection w/in 5 mins	100	95.0		100	0.0000	0.00000	4.0	1.00
42: Determine Operating State	Seconds	1.0		60.0	10.0	2.6	0.00000	3.0	0.45
43: Determine Operating State	Percent Accuracy	100	97.0		99.1	0.56	0.00008	5.0	0.98
46: Track Operating Profile	Scale: 1 - 5	5.0	3.0		4.5	0.25	0.00000	3.0	0.80
49: Provide Diagnostic Severity (Confidence) Level	% of conditions detected out of number simulated	100	90.0		100	0.0000	0.00000	4.0	1.00
54: Diagnose Fault	% of alarms detected out of number simulated dur	100	95.0		100	0.0000	0.00000	5.0	1.00
55: Diagnose Fault	Number of Missed Detections during demo	0.0000		1.0	0.0000	0.0000	0.00000	5.0	1.00
60: Determination of	% of conditions detected out of number simulated	100	95.0		100	0.0000	0.00000	5.0	1.00
60.1: Determination of	Number of Missed Detections during demo	0.0000		1.0	0.0000	0.0000	0.00000	5.0	1.00
Total							0.00008	44.0	0.93

Figure 175 Machinery Monitoring Worksheet

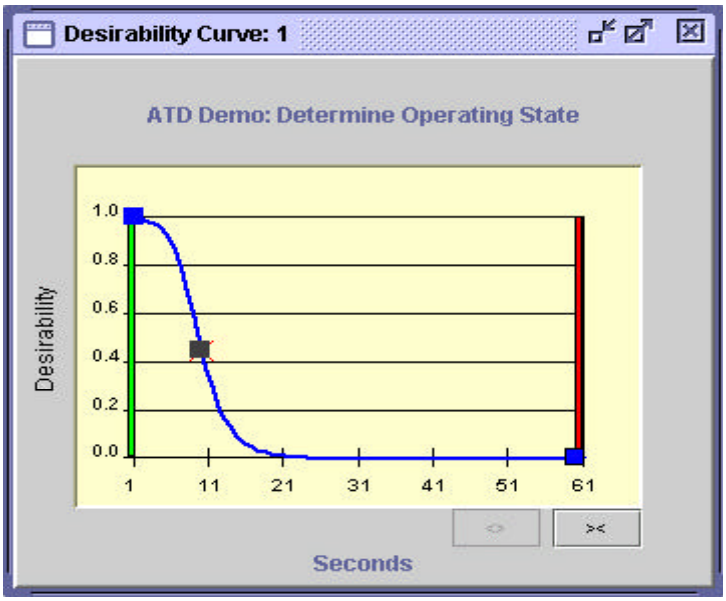
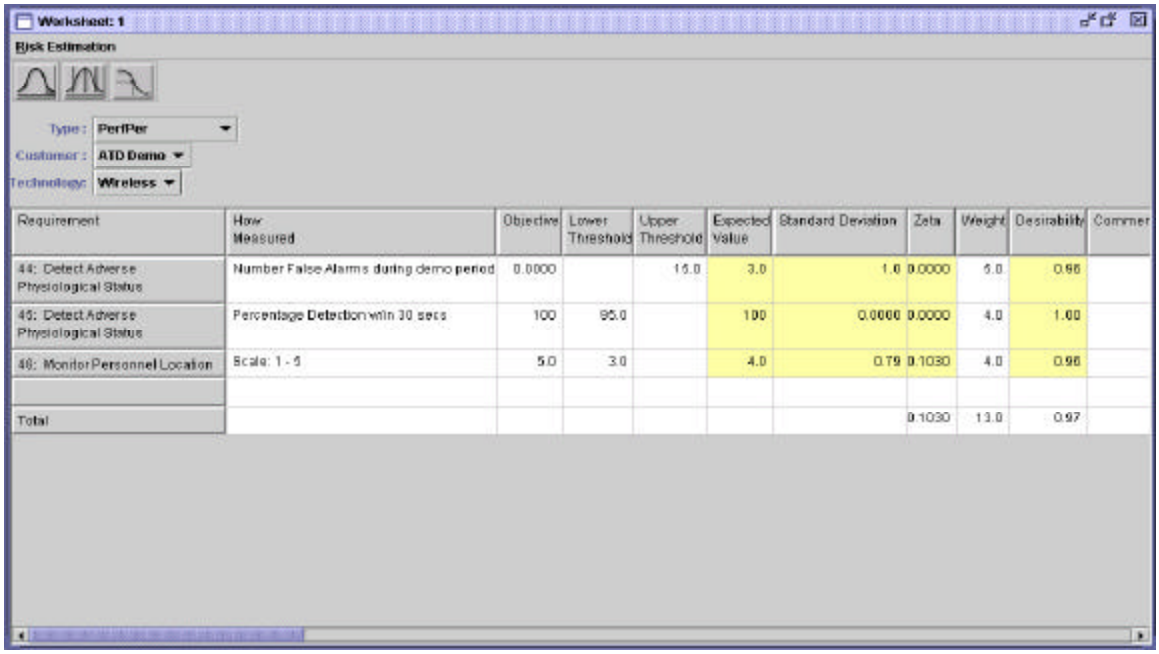


Figure 176 Determine Operating State Desirability Curve

6.2.4.9 Personnel Monitoring (PerfPer) Worksheet

The Personnel Monitoring Worksheet is shown in Figure 177. As the results show, the RSVP technology performed well on all of these requirements providing a total Zeta of 0.1303 and a total Desirability of 0.97. Again, sensitivity to weights was investigated and showed that the total desirability is unchanged if all weights are set to 1.0.



Worksheet: 1

Risk Estimation

Type: PerfPer
Customer: ATD Demo
Technology: Wireless

Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability	Commer
44: Detect Adverse Physiological Status	Number False Alarms during demo period	0.0000		15.0	3.0	1.0	0.0000	5.0	0.96	
45: Detect Adverse Physiological Status	Percentage Detection within 30 secs	100	95.0		100	0.0000	0.0000	4.0	1.00	
46: Monitor Personnel Location	Scale: 1 - 5	5.0	3.0		4.0	0.79	0.1030	4.0	0.96	
Total							0.1030	13.0	0.97	

Figure 177 Personnel Monitoring Worksheet

6.2.4.10 Structural Monitoring (PerfStruct) Worksheet

The RSVP technology also responded well to all requirements in the Structural Monitoring Worksheet shown in Figure 178. On six out of the seven requirements, the RSVP technology met or exceeded the objective value, yielding a total Zeta of only 0.00001 and a total Desirability of 0.98. Sensitivity analysis showed that the total desirability is unchanged if all weights are set to 1.0.

Notice that two of the requirements--Monitor Hatch Closure and Monitor Hatch Open--were not considered in the analysis.

Worksheet: 1

Risk Estimation

Type: PerfStruct
Customer: ATD Demo
Technology: Wireless

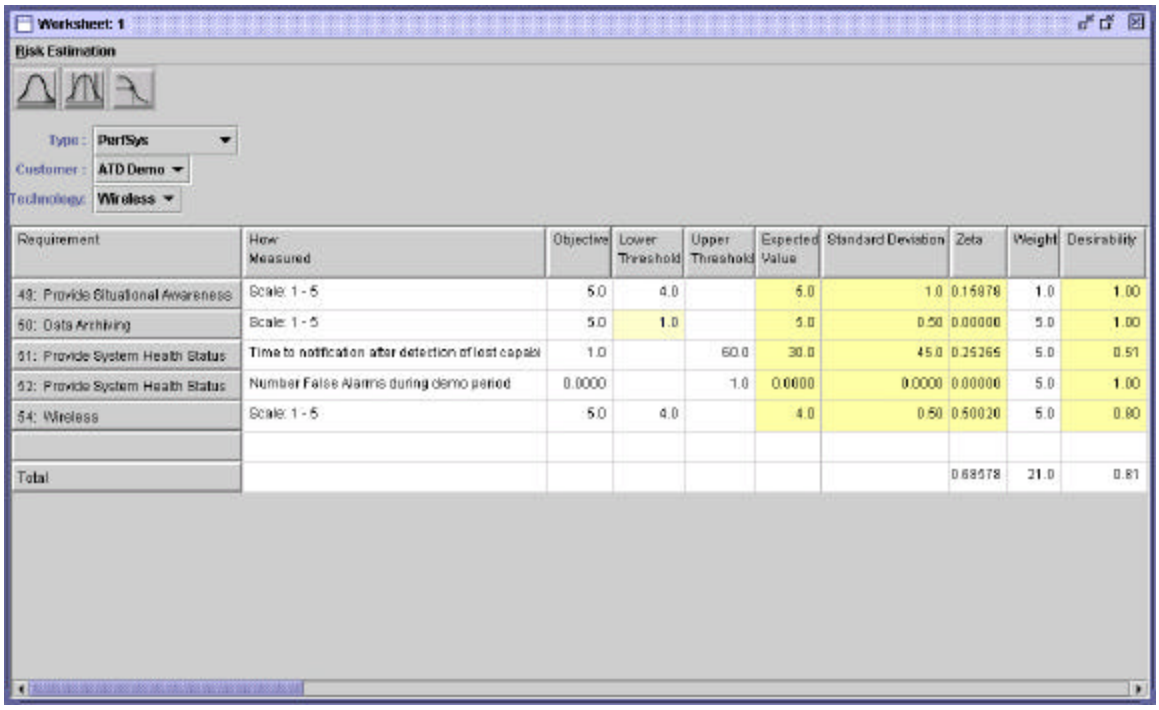
Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability
31: Monitor Hull Stress	Measurement Accuracy (psi)	10.0		100	30.0	5.0	0.00000	2.0	0.79
36: Monitor Hull Acceleration	Measurement Accuracy (g)	0.10		0.20	0.0100	0.045	0.00001	6.0	1.00
36.1: Monitor Hull Shock	Measurement Accuracy (g)	1.0		5.0	1.0	0.0000	0.00000	4.0	1.00
67: Measure Flooding	Measurement Accuracy (inches)	0.50		0.75	0.50	0.0000	0.00000	5.0	1.00
68: Measure Flooding	Number False Alarms during demo period	0.0000		1.0	0.0000	0.0000	0.00000	5.0	1.00
70: Monitor Hatch Closure	Measurement Accuracy (percent)	100	95.0		100			0.0	1.00
71: Monitor Hatch Open	Measurement Accuracy (percent)	100	95.0		100			0.0	1.00
Total							0.00001	21.0	0.98

Figure 178 Structural Monitoring Worksheet

6.2.4.11 System-Level Monitoring (PerfSys)Worksheet

The analysis pointed to two of the requirements in the System-Level Monitoring Worksheet (Figure 179) as potential areas for improvement of the RSVP Technology. The Provide System Health Status requirement had a Zeta of 0.25265 and a Desirability of 0.51. The reason for the somewhat higher Zeta is that the expected value for the requirement was 30 with a standard deviation of 45. This large standard deviation caused the higher Zeta. The desirability is a function of the expected value and the desirability curve (which is straight-lined).

The Wireless requirement was measured on a scale of 1 to 5 with 5 indicating the RSVP technology was a completely wireless solution. Since the RSVP ATD Demo had some wired technology, the rating given was a 4. Since 4 was the lower threshold for the requirement, the resulting Zeta was 50 percent. The desirability of 0.8 was a function of the desirability curve that shows the customer is 80 percent satisfied with a technology that rates a 4 on the 1 to 5 scale.


Worksheet: 1

Risk Estimation

Type: PerfSys

Customer: ATD Demo

Technology: Wireless

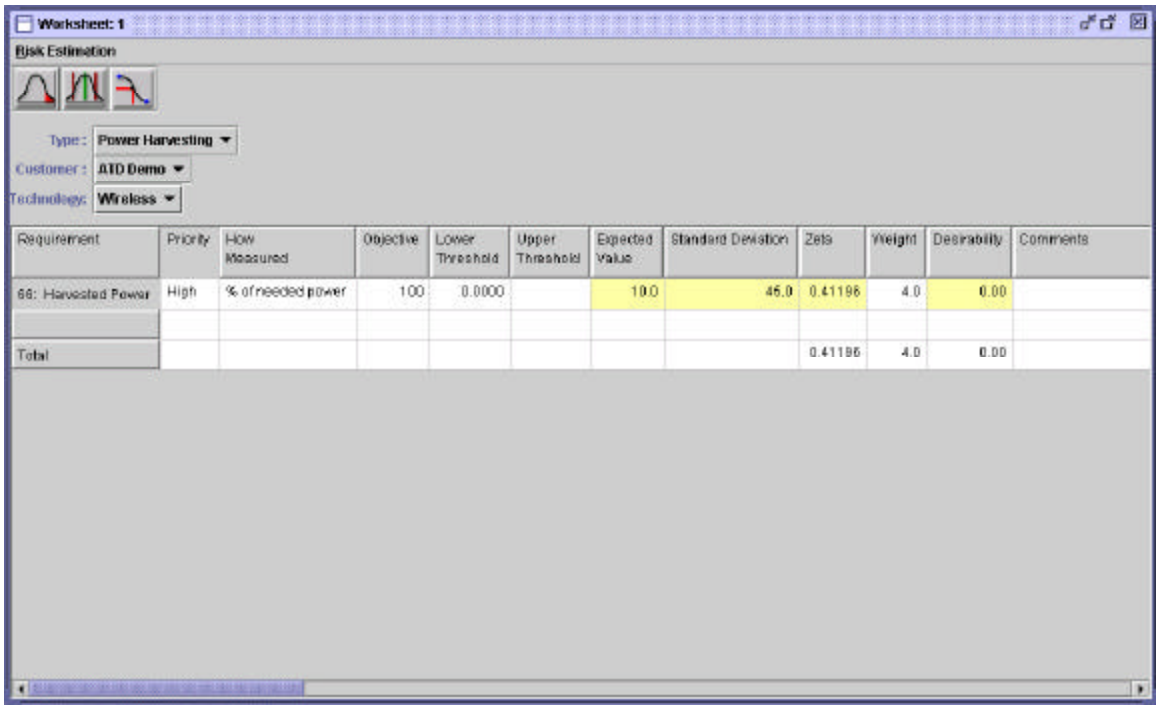
Requirement	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability
49: Provide Situational Awareness	Scale: 1 - 5	5.0	4.0		5.0	1.0	0.15879	1.0	1.00
50: Data Archiving	Scale: 1 - 5	5.0	1.0		5.0	0.50	0.00000	5.0	1.00
51: Provide System Health Status	Time to notification after detection of lost capabi	1.0		60.0	30.0	45.0	0.25265	5.0	0.51
52: Provide System Health Status	Number False Alarms during demo period	0.0000		1.0	0.0000	0.0000	0.00000	5.0	1.00
54: Wireless	Scale: 1 - 5	5.0	4.0		4.0	0.50	0.50020	5.0	0.80
Total							0.68578	21.0	0.81

Figure 179 System-Level Monitoring Worksheet

The overall Zeta was thus 0.66578 due mainly to the Zeta for the Wireless requirement. The overall Desirability was 0.81, due mainly to the Provide System Health Status requirement. The effect of setting all the weights to 1.0 was an increase in total desirability to 0.84. This slight increase is due to the fact that 4 of the 5 requirements already were weighted equally. The analysis shows then that the Provide System Health Status and Wireless requirements need more attention.

6.2.4.12 Power Harvesting Worksheet

There was only one requirement in this category. As the worksheet in Figure 180 shows, the RSVP technology achieved some power harvesting capability, but needs considerable more work to be robust. The RSVP technology did exceed the minimum threshold for the requirement, but only slightly, thus providing a high risk and low desirable solution for harvesting power.



Requirement	Priority	How Measured	Objective	Lower Threshold	Upper Threshold	Expected Value	Standard Deviation	Zeta	Weight	Desirability	Comments
66: Harvested Power	High	% of needed power	100	0.0000		10.0	46.0	0.41196	4.0	0.00	
Total								0.41196	4.0	0.00	

Figure 180 Power Harvesting Worksheet

6.2.5 Value Scorecard

The results of the worksheet analysis are summarized in the Value Scorecard shown in Table 44. We rolled up Desirability and Zeta across all the requirement types, yielding a CSI of 0.226 and an overall Risk of 0.845.

The low CSI is traceable to the following requirements:

Table 44 Value Score Card

Requirement	Requirement Type	Desirability
Reduce Man-hours	Cost	0.40
O&S Cost (Crew)	Cost	0.52
O&S Cost of RSVP	Cost	0.14
Provide System Health Status	System-Level Monitoring	0.51
Harvested Power	Power Harvesting	0.00007

The high risk is traceable to requirements in Table 45:

Table 45 High Risk Requirements

Requirement	Requirement Type	Zeta
Provide System Health Status	System-Level Monitoring	0.25265
Wireless	System-Level Monitoring	0.50020
Harvested Power	Power Harvesting	0.41196

The requirements listed in the two tables above (Table 44 and Table 45) are the drivers for the RSVP technology in terms of risk and customer satisfaction.

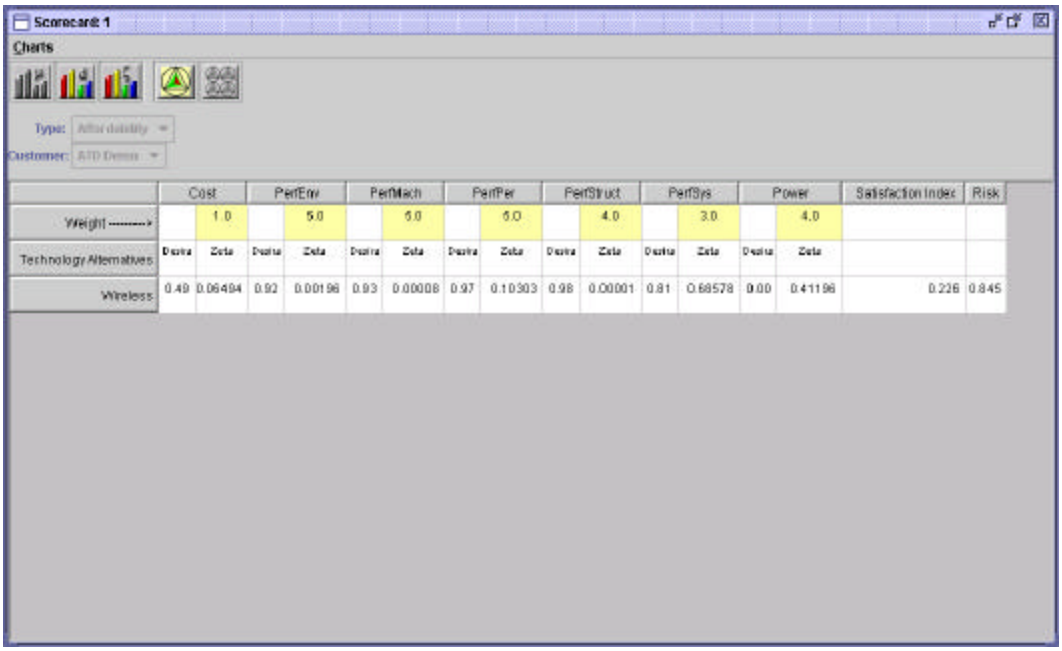


Figure 181 RSVP Affordability Scorecard

Figure 181 shows the results of the Value Scorecard graphically in what we call a Radar Chart. The green indicates the desirability of the RSVP technology and the red indicates the risk associated with the RSVP technology. The reader should not interpret the green and red as areas. To clarify, the Radar Chart shown in Figure 182 has seven spokes. Considering only the Cost spoke for the moment, we assume the spoke at the center of the circle starts at zero (0) and the end of the spoke stops at one (1). Thus, the chart shows that the desirability of the RSVP Technology for cost is approximately 0.5 (half way out the spoke). Referring to the Value Scorecard in Figure, we see that the actual desirability for Cost is 0.49. The risk is small for Cost and in the Radar Chart appears to be around 0.05. Referring to the Value Scorecard again, we see that the Cost risk is 0.06495. To complete the Radar Chart, we plot the desirability and risk on each of the other six spokes. We connect the end points on each spoke for desirability and risk resulting in what looks like an area, but actually is not. The key is to remember to look at how far out on each spoke that desirability and risk reach.

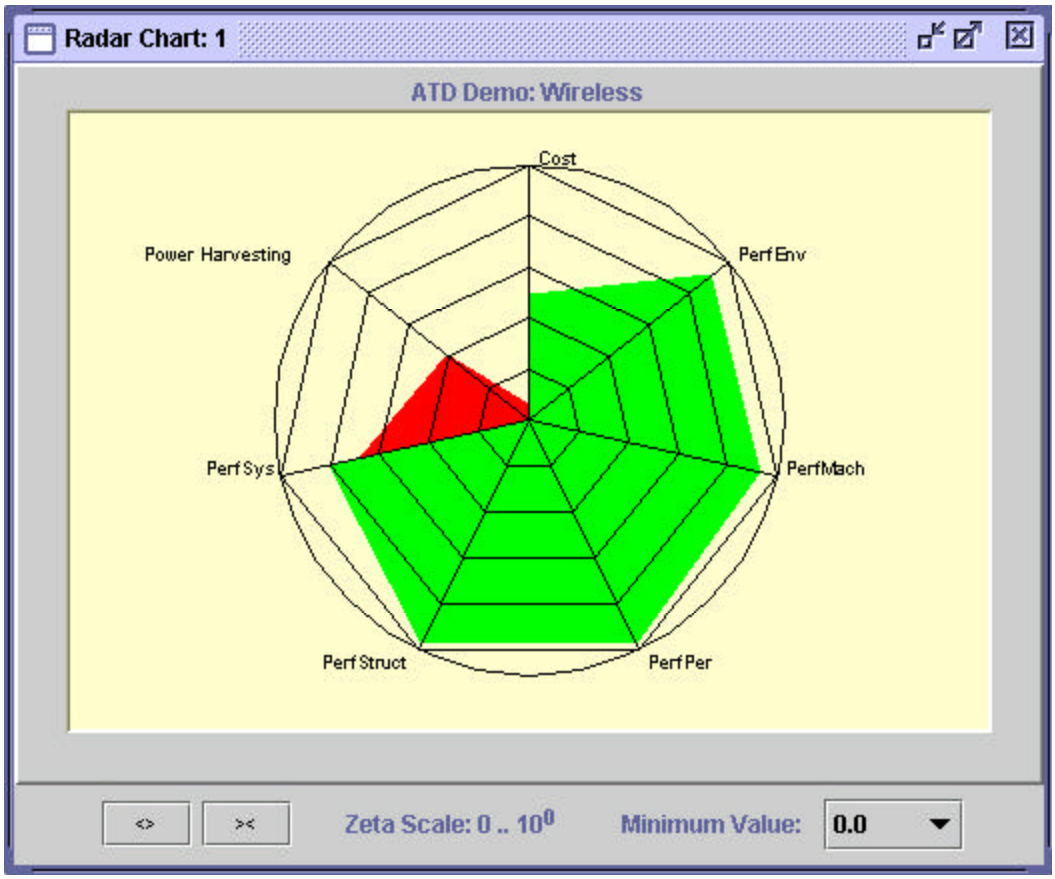


Figure 182 RSVP ATD Demo Radar Chart

6.2.6 Summary

The Value Analysis identified the requirements of the program that are driving risk and customer satisfaction. Specifically, three areas that need more work are Cost, System-Level Monitoring and Power Harvesting. Overall, the program met all of the Exit Criteria since all requirement thresholds were met. In fact, many of the objectives were met or exceeded.

7.0 Recommendations

7.1 Technology

7.1.1 Wireless

There is a tremendous momentum in the RF market to use a Bluetooth and 802.11b solution in a given wireless system architecture. For RSVP, Bluetooth and 802.11 are not viable solutions for a truly autonomous (no external power) sensor network. Batteries will operate for a limited time period. If system architects are willing to make the tradeoff of providing external power and increasing total system cost then commercially available radios are certainly viable.

7.1.2 Sensors

There were several efforts in both academia and industry that are relevant to the RSVP Sensor Cluster but one particular effort illustrates how, in the future, the RSVP Sensor Cluster will achieve the small size relative to today's Sensor Cluster.

7.1.2.1 MEMS Spectrometer for Infrared Gas Analysis

The device was produced by a team from the Swiss Federal Institute of Technology Lausanne - Figure 183. The MEMS infrared spectrometer can be selectively tuned for gas analysis and quantification. It contains a tunable optical filter of porous silicon that allows for the user to measure the infrared absorption of a gas mixture at different wavelengths serially with the use of one single detector. The tunable filter is typically 1.0 x 1.8 mm^2 and is tilted by a microactuator. Selective sensing for CO2 and CO by their absorption bands at 4.23 µm and 4.65 µm has been shown. The concept is illustrated below and is then followed by a photograph of the device - Figure 184. Different filters and filter combinations can be added to the device to cover a specific or broader range of chemical detection interests.

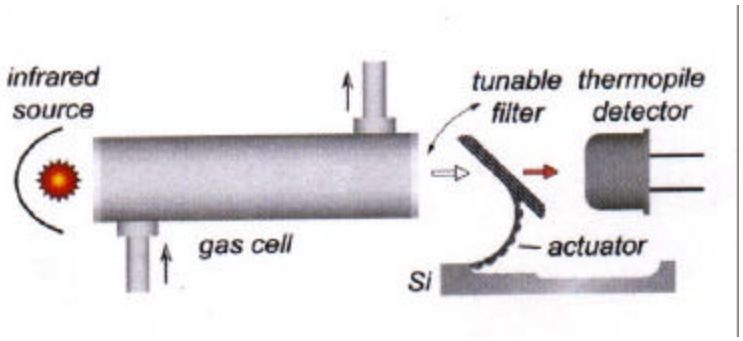


Figure 183 MEMS Spectrometer Concept Illustration

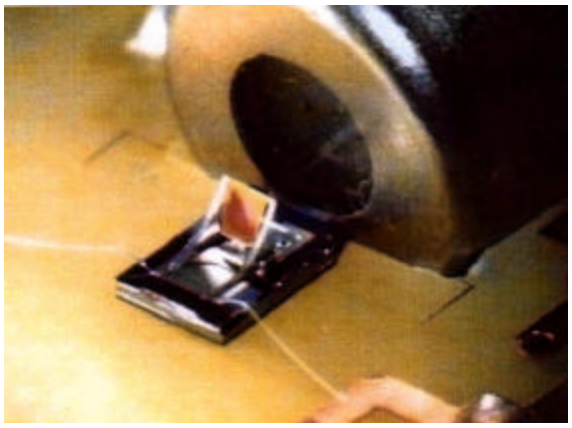


Figure 184 Photography of MEMS Spectrometer

7.1.3 Power Harvesting

7.1.3.1 New Thermoelectric Material For Energy Harvesting

Hi-Z Technology, Inc. has been developing a new type of material for the direct conversion of heat to electricity. This material is made of multiple layers of two materials, of different band gaps. Each layer is about 100 thick and called "quantum well" thermoelectrics. The measured thermoelectric properties of this material indicate that it can convert heat to electricity at an efficiency that is roughly four times that of the best currently available bulk thermoelectric material. One of the physical properties that makes quantum wells particularly suitable for energy harvesting generators is its high Seebeck coefficient (volts/ C) which means that higher voltages can be obtained with a very low temperature difference.

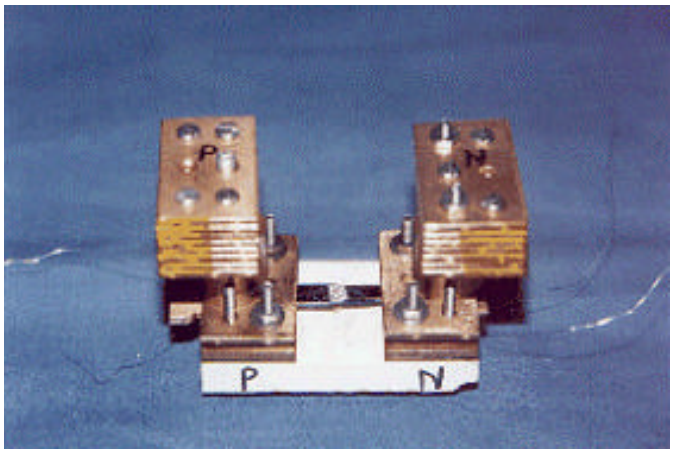


Figure 185 Schematic of P-N Couple

The size and weight of the energy harvesting generator is a direct function of the thermal efficiency of the conversion because the size of the generator is dictated by the size of the air side heat exchanger. A large surface area is required to transfer the energy with minimal temperature loss across the boundary film. A factor of four increase in efficiency provided by the quantum wells will result in a factor of four decrease in the air side heat exchanger size and weight.

7.1.3.2 New Thermoelectric Wafer Materials

The Research Triangle Institute in North Carolina has reported a major advance: tiny "superlattice" structures that appear to be more than twice as efficient as previous thermoelectric materials. The nano films consist of several alternating layers, each less than five nanometers thick. These layers block the travel of atomic vibrations that produce heat flow but still let the electrons flow as current.

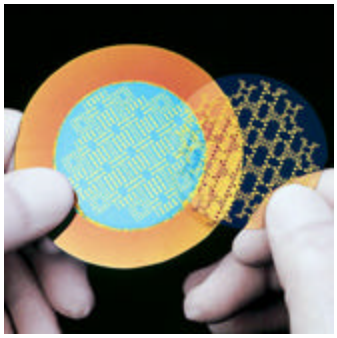


Figure 186 The Research Triangle Institute Thermoelectric Wafer Device

7.2 MEMS-Based Power Generation

The MEMS-based power generation community is primarily focused in microturbomachinery, thermoelectrics (TEs), and vibration to electric systems.

7.2.1.1 Microturbomachinery

The microturbomachinery effort is lead by Martin Schmidt of MIT. The team at MIT has demonstrated several of the individual pieces of the microturbine but still have several significant "miracles" to overcome. No other organizations appear to be playing this area.

7.2.1.2 Thermoelectrics

Both MIT and University of Michigan presented papers on thermoelectric generators. Both thermoelectric generator efforts *in concept* use a micromachined combustion chamber for heat generator. The MIT work is still very immature and is demonstrating only certain key principles of the TE side of the power generator. The MIT team stated they've already demonstrated the difficult parts of the micromachined combustion chamber half of the problem. The University of Michigan effort, lead by Khalil Najafi, presented an actual thermoelectric generator consisting of MEMS TE device coupled with a micromachined combustion chamber. A video was presented that showed an operational TE system. It was encouraging to see a more integrated systems approach to the generator rather than individual pieces. Both teams project output power levels to be in the range of 20-40μW/thermocouple at 450°C (operating temperature). The early results from the University of Michigan support these claims. Figure 185 is a picture of the actual University of Michigan TE generator.

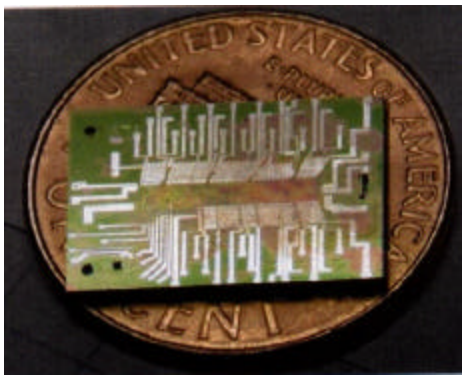


Figure 185 University of Michigan-TE Device

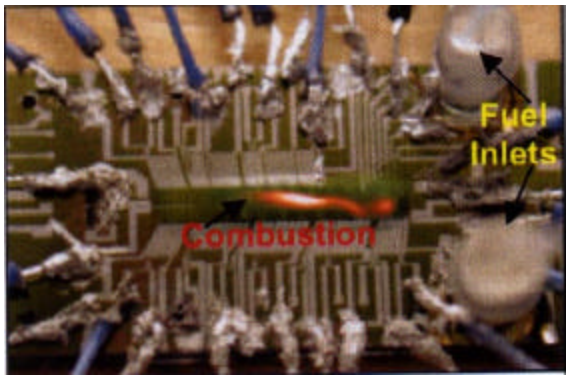


Figure 186 TE with Combustion Chamber

7.2.1.3 Vibration to Electric Generators

Neil N. H. Ching (Chinese University of Hong Kong) presented a device that was very immature in nature but demonstrated the concept of vibration to electrical conversion. Essentially the device is a miniature electromagnetic generator. A small magnetic mass is mounted at the end of MEMS spring near a coil. The vibration source causes the magnet to pass by the coil thus inducing a voltage. The problem with this type of power generation is that the device needs to be "tuned" to the specific vibration source frequency for maximum energy transfer and if the device not sensing that particular frequency then the device is essentially non-operational. There are a few companies and universities investigating the possibility of having an adaptive approach that searches or adapts to the optimum frequency when the vibration conditions change. The output power level for the above device is approximately 100µW.

7.2.1.4 RSVP Power Scavenging Efforts

RSVP has both a TE and a vibration to electric generator. The RSVP TE device is from Hi-Z Technology (San Diego, CA) and the vibration to electric device is from MJR Scientific (Salt Lake City, UT). The TE device is not MEMS-based and has lower output power levels due to the fact that RSVP is operating at room temperature which is at the low end of the efficiency curve for the material used in TE devices. The vibration to electric device is MEMS based and has similar output power level projections.

8.0 References

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