Physiological Monitoring Systems for Emergency Responders

SAVER Assessment Report

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FOREWORD

The National Urban Security Technology Laboratory (NUSTL) is a federal laboratory within the U.S. Department of Homeland Security (DHS) Science and Technology Directorate (S&T). Located in New York City, NUSTL is the only national laboratory focused exclusively on supporting the capabilities of federal, state, local, tribal, and territorial responders to address the homeland security mission. The laboratory assists responders with the use of technology to prevent, protect against, mitigate, respond to, and recover from homeland security threats and incidents. NUSTL provides expertise on a wide range of subject areas, including chemical, biological, radiological, nuclear, and explosive detection, personal protective equipment, and tools for emergency response and recovery.

NUSTL manages the System Assessment and Validation for Emergency Responders (SAVER) program, which provides information on commercially available equipment to assist response organizations in equipment selection and procurement. SAVER knowledge products provide information on equipment that falls under the categories listed in the DHS Authorized Equipment List (AEL), focusing primarily on two main questions for the responder community: "What equipment is available?" and "How does it perform?" The SAVER program works with responders to conduct objective, practitioner-relevant, operationally-oriented assessments and validations of commercially available emergency response equipment. Having the right tools provides a safer work environment for responders and a safer community for those they serve.

NUSTL is responsible for all SAVER activities, including selecting and prioritizing program topics, developing SAVER knowledge products, and coordinating with other organizations to leverage appropriate subject matter expertise. In conjunction with the Department of Energy Pacific Northwest National Laboratory, NUSTL conducted an assessment of commercially available physiological monitoring systems for emergency responders. This equipment falls under the AEL reference number 01ZA-01PPMS, titled "Personnel Physiological Monitoring System".

SAVER reports are available at www.dhs.gov/science-and-technology/saver.

Visit the NUSTL website at www.dhs.gov/science-and-technology/national-urban-security-technology-laboratory, or contact the lab at NUSTL@hq.dhs.gov.

U.S. Department of Homeland Security

SAVER

System Assessment and Validation for Emergency Responders

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EXECUTIVE SUMMARY

Physiological monitoring systems are worn by first responders to collect and relay real-time physiological data to remote command displays during incident responses. These systems are used to monitor the health status of staff, especially during strenuous activity or potentially hazardous conditions, to help determine when they are experiencing life signs that pose a risk to their health and/or safety.

In November 2022, the Systems Assessment and Validation for Emergency Responders (SAVER) program conducted an operational assessment of commercially available physiological monitoring systems. The assessment took place at the Orange County Fire Training Center in New Hampton, New York. The Department of Energy Pacific Northwest National Laboratory supported planning and execution of the assessment. The National Institute of Standards and Technology also supported execution of the assessment.

Seven experienced firefighters from various jurisdictions served as evaluators for this assessment. The evaluators' experience in their discipline ranged from 7 to 42 years. Evaluators assessed five different technologies according to specifications and operational scenarios identified in the assessment plan. Prior to the event, the activities were reviewed for compliance with regulations for privacy protection and human subjects testing by the appropriate DHS offices.

The purpose of this assessment report is to provide emergency responders with information to guide their agencies in making operational and procurement decisions. Emergency responder agencies should consider overall capabilities, technical specifications, and limitations of physiological monitoring systems in relation to their agency's operational needs when making equipment selections. Agencies should also consider impacts associated with integrating this equipment into their power and information technology infrastructure, data management, concept of operations, and required maintenance.

Prior to the assessment, a SAVER focus group of first responders identified 25 evaluation criteria, assigned each criterion to one of five SAVER categories (i.e., affordability, capability, deployability, maintainability and usability) and then assigned each criterion weight for its level of importance. Once criteria were weighted, the five SAVER categories were assigned percentages to represent each category's importance relative to other categories. The affordability, capability, deployability, maintainability and usability categories for this technology were weighted by the focus group as 0% (information only), 35%, 15%, 15% and 35% respectively.

Based on focus group recommendations, SAVER market research and product availability, the following five vendors and their associated products were selected for assessment:

- Empatica, Embrace Plus
- Equivital, eq02+LifeMonitor and Black Ghost
- Five Vital Signs, Detect-C
- Kenzen, Kenzen Device
- Slate Safety, Band V2

During the assessment, evaluators rated the physiological monitoring systems based on the evaluation criteria established by the focus group. The assessment was separated into two phases: the specification assessment and the operational assessment. Evaluators assessed the products based on vendor-provided information during the specification assessment. Hands-on experience using the products in five scenarios served as the basis for the operational assessment.

During the “Start Up" scenario, evaluators donned the physiological sensors and activated sensors and software. During the “Stair Climb” scenario, evaluators climbed up and down three flights of stairs while carrying hose pack and wearing full turnout gear and self-contained breathing apparatus (SCBA). During the “Task-Oriented Air Consumption” (TOAC) Activities” scenario, evaluators conducted forced entry, search, and rescue tasks while wearing full turnout gear and SCBA. During “Incident Command Monitoring,” evaluators used command monitoring software to monitor the vital signs of other evaluators who were concurrently conducting the Stair Climb and TOAC Activities. During the “Reuse” scenario, evaluators deactivated and doffed the sensors and prepared them for their next use.

Evaluators concluded that one of the products met all their expectations across all the evaluation criteria. The other four products did not meet all their expectations on at least two to as many as 12 of the criteria. The evaluation criteria with the greatest variance of scores were health status alerting, wearer interface, remote sensor platform and command interface. Overall product scores ranged from 3.1 to 4.3. The following table presents the overall scores as well as the category scores for each product. Products are listed in order from highest to lowest overall score.

Overall Scores Summary Table

Product	Overall Score	Overall	Capability	Usability	Deployability	Maintainability	Affordability
Slate Safety Band V2		4.3	4.3	4.3	4.3	4.3	NA
Equivital eq02+ LifeMonitor and Black Ghost		4.1	4.2	3.9	4.4	4.0	NA
Five Vital Signs Detect-C		3.4	3.4	3.1	3.5	3.8	NA
Kenzen Kenzen		3.2	2.7	3.5	3.0	3.8	NA
Empatica Embrace Plus		3.1	2.5	3.1	3.6	3.9	NA
	0 1 2 3 4 5						

Key: 1 (least favorable) to 5 (most favorable)

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1.0 INTRODUCTION

Physiological monitoring systems are worn by first responders and collect and relay real-time physiological data to remote command displays during incident responses. These systems are used to monitor the health status of staff, especially during strenuous activity and in potentially hazardous conditions, to help determine when they are experiencing life signs that pose a risk to their health and/or safety.

In November 2022, the System Assessment and Validation for Emergency Responders (SAVER) program, in conjunction with the Department of Energy Pacific Northwest National Laboratory (PNNL) and the National Institute of Standards and Technology (NIST), assessed physiological monitoring systems for emergency responders at the Orange County Fire Training Center (OCFTC) in New Hampton, New York. The purpose of the assessment was to obtain information on physiological monitoring systems that would be useful in making operational and procurement decisions. The assessment activities were based on recommendations gathered in October 2020 from a focus group of emergency responders with experience using physiological monitoring systems. The "Physiological Monitoring Systems Focus Group Report" [1] can be found on the SAVER website.

1.1 Participant Information

Seven emergency responders assessed the physiological monitoring systems following assessment procedures developed by NUSTL and PNNL. All evaluators were experienced firefighters; five were also emergency medical service providers and, hence, familiar with the use of physiological measures as status-of-health indicators. Evaluators were selected for the assessment based on their geographic location, responder discipline, and professional experience, as well as their operational experience using physiological monitoring systems. One evaluator was female while the rest were male. Table 1-1 lists each participant's professional information.

Table 1-1 Evaluators' Professional Backgrounds

Evaluator Discipline	Years of Experience	State
Firefighter/Emergency Medical Technician	42	MD
Firefighter/Paramedic	30	CA
Firefighter	26	VA
Firefighter	18	MD
Firefighter/Paramedic	14	GA
Firefighter/Emergency Medical Technician	10	MD
Firefighter/Emergency Medical Technician	7	GA

1.2 Assessed Products

Five physiological monitoring systems were selected and acquired for the assessment based on market research and recommendations from the focus group. Additionally, when determining the scope of product types to include in the assessment, the assessment team established the following product requirements, identifying specifications, attributes, or characteristics a product should possess to be considered for the assessment:

- Monitors and wirelessly transmits physiological conditions in real-time (e.g., temperature, heart rate) for remote viewing of the data in real time

- Reports heart rate or pulse rate and body temperature (either skin or core body temperature)
- Alerts, notifies or updates remote users (such as incident command) of potential health concerns for wearers based on physiological data
- Operates under environmental conditions experienced by first responders in the performance of their duties
- Is available to emergency responder organizations as a commercial off-the-shelf (COTS) or government-off-the-shelf (GOTS) product

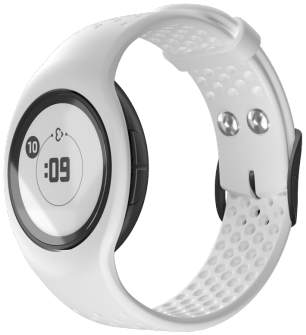
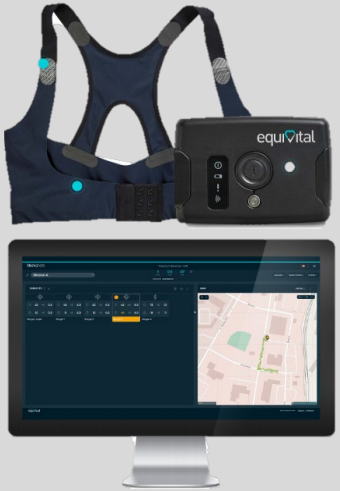
Focus group participants suggested the project team also consider the availability of multiple form factors, advising that products included in the assessment should be representative of the various form factors that are available. Participants also reiterated that the evaluation criteria they had identified should be used to guide product selection.

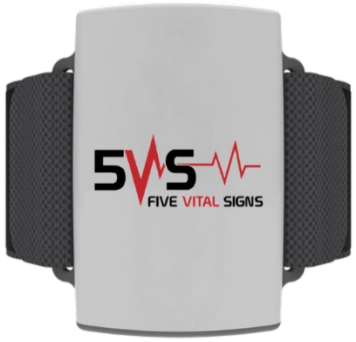
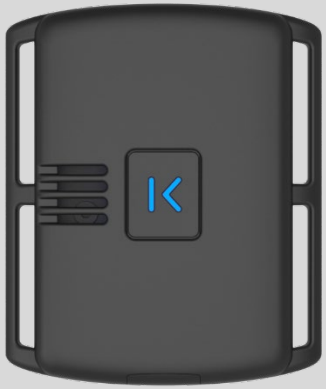
The team found two factors related to the evaluation criteria particularly significant to their selection process:

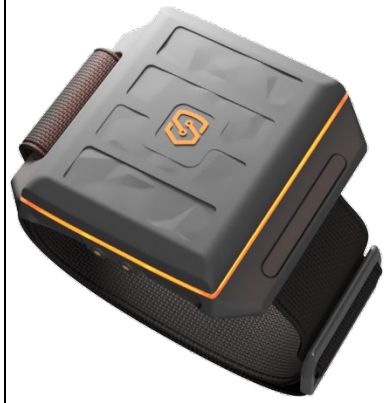
- Ability to obtain electrocardiogram (ECG) readings, as opposed to only heart or pulse rate, since greater capability potentially indicates greater quality
- Battery life, as products with shorter battery life would require more frequent recharging or battery replacement and would be more likely to lose power during use

Table 1-2 shows the products selected for assessment and their key specifications.

Table 1-2 Assessed Products' Key Specifications

Product	Cost Structure	Form Factor	Physiological Measures	Alerts	Battery Information	Command Interface	Data Transmission
 Empatica Embrace Plus	24-month contract $64/user, monthly (10+ users) $53.20/user, monthly (100+ users) $40.40/user, monthly (1000+ users)	Wristband/ smartwatch	Pulse rate Pulse rate variability Respiratory rate Blood oxygen saturation Sleep detection Movement intensity Electro-dermal activity Wearing detection Temperature	No real time alerts to command Algorithm can be integrated	Type: Internal Lithium ion Duration: Up to 60 hours Recharge time: 90 minutes	Web portal through secure cloud service Temperature and pulse rate displayed Manual refresh to see most recent data	1. Sensor to mobile device via Bluetooth 2. Mobile device to cloud server via Wi-Fi or cellular 3. Cloud server to command interface via Wi-Fi or cellular
 Equivital eq02+ LifeMonitor and Black Ghost	One time cost of up to $1000 per unit*	Smart garment	Two- lead electrocardiogram Heart rate %HR Max† Respiration rate activity Posture Fall detection Core temperature Skin temperature HSI$^{\Phi}$ HSI+15$^{\Phi}$	Stoplight health status Configurable out-of-tolerance thresholds	Type: Internal Lithium ion with optional AA battery pack Duration: 24 hours continuous monitoring/ 48 hours with additional battery pack Recharge time: 60 minutes	Internet software application (app) Automated 15-second refresh rate Multiple configurations for viewing data, including maps with GPS location	1. Sensor to mobile device via Bluetooth 2. Mobile device to cloud server via Wi-Fi or cellular 3. Cloud server to command interface via Wi-Fi or cellular

Product	Cost Structure	Form Factor	Physiological Measures	Alerts	Battery Information	Command Interface	Data Transmission
 Five Vital Signs Detect-C	$1000 per device Price lowers if bought in volume	Armband	Heart rate, Respiration rate Body temperature Ambient temperature Blood oxygen saturation Fall detection Activity	Configurable out-of-tolerance thresholds Haptic and visual alerts to wearer's sensor	10 days	Web portal with secure cloud access Customizable dashboard with real time measurement Access to historical data and reporting	1. Sensor to mobile device via Bluetooth 1a. Sensor to cloud server via Wi-Fi, LoRaWAN or cellular 2. Mobile device to cloud server via Wi-Fi or cellular 3. Cloud server to command interface via Wi-Fi or cellular
 Kenzen Kenzen Device	Device: $350/user, yearly Data hosting and security: $2,500/year Setup/ implementation: $2,000/location	Armband	Core body temperature Heart rate Skin temperature and humidity Environmental temperature and humidity	Stop work and return to work Haptic and visual alerts on sensor Personal alerts on phone app Team alerts on phone app Color-coded heat status indicators	16-18 hours	Web portal access to dashboard with real time data with 10 users per page	1. Sensor to mobile device via Bluetooth 2. Mobile device to cloud server via Wi-Fi or cellular 3. Cloud server to command interface via Wi-Fi or cellular

Product	Cost Structure	Form Factor	Physiological Measures	Alerts	Battery Information	Command Interface	Data Transmission
 Slate Safety Band V2	Device: $495 Replacement strap: $5 (regular)/$7 (large) Remote gateway: $995 Starter kit case (holds 10): $700 Single charger: $10 Multi-charger: (for 5 devices): $100 Multi-charger adapter (for 12 devices): $100 Onsite support: $250/hour per person (minimum 12 hours) Software service: $15/device, monthly	Armband	Heart rate HRLV# Core Temperature Exertion GPS location Calories burned Distance traveled	Haptic and visual alerts on sensor SOS tap alert on sensor Stoplight view on command interface Text and email messages	24 hours with GPS 100 hours without GPS	Secure web portal from cloud Views include chart, map and individual detailed view	1. Sensor to mobile device via Bluetooth 1a. Sensor to cloud server via Wi-Fi or cellular 2. Mobile device to cloud server via Wi-Fi or cellular 3. Cloud server to command interface via Wi-Fi or cellular

Notes: The specifications in this table represent the equipment as assessed.
* Stated by vendor during assessment
† %HR Max is the vendor's calculated value for heart rate
Φ Heat strain index (HSI) is the vendor's calculation of the current and predicted (15 minutes out, "+15") heat stress level
Heart rate limit value (HRLV) is the vendor's calculated value based on an individual's heart rate and age

2.0 EVALUATION CRITERIA

The SAVER focus group on physiological monitoring systems identified 25 evaluation criteria and assigned each criterion to one of the five established SAVER assessment categories described below:

- **Affordability** criteria relate to the total cost of ownership over the life of the product, including purchase price, training costs, warranty costs, recurring costs, and maintenance costs
- **Capability** criteria relate to product features or functions needed to perform responder-relevant tasks
- **Deployability** criteria relate to preparing to use the product, including transport, set up, training, and operational/deployment restrictions
- **Maintainability** criteria relate to the routine maintenance, storage, calibration, and minor repairs performed by responders, as well as included warranty terms, duration, and coverage
- **Usability** criteria relate to ergonomics and the relative ease of use when performing responder relevant tasks

The focus group participants assigned weights, indicating the level of importance of each evaluation criterion and the five SAVER assessment categories. Evaluation criteria were weighted on a 1 to 5 numerical scale, with 1 indicating that an evaluation criterion is of minor importance and a 5 indicating that an evaluation criterion is of utmost importance. Four criteria were designated "information only." These criteria were neither weighted nor scored; however, as relevant product specifications (e.g., price, warranty information), they are included in this report. One criterion was not assessed since the information provided by all vendors indicated that it was not relevant to their product. As such, it was treated the same as the "information only" criteria.

The SAVER assessment categories were then assigned a percentage to represent each category's importance relative to the other categories. Table 2-1 presents the evaluation criteria and their associated weights as well as the percentages assigned to the SAVER categories. Evaluation criteria are defined in Appendix A.

Table 2-1 Evaluation Criteria

SAVER CATEGORIES				
Capability	**Usability**	**Deployability**	**Maintainability**	**Affordability**
Overall Weight 35%	Overall Weight 35%	Overall Weight 15%	Overall Weight 15%	Information Only
Evaluation Criteria				
Health Status Alerting Weight: 5	**Accuracy** Weight: 5	**Scalability** Weight: 5	**Cleaning/ Decontamination** Weight: 5	**List Price** Information Only
Physiological Measures Weight: 5	**Battery Life** Weight: 5	**Software Compatibility** Weight: 5	**Durability** Weight: 5	**Additional and Recurring Costs** Information Only
Remote Sensor Platform Weight: 5	**Comfortable Fit** Weight: 5	**Third-Party Software Integration** Weight: 5	**Battery Type** Weight: 4	**Contract Listing** Information Only
Data Privacy Weight: 4	**Command Interface** Weight: 5		**Customer Support** Weight: 4	
Data Sharing Weight: 4	**Ease of Donning and Activation** Weight: 5		**In-House Maintenance** Not Assessed	
Profiles or Baselines Weight: 3	**Compatibility with PPE** Weight: 4			
Location Services Information Only	**Wearer Interface** Weight: 4			

3.0 ASSESSMENT METHODOLOGY

Each product was assessed in two phases: (1) a specification assessment and (2) an operational assessment. Throughout the assessment, evaluators worked in teams of up to four and were further separated into sub-teams of up to two (see Table 3-1 for details showing how each team assessed different products and each team member perform different activities simultaneously). Data collectors from NUSTL and NIST observed each evaluator as they completed the assessment activities.

Focus group participants previously provided recommendations on which criteria should be evaluated by a specification assessment or an operational assessment. In some cases, criteria were evaluated by both, in other cases criteria were not assessed, but relevant information is included in the assessment report.

3.1 Phase 1: Specification Assessment

The specification assessment was held in the main classroom building of the OCFTC. During this portion of the assessment, product vendor representatives provided a presentation on their product, which included an overview of a system, its key features and specifications, and a brief training on how to use it. During their presentation, vendor representatives also addressed each evaluation criteria (listed in Table 2-1) that had a specification component. Evaluators were provided with a reference sheet of the features and specifications of each product and how those characteristics related to the evaluation criteria defined by the focus group.

3.2 Phase 2: Operational Assessment

During the operational assessment, evaluators became familiar with each product's proper use, capabilities, and features. The vendor representatives and NUSTL/NIST test team assisted evaluators with product familiarization. Evaluators also had access to the reference material included with each product upon purchase.

Evaluators then assessed each physiological monitoring system based on their hands-on experience using it throughout the operational phase of the assessment. The physiological monitoring systems were assessed in five scenarios: (1) Start Up, (2) Stair Climb, (3) Task Oriented Air Consumption (TOAC) Activities, (4) Incident Command Monitoring, and (5) Reuse. Up to four evaluators assessed the same product at the same time. Each of these teams was further divided into sub-teams of two that alternated between scenarios 2, 3, and 4. A sample sequence of an evaluator's operational activities is given in Table 3-1.

The operational scenarios were designed to mirror the Task-Oriented Air Consumption (TOAC) [2] test, which is administered by the Orange County Fire Training Center. The TOAC test is similar to, and can be administered as an alternative to, the Candidate Physical Aptitude Test (CPAT) [3], which is typically required for employment by most fire departments. Evaluators completed each scenario sequentially with a single product, then provided responses and comments to a set of questions (which data collectors entered onto assessment work sheets) before beginning the scenarios again with the next product.

Table 3-1 Sample Operational Assessment Sequence

Rotation	Assessment Activity			
	Evaluators 1 & 2	Evaluators 3 & 4	Evaluators 5 & 6	Evaluator 7
1	Specification Assessment, Product A		Specification Assessment, Product B	
2	Start Up, Product A		Start Up, Product B	
3	Stair Climb, Product A	Incident Command, Product A	TOAC Activities, Product B	Incident Command, Product B
4	TOAC Activities, Product A		Stair Climb, Product B	
5	Incident Command, Product A	Stair Climb, Product A	Incident Command, Product B	TOAC Activities, Product B
6		TOAC Activities, Product A		Stair Climb, Product B
7	Reuse	Reuse	Reuse	Reuse

3.2.1 Start Up

The Start Up scenario focused on donning and activating the physiological monitoring device. In a conference room setting, evaluators conducted the following tasks:

- Activated all devices (sensors and monitoring platforms), applied sensors as appropriate, and adjusted to fit
- Confirmed sensors were operational and communicating with monitoring platforms and data servers
- Made observations about the perceived durability of the sensor
- Opened and examined the layout of the wearer interface (e.g., mobile app) and adjusted the interface, if applicable
- Adjusted system settings, if applicable
- Activated command user interface on appropriate device (e.g., laptop, tablet)
- Added all monitored individuals in the command interface
- Set or adjusted out-of-tolerance thresholds for wearers
- Lay down on a cot in plain clothes to gauge comfort of the sensor while sleeping

Evaluation Criteria Assessed
Remote Sensor Platform
Profiles or Baselines
Comfortable Fit
Command Interface
Ease of Donning and Activation
Wearer Interface
Scalability
Durability

- Used a finger pulse oximeter and contactless thermometer to measure and record baseline heart rate and temperature respectively
- Donned personal protective equipment (PPE) including turnout gear, helmet, boots, and gloves

3.2.2 Stair Climb

The Stair Climb scenario was conducted in the tower building at the OCFTC and was designed to emulate the stair climb portion of the TOAC test, which is generally the most time-consuming portion. During this scenario, evaluators donned a 3M Scott AirPak X2 self-contained breathing apparatus (SCBA) with a 3M Scott AV-2000 facepiece and carried a hose pack (folded 50-foot length of 2 ½ inch hose) up three stories inside the tower building and then descended the stairs while still carrying the hose. Evaluators then removed the SCBA facepiece upon completion of this scenario, measured and recorded heart rate and temperature, and rested for a brief period to simulate rehabilitation.

Evaluation Criteria Assessed
Health Status Alerting
Profiles or Baselines
Accuracy
Comfortable Fit
Compatibility with PPE
Wearer Interface
Durability

In the process of performing this activity, evaluators triggered out-of-tolerance alerts for those physiological measures with thresholds that could be adjusted. Before beginning the stair climb, these thresholds were adjusted to values that did not pose a risk to evaluator safety (e.g., the threshold for heart rate alerts were lowered from the product's default values to 100 beats per minute) so that health status alerting could be tested safely. Evaluators also viewed and/or sensed alerts on their personal devices, if available. Additionally, they made observations about the perceived durability of the sensor.

Upon completion of the Stair Climb scenario, evaluators proceeded to either the TOAC Activities scenario or the Incident Command Monitoring scenario. If an evaluator had completed the TOAC Activities scenario prior to the Stair Climb, they fully doffed their SCBA at this time.

3.2.3 TOAC Activities

The TOAC Activities scenario was designed to emulate various other tasks in the TOAC including forced entry, search, and rescue. This scenario also took place at the tower building. During this scenario, evaluators donned SCBAs (described above in 3.2.2) and conducted the following tasks:

- **Forced Entry:** Used a 10-pound sledgehammer to hit a bumper on the exterior wall of the tower building while wearing full turnout gear and SCBA. The bumper was elevated approximately 4 feet above the ground and evaluators hit the bumper 10 times at their own pace

Evaluation Criteria Assessed
Health Status Alerting
Profiles or Baselines
Accuracy
Comfortable Fit
Compatibility with PPE
Wearer Interface
Durability

- **Search:** Crawled through a 64-foot tunnel maze at their own pace while wearing full turnout gear and SCBA. The tunnel's exterior dimensions were 3 feet high and 4 feet wide. The tunnel also included two 90-degree turns, multiple obstacles, and areas in which the height and width were significantly narrower than the exterior dimensions
- **Rescue:** Dragged a 165-pound mannequin a distance of 35 feet, made a 180-degree turn, and dragged the mannequin back to the starting position (for a total of 70 feet). For this task, a mannequin made of hose packs was used. While a harness was attached to the mannequin for easy carrying, so that they could assess dexterity while wearing the physiological sensor, evaluators carried the mannequin under its arms

Throughout this scenario, evaluators viewed and/or sensed alerts on personal devices, if available, and made observations about the perceived durability of the sensor.

Upon completion of these tasks, evaluators again measured their heart rate and temperature and rested for a few minutes (simulated rehabilitation) as in the Stair Climb scenario. Evaluators then proceeded to either the Stair Climb scenario or the Incident Command Monitoring scenario. They fully doffed their SCBA if they had completed the Stair Climb prior to this scenario.

3.2.4 Incident Command Monitoring

The Incident Command Monitoring scenario took place in the storage garage at the OCFTC. During this scenario, evaluators monitored other evaluators who were concurrently conducting the Stair Climb and TOAC Activities scenarios. Evaluators engaged in this scenario looked for trends in the wearers' vital signs and reconfigured the command interface to view available data layout options. NUSTL/NIST team members reported the manual heart rate and temperature measurements from the Stair Climb and TOAC Activities scenarios to the evaluators manning the Incident Command Monitoring scenario. Evaluators then compared these measurements to measurements being provided by the sensors in order to help assess the perceived accuracy of a system. When possible, evaluators on the command interface observed and resolved out-of-tolerance alerts from the system.

Evaluation Criteria Assessed
Health Status Alerting
Profiles or Baselines
Accuracy
Comfortable Fit
Command Interface
Wearer Interface

3.2.5 Reuse

After completing the Stair Climb, TOAC Activities, and Incident Command Monitoring scenarios, evaluators returned to the main classroom building for the reuse scenario. This scenario focused on doffing sensors and preparing the system for its next user. Evaluators doffed turnout gear and then doffed, deactivated, and cleaned and/or decontaminated the physiological sensors. Evaluators also completed data retrieval and archiving tasks to prepare the product for its next use, then replaced or set the sensor batteries to charge.

Evaluation Criteria Assessed
Remote Sensor Platform
Cleaning/Decontamination
Durability
Battery Type

3.3 Data Gathering and Analysis

After each scenario, data collectors used a questionnaire to record the evaluators' scores for each product according to the evaluation criteria listed in section 2.0. The questionnaire included specific questions for each criterion that the data collectors read to the evaluators. Evaluators then scored the criteria using the following 1 to 5 scale:

1) The product meets none of my expectations for this criterion.
2) The product meets some of my expectations for this criterion.
3) The product meets most of my expectations for this criterion.
4) The product meets all my expectations for this criterion.
5) The product exceeds my expectations for this criterion.

Once assessment activities were completed, evaluators had an opportunity to review their criteria ratings and comments for all products and to adjust them as necessary. The assessment team calculated each final criterion score as an average across the multiple times evaluators rated it throughout the assessment. The team calculated the overall averaged assessment and category scores for each product using the formulas in Appendix B.

Data collectors also captured evaluators' comments on advantages and disadvantages as well as general comments about the assessed products and on the assessment process. The evaluators' comments were reviewed and are summarized in this assessment report.

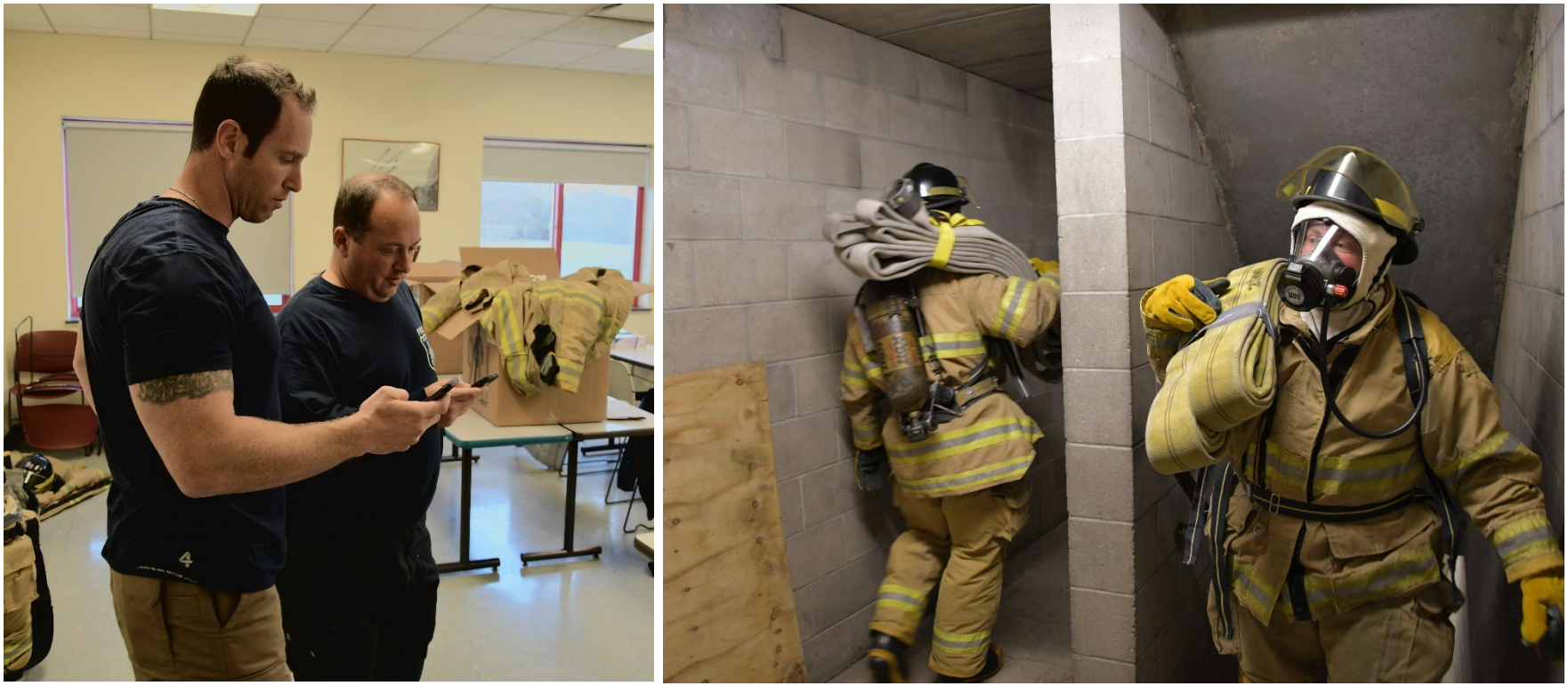


Figure 3-1 Assessment Activities: Evaluators self-monitor vital signs through a mobile app (left) and conduct the Stair Climb inside Tower Building (right).

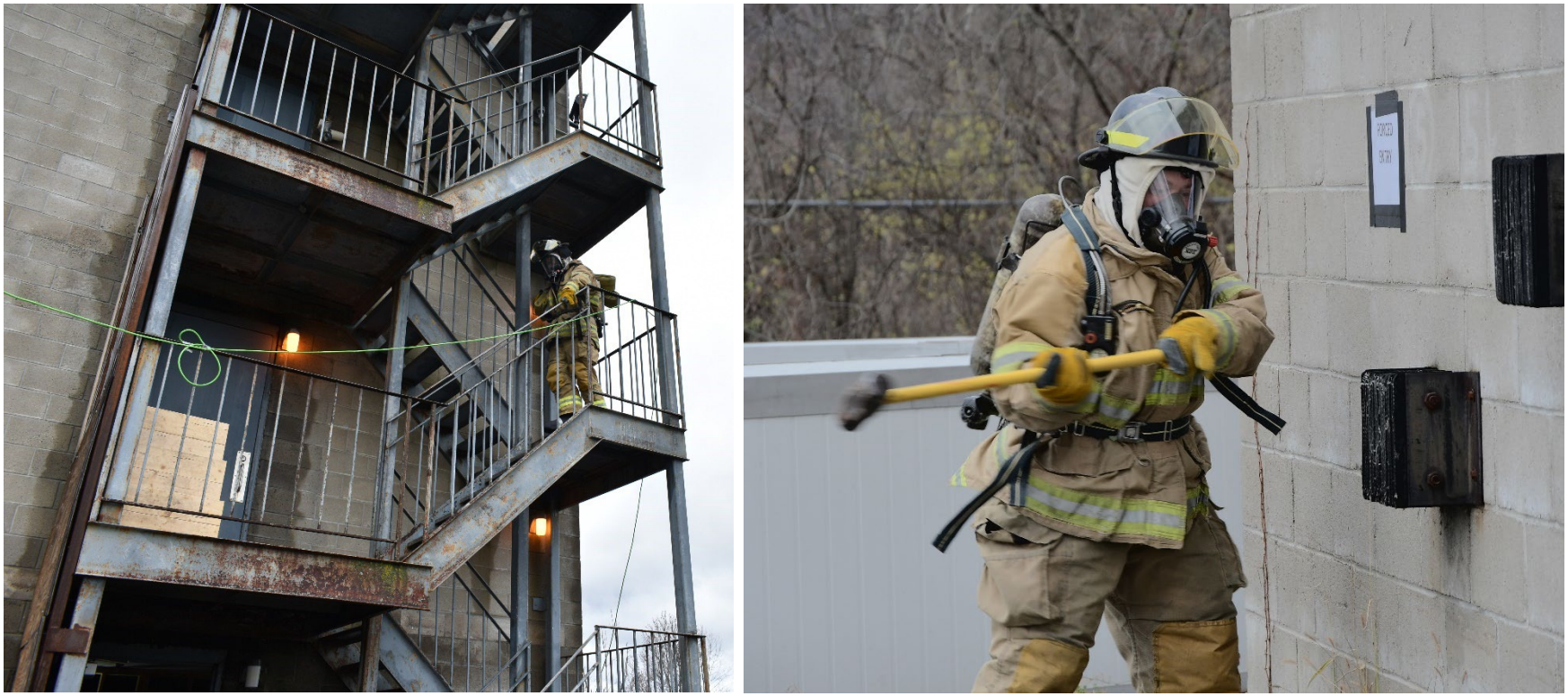


Figure 3-2 Assessment Activities: An evaluator conducts the Stair Climb on Tower Building's exterior (left) and another conducts the Forced Entry activity (right).

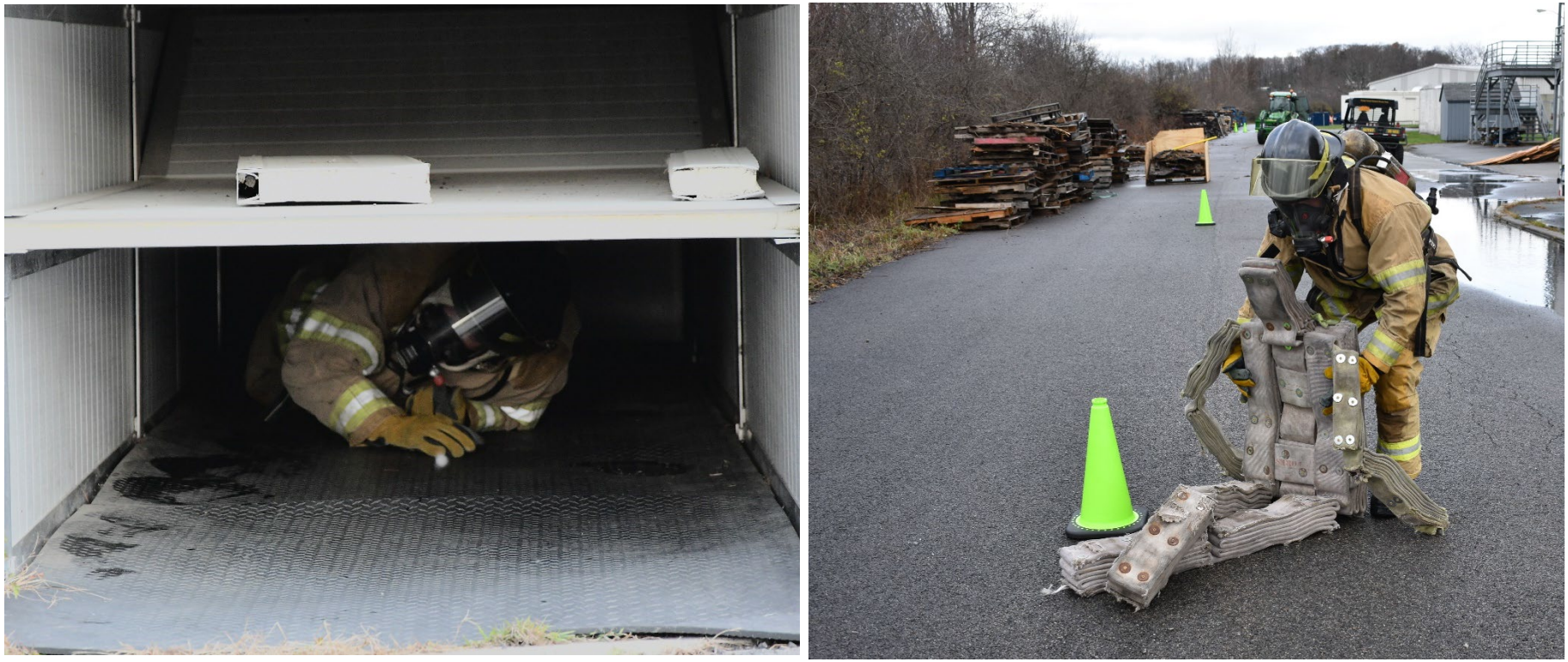


Figure 3-3 Assessment Activities: An evaluator conducts the Search activity (left); another evaluator, the Rescue (right).

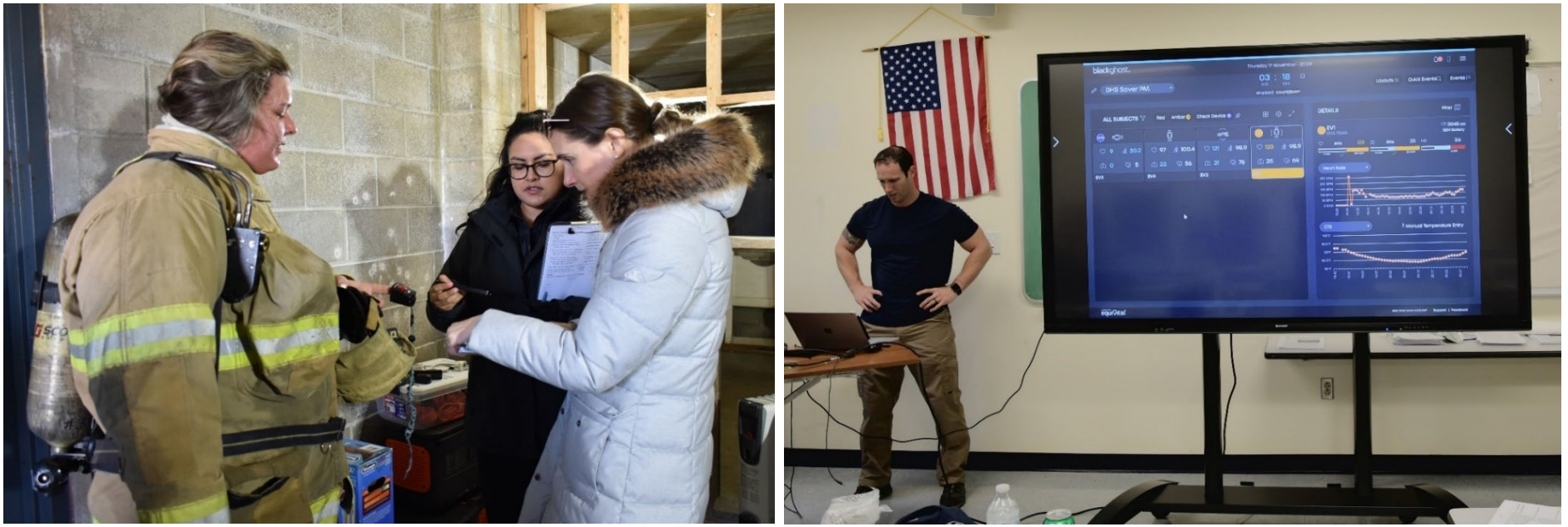


Figure 3-4 Assessment activities: Data collectors manually measure an evaluator's heart rate (left). Using the command interface, an evaluator remotely monitors users' vital signs (right).

4.0 ASSESSMENT RESULTS

Overall scores for the physiological monitoring systems ranged from 3.1 to 4.3. The assessment results are presented in Table 4-1 and Table 4-2, while additional details and evaluator comments on each product are provided in sections 4.1 through 4.6.

Table 4-1 presents the overall assessment score and category scores for each product. Products are listed in order from highest to lowest overall score throughout this section. Calculation of the overall score uses the raw scores for each category, prior to rounding. Products with the same overall score are listed in order based on the raw data. Category definitions are provided in Appendix A.

Table 4-1 Assessment Results

Product	Overall Score	Overall	Capability	Usability	Deployability	Maintainability	Affordability
Slate Safety Band V2		4.3	4.3	4.3	4.3	4.3	NA
Equivital eq02+ LifeMonitor and Black Ghost		4.1	4.2	3.9	4.4	4.0	NA
Five Vital Signs Detect-C		3.4	3.4	3.1	3.5	3.8	NA
Kenzen Kenzen		3.2	2.7	3.5	3.0	3.8	NA
Empatica Embrace Plus		3.1	2.5	3.1	3.6	3.9	NA

Key: 1 (least favorable) to 5 (most favorable)

Table 4-2 presents the average evaluation criteria scores the products received from the evaluators for each evaluation criterion. A green, fully shaded circle represents the highest rating, while a red, unshaded circle represents the lowest rating.

Table 4-2 Evaluation Criteria Ratings

Key (X < 1.5) (1.5≤ X <2.5) (2.5≤ X <3.5) (3.5≤ X <4.5) (4.5 ≤ X)		Products				
Category	**Evaluation Criteria**	**Empatica Embrace Plus**	**Equivital eq02+ LifeMonitor and**	**Five Vital Signs Detect-C**	**Kenzen Kenzen Device**	**Slate Safety Band V2**
Capability	Health Status Alerting	○	◕	◔	◑	●
	Physiological Measures*	◑	●	◕	◑	◕
	Remote Sensor Platform	◔	◑	◕	○	◕
	Data Privacy*	◕	◕	◕	◕	◕
	Data Sharing*	◕	●	◑	◔	◕
	Profiles or Baselines	◔	●	◕	◑	●
Usability	Accuracy	◔	◕	◑	◕	◕
	Battery Life*	●	◕	◑	◔	◕
	Comfortable Fit	◕	◕	◕	◕	◕
	Command Interface	◑	●	◔	◑	●
	Ease of Donning and Activation	◑	◕	◕	◑	●
	Compatibility with PPE	◕	◕	◕	◕	◕
	Wearer Interface	○	◔	○	◑	●
Deployability	Scalability	◑	◕	◕	◑	●
	Software Compatibility*	◕	◕	◕	◕	◕
	Third-party Software Integration*	◕	●	◑	◑	◕
Maintainability	Cleaning/Decontamination	◕	◕	◕	◕	◕
	Durability	◑	◕	◕	◕	●
	Battery Type	◕	◕	◑	◑	◕
	Customer Support*	◕	◕	◕	◕	◕

* These criteria were assessed by specification only.

4.1 Empatica, EmbracePlus

The Empatica EmbracePlus, shown in Figure 4-1, captures a wearer's physiological data using a wrist-worn device. It was the only wrist-worn product in this assessment. The product measures the wearer's pulse rate, pulse rate variability, skin temperature, respiratory rate, blood oxygen saturation, electrodermal activity, movement intensity, wearing detection, and sleep detection.

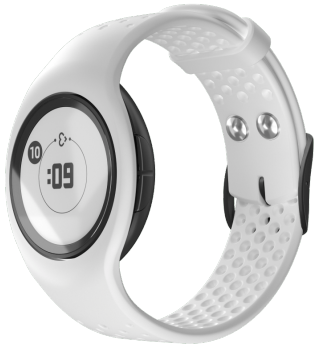


Figure 4-1 Empatica EmbracePlus

Image Credit: Empatica

The data is wirelessly transferred by Bluetooth to a nearby or on-body smartphone running an application (app) called the Care App (compatible with both Android and iOS devices) and from there to the Empatica cloud using either Wi-Fi or cellular data. Empatica's Care Portal software can be used to monitor and manage wearer data using most internet browsers. The data is encrypted (in transit and at rest) and is both Health Insurance Portability and Accountability Act (HIPAA) and General Data Protection Regulation (GDPR) compliant. The data may be shared by access to the storage in the cloud or downloaded files.

According to the vendor, the 3.8-volt lithium-ion battery in the sensor device will typically operate the unit for 60 hours in a default sensor mode before needing to be recharged. The charging is accomplished with a magnetically attached universal serial bus (USB) powered device and takes about 90 minutes to fully charge a discharged unit.

The product can be purchased under a 24-month program with costs that vary from $64.00 per user per month for under 100 units to $40.40 per user per month for 1,000 or more units.

The Empatica EmbracePlus received an overall assessment score of 3.1, which was the lowest of the five products assessed. Evaluator comments provided throughout the assessment are reported below, grouped by SAVER category. In each category, the criteria are listed according to their order of importance as assigned by the physiological monitoring systems focus group (see Table 2-1).

4.1.1 Capability

The Empatica EmbracePlus received a capability score of 2.5. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Health Status Alerting:** One evaluator said that the EmbracePlus met some of their expectations regarding the ability to provide alerts to command, and six evaluators said that it did not meet any of their expectations. Evaluators found the limited health status alerting capability was one of the more significant disadvantages of this product. The evaluators mentioned that the user interface provided data and showed trends but lacked the capability to actually provide alerts. One evaluator commented that providing alerts is essential for first responder use cases.
- **Physiological Measures:** One evaluator stated that the EmbracePlus met their expectations regarding measures provided by the product. Four evaluators said that it met most of their expectations, and two said it met some of their expectations. Several of the evaluators noted that they would prefer to have core body temperature measurements rather than skin temperature, which the EmbracePlus provided.

- **Remote Sensor Platform:** Evaluators gave the product a relatively low score for this criterion. Four evaluators said that it only met some of their expectations for this criterion, and three said that it met none. Four evaluators noted that needing to have a cell phone with the firefighter would be a concern. During the assessment, evaluators expressed many concerns with systems that required a phone including that most phones aren't intrinsically safe, their reluctance to carry additional equipment, that using a cell phone during response operations is not feasible, the additional cost associated with phones and their service, and that dependance on cellular infrastructure is not ideal. One evaluator mentioned that neither the app nor the software portal was user friendly. Another evaluator reported connection issues, and that the product would not sync to the phone for very long. One evaluator, nonetheless, appreciated that the cell phone app would store two days of data.
- **Data Privacy:** Six evaluators stated that the EmbracePlus met all their expectations concerning data privacy, while one evaluator said that it met most of them. One evaluator noted that data privacy depends on how usernames are set up. The evaluator that gave the lower score, mentioned that the encryption was suitable, but they could not access all the desired data.
- **Data Sharing:** Five evaluators said that the ability to share data using this product met all their expectations, and two said that it met most of theirs. One evaluator indicated that the process to share data was not easy to perform. A couple of other evaluators noted, in a bit more detail, that it cannot be done immediately and requires a user to download data, which can then be sent to another party. One of those evaluators added that the product sufficiently stores about 8 GB of data per day per wearer.
- **Profiles or Baselines:** Evaluators considered the results of the EmbracePlus's capability to create profiles or baselines for individual wearers of low but mixed quality. Three evaluators said that it met most of their expectations, three evaluators said that it met some of their expectations, and one evaluator said that it met none of their expectations. One evaluator liked that the product will automatically build a profile with twenty-four hours of data. Another evaluator mentioned that the system's data management prevents the transfer of a unit to a new user, thereby the product cannot be shared by responders, and every responder would require their own device.
- **Location Services:** According to the product vendor, the ability to determine the location of wearers isn't currently available. One evaluator commented that the use of GPS location would significantly decrease the battery life. Another evaluator mentioned that since the EmbracePlus requires the wearer have a mobile phone that the phone could be used for tracking the wearer.

4.1.2 Usability

The Empatica EmbracePlus received a usability score of 3.1. Evaluator feedback on evaluation criteria related to this SAVER category included:

- Accuracy: The EmbracePlus received mixed ratings on accuracy from the evaluators. Three evaluators said that it met most of their expectations, three said that it met some of their expectations, and one evaluator said that it met none of their expectations. Evaluators commented that for some but not all of them both the heart rate and temperature values measured by the Empatica device differed substantially from the values measured with the pulse oximeter and contactless thermometer. A couple of evaluators commented that the internet portal had to be refreshed manually to obtain current values which made it more difficult to view current values than if they were streaming in real time. One evaluator noted a positive attribute was that its accuracy was not affected by tattoos like some other physiological monitoring system sensors.
- Battery Life: Five evaluators found that the product's battery life stated by the vendor exceeded their expectations, and two evaluators said that it met all their expectations. For the EmbracePlus, this was its most highly rated criterion of the assessment. Evaluators found the 60 hours of battery life (with the device's default settings) is acceptable. One evaluator favorably mentioned that even if set for the highest power load, the battery is expected to last 24 hours on one charge. Other evaluators referred to the possibility that with some setting changes a full charge could run the device for up to two weeks.
- Comfortable Fit: Five evaluators said that the comfort of wearing the EmbracePlus met all their expectations, and two evaluators stated that it met most of their expectations. Evaluators indicated that they had no issues wearing it, did not notice it was on while performing activities and thought they would be able to sleep well with it on. One evaluator compared it to the comfortable fit of a wristwatch. One evaluator liked that the company makes band extenders for those with larger wrists. One evaluator mentioned that wearing the sensor left impressions on their wrist, however several evaluators had impressions on their wrist from wearing it.
- Command Interface: One evaluator said that the usability of the command interface met all their expectations, two evaluators said that it met most of their expectations, and four evaluators said that it met some of their expectations. Several evaluators pointed out that the lack of streaming data on the command interface was a disadvantage of this product; the system required that users manually refresh the web portal to get the latest synced values. A couple of the evaluators noted that streaming real-time data on the display is essential when using physiological monitoring systems. Evaluators also expressed disapproval that the product does not provide alerts through the command interface. One evaluator thought it would be a useful product for monitoring the overall health and safety of firefighters but would not be effective for real-time needs during an incident. Some positives were also noted: one evaluator liked that you could see trends in the data and visualize all wearers on one screen, and another evaluator thought the dashboard was easy to navigate.

- **Ease of Donning and Activation:** Three evaluators stated that the ability to quickly put on the EmbracePlus and begin monitoring met all their expectations, while two said that it met most, and another two said that it met only some. Three evaluators reported challenges placing the device on their wrist with one hand. One of them specifically mentioned that the snaps on the band were tricky to use. The vendor stated that they have a newer strap design with a buckle. One of the evaluators reported that it was easy to put on their wrist. At least three of the evaluators had issues syncing the device with the phone app via Bluetooth and thus issues activating the product. One evaluator stated that it was difficult to set up the EmbracePlus before using it. Another evaluator pointed out that a Wi-Fi network was needed to activate the device, a potential drawback. One evaluator mentioned that they liked that it was not necessary to set up a user profile before beginning to use the product.
- **Compatibility with PPE:** Six evaluators said that the compatibility with PPE met all their expectations, and one evaluator said that it met most of theirs. All evaluators agreed that the wrist-worn device did not interfere with any PPE nor did their PPE interfere with the operation of the product. Evaluators expressed concern there could be a conflict between using a wrist-worn device in place of personal devices or other products that are worn by firefighters, either as part of their uniform or their personal preference. Some evaluators thought the sensor location was fine.
- **Wearer Interface:** Three evaluators said that the wearer interface met some of their expectations, and four evaluators said that it met none of their expectations. Evaluators noted the wrist-worn device would not provide alerts other than for low battery. They mentioned that they could see physiological data on the phone app, but that it did not provide any alerts either.

4.1.3 Deployability

The Empatica EmbracePlus received a deployability score of 3.6. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Scalability:** Three evaluators said that the EmbracePlus met all their expectations regarding its ability to be scalable, two evaluators said that it met most of their expectations, and another two that said it met some of theirs. Evaluators noted that because data privacy management prevents a single device from being worn by multiple users, each individual would need to have their own device. They found the product a scalable solution but indicated it would be more costly than if users could share sensors. An evaluator commented that agencies could not scale down or turn off active. One evaluator said the product seems more suitable for long-term monitoring than for shorter, intermittent use cases.
- **Software Compatibility:** One evaluator said that the compatibility of the product's software with multiple platforms exceeded their expectations; four evaluators said that it met all their expectations; and two said that it met most of theirs. Evaluators mentioned that because the command interface is a web portal, it requires internet access and a stable Wi-Fi connection at the incident location which can be a challenge. The evaluators liked that the command interface can be accessed by different users on multiple computers simultaneously, and that all smartphones would be able to run the app.
- **Third-party Software Integration:** On the ability to support third-party software integration, two evaluators said that the product exceeded their expectations, two evaluators said that it met all their expectations, and three evaluators said that it met most of their expectations. One evaluator thought perhaps proprietary aspects of the product might inhibit software integration capabilities.

4.1.4 Maintainability

The Empatica EmbracePlus received a maintainability score of 3.9. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Cleaning/Decontamination:** Two evaluators said that the EmbracePlus exceeded their expectations, and five evaluators said that it met all their expectations. Evaluators found it was easy to clean the sensor with isopropyl alcohol and a cotton pad. One evaluator said, however, that it could be difficult to decontaminate the many small holes in the wrist strap.
- **Durability:** Three evaluators stated that the product's apparent durability met all their expectations, and another three said that it met most of theirs. One evaluator said that it only met some of their expectations. Despite the relatively high scores, evaluators expressed concerns about the ruggedness of the sensor device, noting that the vendor did not share any durability specifications (e.g., ingress protection (IP) ratings [4] or MIL-SPEC testing).Evaluators suggested the glass face could be subject to damage or scratching (despite its being made of scratch-resistant material) and the lifespan of the silicone wrist strap could be limited.
- **Battery Type:** Two evaluators said the battery type exceeded their expectations, four evaluators said that it met all their expectations, and one evaluator said that it met most of their expectations. One evaluator said that the product's rechargeable batteries' lifetime of two years is a disadvantage of the device. Similarly, another evaluator noted that they would have preferred it use replaceable batteries, so that the device would not have to be returned to the manufacturer for a battery change service. Evaluators recognized that the battery charging seemed quick and easy, and indicated that a future on-arm charger, currently in development by the manufacturer, would be a welcome feature.
- **Customer Support:** One evaluator said that customer support options exceeded their expectations, while six evaluators said that it met all their expectations. Evaluators made positive comments about Empatica providing 24-hour reach back with the purchase, users' having support available 99% of the time within the same day for urgent issues by phone or email, and the online access to troubleshooting materials.
- **In-House Maintenance:** Evaluators noted that no in-house service or calibration is needed for the EmbracePlus.

4.1.5 Affordability

All criteria in the Affordability category are "information only." These criteria did not contribute to the product's overall score, but the NUSTL team still recorded responder comments regarding them:

- **List Price:** Evaluators had an unanimously negative impression of the affordability of the EmbracePlus for use within firefighting agencies. They estimated the cost would exceed $300,000 a year for a department with about 500 staff to be monitored. They also felt the required contract period of two years is too long.
- **Additional and Recurring Costs:** One of the evaluators noted that the need for a cell phone with data service is an associated cost to using this product.
- **Contract Listing:** There is no contract listing applicable to the EmbracePlus.

4.2 Equivital, eq02+ LifeMonitor and Black Ghost

The Equivital eq02+ LifeMonitor and Black Ghost uses a chest-harness-mounted sensor to capture the wearer's physiological data. It was the only chest-worn product in this assessment. The product measures the wearer's two-lead ECG, heart rate, % heart rate maximum, respiration rate, activity, posture, fall detection, core and skin temperature, and heat strain index.

Data is wirelessly transferred by Bluetooth low energy to a nearby or on-body smartphone or radio and from there it is transferred – using either Wi-Fi, cellular data or radio frequency – to the cloud or a server. Equivital's computer software, Black Ghost, can be used to monitor and manage wearer data with an internet connection. The data are encrypted following the National Institute of Standards and Technology (NIST) recommended practices, which includes multi-factor authentication, user definable compromised password lists, highly secure data servers and services, and audit and security logging. The product is compliant with the Health Insurance Portability and Accountability Act and General Data Protection Regulation. Data sharing may be accomplished using a secure application programming interface.

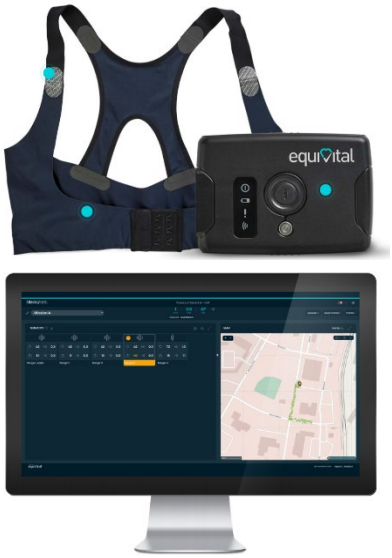


Figure 4-2 Equivital eq02+ LifeMonitor (top) and Black Ghost (bottom)

Image Credit: Equivital

According to the vendor, the rechargeable lithium-ion battery in the sensor device will provide up to 24 hours of continuous monitoring on a single charge. The battery is hot-swappable, so it can be replaced as needed without interrupting the system operation. External battery packs which accept commercially available AA batteries are available. It takes about one hour to fully charge a completely discharged unit.

The product can be purchased through either operational expenditure (OpEx) or capital expenditure (CapEx) pricing models. With CAPEX purchases, additional expenses include the software and replacement components. The cost of Equivital eq02+ LifeMonitor with Black Ghost software was said to be about $1000 per unit over a five-year period. The product is available through the General Services Administration (GSA) purchasing.

The Equivital eq02+ LifeMonitor and Black Ghost received an overall assessment score of 4.1. Evaluator comments provided throughout the assessment are reported below, grouped by SAVER category. In each category, the criteria are listed according to their order of importance as assigned by the physiological monitoring systems focus group (see Table 2-1).

4.2.1 Capability

The Equivital eq02+ LifeMonitor and Black Ghost received a capability score of 4.2. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Health Status Alerting:** Two evaluators stated the product exceeded their expectations regarding the ability to provide alerts, three said that it met all their expectations, and two said that it met most of their expectations. Evaluators commented positively on the timeliness of sensor data and alerts (i.e., its refresh rate of about every 15 seconds) and the details provided with the alerts. One evaluator noted that the system was showing alerts for some things that were not even on the software/command dashboard. Evaluators noted that the system did not provide any haptic alerts to the wearer, but the vendor indicated that this was in development.
- **Physiological Measures:** Six evaluators said that the measures provided by the eq02+ LifeMonitor exceeded their expectations, while one said that it met all their expectations. Most evaluators noted that having a two-lead ECG, as opposed to just heart rate measurements, was beneficial even though, as one evaluator noted, the EKG had some delay appearing on the dashboard. Two evaluators also said the heat strain index was a good measure to have for firefighting applications. One evaluator remarked that the 15-second refresh rate was a positive feature. Two evaluators pointed out that they would have liked for the device to have included a measure of blood oxygen saturation as well.
- **Remote Sensor Platform:** One evaluator said that the product exceeded their expectations, one said that it met all their expectations, and five stated it met most of their expectations. Evaluators commented that needing to transmit data to a separate on-body device (e.g., phone or radio) was not ideal. Most evaluators, however, did like that the product will communicate through a handheld radio since those are almost always with each responder already. For this assessment, though, smartphones – not radios – were used as the on-body device. One evaluator commented that they did not observe any issues with the pairing or connectivity to the smartphone.
- **Data Privacy:** One evaluator said the Equivital eq02+ LifeMonitor and Black Ghost exceeded their expectations concerning data privacy, and the six others said it met all their expectations. Evaluators' comments included that it's good to have HIPAA compliance, that they felt high confidence in the protection of data privacy, and the system made it easy to identify individual wearers.
- **Data Sharing:** Four evaluators said that the ability to share data using this product exceeded their expectations, while three evaluators said it met all their expectations. An evaluator noted that the data can be saved as a mission and be stored on any device, such as smartwatches. Another evaluator thought that the ability to share data was particularly useful for the case of ECG data since it captures detailed information that cannot otherwise be easily relayed. An evaluator pointed out that the data sharing process seemed easy to perform. One evaluator mentioned that an advantage of the Equivital system is that physiological data can be integrated with telemetry data recorded and transmitted by newer SCBA models.
- **Profiles or Baselines:** Four evaluators said the ability to create profiles or baselines for individual wearers with this product exceeded their expectations, and three said it met all of theirs. The evaluators liked that the product permits the user to apply alarm thresholds for a group or an unlimited number of individual wearers. One evaluator mentioned they could easily adjust the profiles between wearers and use the dashboard to relabel the wearer as desired.

- **Location Services:** When a smartphone is used to transmit the data, locations of the wearers is available in the data through the global positioning system (GPS). Several evaluators pointed out they would rather use the Equivital system with a radio than a smartphone, which would limit the ability to take advantage of location services. This capability is available as a map on the command interface and does not include a three-dimensional position; it is possible to replay tracks at real-time or faster speeds.

4.2.2 Usability

The Equivital eq02+ LifeMonitor and Black Ghost received a usability score of 3.9. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Accuracy:** Three evaluators said the perceived accuracy of this product exceeded their expectations, and four evaluators said that it met all their expectations. Evaluators noted positives like not seeing any false alerts, the system alerting users when the sensor was not mounted properly, the system being approved by the US Food and Drug Administration , and their satisfaction with the product's overall accuracy.
- **Battery Life:** Two evaluators said the battery life of the eq02+ LifeMonitor and Black Ghost exceeded their expectations, and five evaluators said it met all their expectations. The 24-hour duration of a fully charged battery was acceptable to the evaluators since it would last for a full duty shift. Evaluators noted positive features of the battery including it having a hot-swappable option and an external battery pack with commercial alkaline cells that would enable the system to run without interruption. One evaluator suggested there should be a pouch for the external battery pack, so that it would be held in place.
- **Comfortable Fit:** One evaluator said the comfort of the product's sensor exceeded their expectations, three said it met all their expectations, and three said it met most of their expectations. The comments provided by evaluators also varied. In particular, some said they did not even notice they were wearing it under their turnout gear after a few minutes, while others said it was comfortable but remained noticeable. Males who wear the chest harness might find it more noticeable than females that typically wear tight clothing around their chest, such as a bra. The female evaluator gave the eq02+ LifeMonitor the highest score among the evaluators for this criterion and stated that the product was very supportive and comfortable. Evaluators noted that with multiple sizing options available for the chest harness, users would need to select the appropriate size.
- **Command Interface:** Evaluators considered the command interface to be a distinct advantage of this product. All seven evaluators said that the Black Ghost software exceeded their expectations. Evaluators commented the dashboard was well organized, intuitive, user-friendly, and easy to use. Other positive feedback about the dashboard included the customizability of what data is displayed, that environmental temperature can be included in the display, and its geofencing and mapping capabilities. Evaluators also liked that access to data can be controlled and limited by a user role that the dashboard's data recording and playback features could be used for after-action reporting, and that events could be set and stopped.

- **Ease of Donning and Activation:** Four evaluators stated that the ability to quickly put on the eq02+ LifeMonitor and Black Ghost and begin monitoring met all their expectations, while three said it met only some of their expectations. Most evaluators mentioned that the placement of the chest harness takes more time than sensors worn elsewhere on the body, but it was not very difficult to don. Evaluators noted using this product requires correct sizing to ensure it will function properly and that wearers would need to verify that the straps and sensor are in the correct positions. One evaluator found the snaps on the harness a bit challenging to use but thought snaps were a good approach to making the harness slimmer relative to a buckle or Velcro options. That evaluator also mentioned that donning and doffing the device requires privacy since it's worn on the chest under clothing.
- **Compatibility with PPE:** One evaluator said the compatibility of the product with their PPE exceeded their expectations, four evaluators said it met all their expectations, one evaluator said it met most, and one evaluator said it met some of their expectations. Those evaluators who gave the product a favorable score for this criterion noted that it was comfortable and did not interfere with their PPE. One evaluator mentioned that, while it did not interfere with their PPE or activities they performed, it would be impossible to adjust the sensor without taking off their PPE. Another pointed out that the sensor would not be easy to don just before an emergency response since it must be worn under clothing and PPE.
- **Wearer Interface:** Feedback on this criterion varied widely. One evaluator said the wearer interface exceeded their expectations, one said it met most, two said it met some, and three said it met none of their expectations. Most of the evaluators' perceived shortcomings such as its not sending a haptic alert to the wearer, the need to use a phone to see any data or alerts for themselves, and that using handheld radio to transmit data would mean that user could not receive any direct alerts from the product. One evaluator noted that the vendor indicated that they would develop alerts for the wearer in the future.

4.2.3 Deployability

The Equivital eq02+ LifeMonitor and Black Ghost received a deployability score of 4.4. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Scalability:** Three evaluators said the scalability of the product exceeded their expectations, and four evaluators said it met all of theirs. Evaluator comments were all favorable and included: that it is easy to addition new wearers, that a large (essentially unlimited) number of wearers can be monitored, that the command interface is easy and user friendly for monitoring multiple wearers, that command can sort wearers on the interface by type of alert, and that a single sensor could be exchanged for use by multiple wearers.
- **Software Compatibility:** Two evaluators said the compatibility of the product software with multiple platforms exceeded their expectations, and five evaluators said it met all their expectations. Evaluators noted that the software could run on multiple types of devices. One evaluator mentioned that they did not like that the command interface is installed on a laptop. Because installing the software can pose administrative and other challenges, they would have preferred a web-based interface. One evaluator liked the ability for multiple people to monitor the data at the same time on different platforms.

- **Third-party Software Integration:** On the ability to support third-party software integration, four evaluators said the product exceeded their expectations while three said it met all their expectations. Four evaluators commented on the benefits of being able to incorporate data from other sensors and systems into the product's user interface. Evaluators also pointed out that the eq02+ LifeMonitor data being able to be exported to other systems is a plus. One evaluator noted favorably that the vendor provides the necessary support to accomplish the data exchange between systems.

4.2.4 Maintainability

The Equivital eq02+ LifeMonitor and Black Ghost received a maintainability score of 4.0. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Cleaning/Decontamination:** One evaluator said that the product exceeded their expectations, five evaluators said that it met all their expectations, and one said that it met most of their expectations. Most evaluators thought it would be easy to clean the sensor by wiping it with a disinfectant and easy to clean the harness by laundering it. However, one evaluator mentioned that the need to launder the harness could limit its short-term reusability.
- **Durability:** Five evaluators mentioned the product's apparent durability met all their expectations, while one evaluator said it met most of their expectations, and another said it met only some of their expectations. Evaluators appreciated that the sensor has an IP67 rating (i.e., dust tight and can be immersed in water up to one meter), is intrinsically safe, and conforms to standards. The evaluators also expressed concerns about the durability of the harness. One evaluator said that they thought the harness could be subject to tears or damaged snaps. Another mentioned that while the warranty can be extended, they expect the strap would last only six to 12 months if used regularly.
- **Battery Type:** Three evaluators said the battery type in the Equivital eq02+ LifeMonitor exceeded their expectations, and four evaluators said it met their expectations. Evaluators liked the battery options of a rechargeable internal battery and a hot-swappable COTS external alkaline battery pack. An evaluator also expressed that they found the six unit charging station useful and easy.
- **Customer Support:** Two evaluators indicated the customer support stated for the product exceeded their expectations, and five evaluators said it met all their expectations. The evaluators pointed to availability of good website information, video tutorials, a robust train-the-trainer program and phone and email access to vendor assistance as the basis for their scores.
- **In-House Maintenance:** Evaluators noted that in-house service or calibration isn't needed for the Equivital eq02+ LifeMonitor nor would they desire it.

4.2.5 Affordability

All criteria in the Affordability category are "information only." These criteria did not contribute to the product's overall score, but the NUSTL team still recorded responder comments regarding these criteria:

- **List Price:** Evaluators indicated that the cost associated with the Equivital eq02+ LifeMonitor is reasonable at about $1000 per sensor. They appreciated that no subscription service payments were necessary for using the system.

- **Additional and Recurring Costs:** Evaluators noted no recurring costs to consider with the system, but mentioned the potential need to purchase replacement harnesses as they wear out through use.
- **Contract Listing:** Several evaluators liked that the product is listed on the GSA schedule.

4.3 Five Vital Signs, Detect-C

The Five Vital Signs Detect-C uses an armband-mounted sensor to capture the wearer's physiological data. It was one of three armband products in this assessment. The product measures the wearer's heart rate, respiration rate, body temperature, blood oxygenation level, activity, as well as detects falls and the ambient temperature around the sensor.

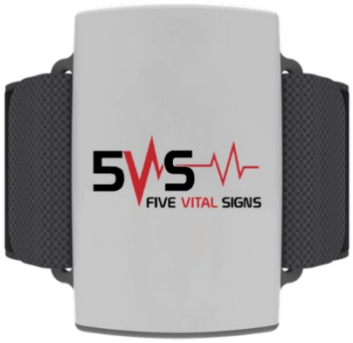


Figure 4-3 Five Vital Signs Detect-C

Image Credit: Five Vital Signs

The data is collected in real time, stored every two minutes, and can be wirelessly transmitted using internal Bluetooth 5 (up to 800 feet), Wi-Fi or LoRaWAN global 4G modem. It does not require any routers, hubs, or other intermediary electronics to transmit data to the command interface. Detect-C's command interface is a customizable web-based portal dashboard that displays multiple wearers' real-time data and provides alerts when a wearer's preset limits are crossed or the wearer falls. Dashboard features include data analytics as well as reporting and downloads of stored historical data. Access to the dashboard is through a secure cloud login. Data sharing may be accomplished using dashboards connected to the server or sending downloaded data. The system is HIPAA-compliant through multiple security measures with customizable usernames that help protect personal information.

According to the vendor, the rechargeable zinc air battery in the sensor device will provide up to 10 days of continuous monitoring on a single charge depending on the mode used and frequency of data transmission (six hours for the real-time use case). The device uses a USB 3.0 fast charger.

The product costs about $1000 per unit with prices adjusted based on the number purchased. Additional costs would include cellular service and a subscription service that varies by customer needs.

The Five Vital Signs Detect-C received an overall assessment score of 3.4. Evaluator comments provided throughout the assessment are reported below, grouped by SAVER category. In each category, the criteria are listed according to their order of importance as assigned by the physiological monitoring systems focus group (see Table 2-1).

4.3.1 Capability

The Five Vital Signs Detect-C received a capability score of 3.4. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Health Status Alerting:** Two evaluators said that the product met most of their expectations in providing alerts to command, and five evaluators said that it met some of their expectations. Evaluators indicated they could not feel the haptic alerts from the sensor and that while the lights could be seen by others, they could not be seen by the wearer. The lights on the sensor would be covered by clothing and PPE during operational use. One evaluator mentioned they could only feel the vibration that indicates the sensor is powering down. Regarding the dashboard alerts, the evaluators noted they could not immediately tell which measures the alerts were generated to indicate.

- **Physiological Measures:** Two evaluators said that the measures provided by the Detect-C exceeded their expectations, three evaluators said that it met all their expectations, and two said that it met most of their expectations. Many of the comments from evaluators were about the lack of an ECG and blood pressure capability with the Detect-C sensors. The vendor mentioned that these measures could be obtained with a separate disposable chest patch sensor they have on the market. A couple of evaluators mentioned that fall detection would not be a measure that they have a need for; they thought it could also trigger false alerts when a firefighter is performing tasks while on the ground, although there was not any indication that this occurred during the assessment.
- **Remote Sensor Platform:** One evaluator said that the product exceeded their expectations regarding this criterion, two evaluators said that it met all their expectations, and four evaluators stated that it met most of their expectations. Evaluators commented that the ability to transmit data without a cellphone was beneficial since they prefer not needing to carry an additional device on their person. One evaluator mentioned they found that data transmission effective and easy, but a couple of others reported a lag in the data transfer that lasted over two minutes, which would not be suitable for incident response.
- **Data Privacy:** Two evaluators said that the Detect-C exceeded their expectations concerning data privacy, and five evaluators said that it met all their expectations. Evaluators liked the ability to enter their choice of the usernames that help protect the identity of each individual's personal data in the system. They also appreciated that the product has US Department of Defense approval for use with satellite communications, providing further assurance that the data privacy is appropriately addressed.
- **Data Sharing:** Six of the evaluators said that the ability to share data using this product met most of their expectations and one evaluator stated it only met some of theirs. Evaluators noted that the process to share data with this system was not as straight-forward as they would like and cannot be done in real time; the user must transmit the data as a downloaded report.
- **Profiles or Baselines:** Five evaluators said that the ability to create profiles or baselines for individual wearers with this product met all their expectations, one evaluator stated that it met most of their expectations, and one evaluator said that it met only some of their expectations. Two evaluators thought that it was not easy to adjust alarm thresholds. Nevertheless, some evaluators liked the product's options to adjust thresholds based on the age, weight, and height of individuals. One evaluator noted that the vendor indicated they plan to provide more user control over the thresholds in the future.
- **Location Services:** Location of the wearers is available data through Bluetooth, Wi-Fi, and LTE networks. However, evaluators only noted the product provides 2-dimensional, not 3-dimensional, location records; they indicated that solution would probably be accurate enough for their needs. They also mentioned the drawback that location was not incorporated into the command interface.

4.3.2 Usability

The Five Vital Signs Detect-C received a usability score of 3.1. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Accuracy:** Two evaluators said the perceived accuracy of the product met all their expectations, four evaluators said it met most of their expectations, and one evaluator said it met only some of their expectations. Evaluators expressed a lack of confidence in body temperature values. Temperature readings of 0° Celsius were observed by evaluators, and the vendor explained that these readings were the result of an improperly placed sensor that resulted in an inability to measure temperature. An evaluator mentioned that it would be better to have some other type of indicator when a temperature reading is not available. Also, one evaluator had a false high temperature reading.
- **Battery Life:** One evaluator said the battery life of the Detect-C met all their expectations, three said it met most of their expectations, and three said it met only some of their expectations. Evaluators stated that when the system is used for real-time monitoring and reporting, the sensor battery drains too quickly (the vendor's specification is six hours) and then requires a one hour recharge during which it is unavailable. One evaluator noted that the battery life would make it reasonable to use for incident responses, but not for long-term monitoring.
- **Comfortable Fit:** Three evaluators said that the comfort of wearing the product's sensor exceeded their expectations, and four evaluators said that it met all their expectations. Most of the evaluator comments were favorable, including that it was comfortable to the point of forgetting one is wearing it, it did not interfere with any movement, it stayed in place, and it is slim and does not get caught on gear. They also appreciated that different sizes are available. A negative comment from one evaluator was that the band irritated their arm after a couple of hours of wear. The vendor indicated the device works over tattoos, but at least one evaluator had to reposition the sensor because of a tattoo.
- **Command Interface:** Three evaluators stated that the command interface for Detect-C met most of their expectations, two said that it met only some of their expectations, and another two said that it met none of their expectations. While evaluators thought the interface was generally easy to use, they also mentioned various drawbacks. Evaluators stated the interface contained too much information and disliked that configuration changes had to be done on individual devices rather than implemented globally on the command interface. They also noted the refresh rate of the interface was not sufficient to get real-time alerts during operational use and would have preferred temperature be displayed in Fahrenheit rather than in degrees Celsius. Other negative evaluators comments included their noting that trends of measurements were not displayed, and that it was difficult to identify what was alarming. One evaluator suggested that it would be better if the individual generating an alarm was displayed at the top of the screen. Another said that they would like to be able to access the history with one button rather than the more time-consuming report creation process that is currently available.
- **Ease of Donning and Activation:** One evaluator said that the ability to quickly put on the Detect-C and begin monitoring exceeded their expectations, five evaluators stated that it met all their expectations, and one evaluator said that it met most of their expectations. Evaluators liked these characteristics for this product and found the sensor relatively easy to put on and activate. One evaluator mentioned that there should be a training component for wearers so they would be able to better interpret the LED indicators on the sensor.

- **Compatibility with PPE:** Two evaluators said that the compatibility with PPE exceeded their expectations, and five evaluators said that it met all their expectations. Most evaluators did not have any issues with this aspect of the product's usability.
- **Wearer Interface:** One evaluator said it met some of their expectations, and six evaluators said that it met none of their expectations. Evaluators stated they did not notice the haptic alerts from the sensor. Further, the display lights on the sensor were covered by clothing and PPE, and the system did not convey any other information to the wearer. Evaluators suggested it would be helpful if the haptic alert sent a stronger vibration. One evaluator suggested a user-configurable haptics setting as a design improvement. Another said that they would prefer a loud and lengthy audible alert.

4.3.3 Deployability

The Five Vital Signs Detect-C received a deployability score of 3.5. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Scalability:** Four evaluators said that this product met all their expectations in regard to its ability to be scalable, and three evaluators stated that it met most of their expectations. Adding monitored individuals requires physically touching each sensor. Evaluators reported it was cumbersome to get everyone displayed on one screen and noted that adding monitored individuals would need to be done at specific times rather than simply whenever desired. Other evaluators said they liked the ease of taking the steps needed to add additional wearers: it would take only about five minutes to get accurate readings and the number of wearers that could be displayed was essentially limitless once they'd been added.
- **Software Compatibility:** Two evaluators said that the compatibility of the product software with multiple platforms exceeded their expectations, and five evaluators said that it met all their expectations. Evaluators liked that the dashboard is accessible on multiple platforms, with both a phone app and a web portal, and can be used by multiple people simultaneously. One evaluator said that the smartphone app was a bonus. Another evaluator added the observation that the app only worked in landscape mode.
- **Third-party Software Integration:** On the ability to support third-party software integration, one evaluator said the product met all their expectations, two evaluators said it met most of their expectations, and four evaluators said it met some of their expectations. One evaluator commented there does not seem to be a seamless way to integrate the system with third-party software, while another mentioned a known application programming interface (API) exists that can accomplish it.

4.3.4 Maintainability

The Five Vital Signs Detect-C received a maintainability score of 3.8. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Cleaning/Decontamination:** Two evaluators said that the Detect-C exceeded their expectations, four said that it met all their expectations, and one evaluator said that it met most of their expectations. Some evaluators thought cleaning was easy and quick for this product. Other evaluators specified that the armbands could be difficult to clean but they could also be laundered or replaced. One evaluator mentioned that submerging the sensor when cleaning, makes it susceptible to damage and added that crevices in the unit could also be tough to clean.

- **Durability:** Six evaluators mentioned that the product's apparent durability met all their expectations, and one evaluator said that it met most of their expectations. Evaluators thought it seemed capable of withstanding the moisture and shock conditions encountered in operational environments. One evaluator commented that while the device is rated at IP65 (dust tight and protected from water jets from any direction), they would have preferred the device had a higher IP water rating (to allow for temporary immersion during cleaning).
- **Battery Type:** Two evaluators said that the battery type in the Detect-C met all their expectations, and five evaluators said that it met most of their expectations. Evaluators liked that the sensor used a rechargeable battery. Several evaluators would have preferred it use a battery that is removeable and replaceable, so that the device can continue to be used for longer periods without recharging and would not need to be returned to the manufacturer in the case of a battery failure. A couple of evaluators mentioned that it would be ideal if the product allowed hot swapping of batteries.
- **Customer Support:** One evaluator said that the customer support options for the product exceeded their expectations, three evaluators said that it met all their expectations, and three evaluators said that it met most of their expectations. Despite the relatively high score, two evaluators noted that very little information was provided on what customer service entails. One evaluator liked that the vendor offers no-cost replacements if a product is damaged from use.
- **In-House Maintenance:** Evaluators noted that in-house service or calibration isn't needed for the Detect-C, nor would most of them have wanted it.

4.3.5 Affordability

All criteria in the Affordability category are "information only." These criteria did not contribute to the product's overall score, but the NUSTL team still recorded responder comments regarding these criteria:

- **List Price:** Evaluators thought the price of the Detect-C was reasonable at about $1000 per sensor. They liked that the price was per device, and not per user, such that a single device could be shared by multiple firefighters and reduce the overall cost.
- **Additional and Recurring Costs:** Evaluators noted that cellular data service and a subscription would be recurring costs that need to be considered. Evaluators also expressed concern that the vendor did not provide information about the subscription price.
- **Contract Listing:** Evaluators noted that they would only be able to purchase the product through the vendor, but additional options would be preferred. A contract listing is not an option.

4.4 Kenzen, Kenzen Device

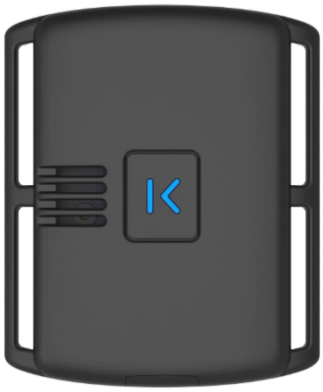


Figure 4-4 Kenzen Kenzen Device

Image Credit: Kenzen

Kenzen's Kenzen Device uses an armband-mounted sensor to capture the wearer's physiological data. It was one of three armband products in this assessment. The product measures the wearer's heart rate, body temperature (core and skin), humidity, as well as the ambient temperature and humidity around the sensor.

The sensor can store approximately two weeks of data, and data is wirelessly transmitted using internal Bluetooth Low Energy to an on-body smartphone. From the phone, data is then transmitted over either Wi-Fi or LTE cellular data to a cloud server. A phone app is used for the wearer's direct interface and shows their individual status and team data. The sensor also has the capability to provide haptic alerts to the wearer. The Kenzen command dashboard is a web portal accessed through an internet browser. The dashboard provides users with administrative functions such as managing users and remote real-time monitoring of up to 10 wearers per page. Color coding on the dashboard provides indications of the wearers' monitoring status. The product has System and Organization Controls II compliance and uses Microsoft Azure for data security and encryption. Data sharing is not currently supported by the system but can be provided as a feature upon request.

According to the vendor, the rechargeable Lithium-ion battery in the sensor will provide up to 18 hours of continuous monitoring on a single charge. The device uses a USB charger that can completely recharge a discharged battery in as little as three hours.

The product device and user fees are $350 per user for each year. An additional $2500 per year per organization is needed to provide data hosting and security. There is also a one-time set up and implementation charge (including onsite training) of $2000. Additional recurring costs include required smartphone and cellular data services.

The Kenzen Device received an overall assessment score of 3.2. Evaluator comments provided throughout the assessment are reported below, grouped by SAVER category. In each category, the criteria are listed according to their order of importance as assigned by the physiological monitoring systems focus group (see Table 2-1).

4.4.1 Capability

The Kenzen Device received a capability score of 2.7. Evaluator feedback on evaluation criteria related to this SAVER category included:

- Health Status Alerting: Three of the evaluators said that product met all their expectations regarding the ability to provide alerts to command, one said that it met most of their expectations, and three said that it met only some of their expectations. Evaluators mentioning that it met their expectations noted that they liked the one minute refresh rate of streaming data on the command interface since it would allow alerts within a minute of a change. They also commented that alerts triggered the sensor to vibrate for about 20 seconds, which they could feel on their arm, and were noticeable on the dashboard. Evaluators who stated that it met only some of their expectations expressed concerns about the need to carry a phone for the data to be transmitted to command (see section 4.1.1 for additional feedback expressed on this topic). These evaluators also said they did not think the haptic alert in the sensor would be noticed by the wearer during an emergency response. One evaluator mentioned that they would have liked if it generated alerts based on the wearer's heart rate, and another thought that the system should have a range of alert levels. (The Kenzen device provides "stop work" and "return to work" alerts that are based on the vendor's proprietary algorithm.)
- Physiological Measures: Four evaluators said that the measures provided by the Kenzen Device met most of their expectations, while three evaluators stated that it only met some of their expectations. Evaluators commented that the system provides only the minimum of desirable physiological measures: heart rate and body temperature. Other measures they said they would like to have include heart rate variability, blood pressure, respiration rate, blood oxygenation saturation, and ECG.
- Remote Sensor Platform: Three evaluators stated that this product met some of their expectations, and four evaluators stated that it did not met meet any of their expectations. When scoring this criterion, the evaluators again cited the need to carry a phone or have one within 30 feet of them as an issue. The evaluators said it was impractical to have a phone during responses, they did not want to have to depend on a cellular infrastructure, and they were concerned with the safety of phones in response environments.
- Data Privacy: Two evaluators said that the product exceeded their expectations regarding this criterion, and five evaluators said that it met all their expectations. Evaluators commented that the data was secure and encrypted appropriately. One evaluator said they liked that the labels assigned to individuals are customizable, so that the identifying information did not contain a person's name. Another evaluator recalled that the vendor mentioned that some agencies don't use Microsoft Azure, however, which is the basis of the product's data security.
- Data Sharing: Three evaluators said that the ability to share data using this product met most of their expectations, and four evaluators said that it met only some of their expectations. Evaluators noted that this capability isn't already available for the Kenzen Device; rather, the vendor said data sharing is a capability that can be added. Most evaluators did not think it would be necessary to share data for the two measures provided by this system (heart rate and temperature) since they could simply report those by radio. One evaluator said they would want permissions within the system to be assigned by role rather than by an individual, and they would want a generic inbox for the command dashboard rather than one assigned to specific users only.

- **Profiles or Baselines:** Five evaluators said that the ability to create profiles or baselines for individual wearers with this product met most of their expectations, and two others stated that it met only some of their expectations. Evaluators reported that they were able to set up profiles for individual users fairly easily, but the process of transferring a sensor between users was too time consuming. Several evaluators mentioned they were not able to change the alert thresholds for individual wearers.
- **Location Services:** The Kenzen Device does not include data on the location of the wearers.

4.4.2 Usability

The Kenzen Device received a usability score of 3.5. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Accuracy:** All seven of the evaluators said that the perceived accuracy of this product met all their expectations. Evaluators thought the values reported were pretty accurate and comparable to the finger pulse oximeter and contactless thermometer values throughout the assessment of the Kenzen Device. They mentioned that the one minute refresh rate of the dashboard data was fine for their use case but could result in some differences between real-time field measured values and those reported on the Kenzen dashboard.
- **Battery Life:** Two evaluators said that the battery life of the Kenzen Device met most of their expectations, four evaluators said that it met only some of their expectations, and one evaluator said that it met none of their expectations. Evaluators stated that needing to recharge a sensor before a 24-hour shift is completed is not practical. They also noted that the time needed to recharge the batteries is too long for a shift change. They thought it would be necessary for the product to have swappable batteries for firefighter use cases. One evaluator also mentioned they do not have sufficient power outlets availability for charging sensors near their fire department vehicles. An evaluator who gave this criterion one of the higher scores said that they would not wear a sensor for an entire shift, so the battery life would be sufficient.
- **Comfortable Fit:** Four of the evaluators reported that the comfort of wearing the sensor exceeded their expectations. Two other evaluators said that it met all their expectations, and one said that it met most of their expectations. Most of the evaluators had favorable comments on this criterion including it was comfortable to the point where they could forget they were wearing it, it stayed in place during assessment activities, and its material did not cause them to become sweaty. One evaluator who gave this criterion a lower score found that it was restrictive when lying down and resting, but another evaluator thought they could sleep in it without any problem.
- **Command Interface:** Three evaluators stated that the command interface for the Kenzen Device met all their expectations, another three said that it met most of their expectations, and one said that it met only some of their expectations. Multiple evaluators considered the interface easy to use. They liked the information displayed by the interface and its layout, the options to dive deeper into an individual wearer's data, and the ability to display at the top of the screen the wearers at most risk. There were also several comments on aspects they did not like about the interface including: lacking a way to view trends in the data, inability to view multiple wearers' data simultaneously, no capacity to customize wearer profiles to assign them to user groups, a noticeable lag for the data displayed, a cumbersome process to change between different wearers displayed, and the use of a yellow status for connectivity issues, which was counterintuitive given expected red-yellow-green indications for health status alerts.

- **Ease of Donning and Activation:** Three evaluators said that the ability to quickly put on the Kenzen Device and begin monitoring met all their expectations, and four evaluators stated that it met most of their expectations. The experience of most of the evaluators was that it was quick and easy to put on and activate by themselves. One evaluator reported they needed the vendor to assist them when the sensor did not initially connect to the smartphone, and another evaluator noted that the activation took longer than they had expected. One evaluator stated that it was not easy to thread all the straps through the slots before applying the sensor. A couple of evaluators also noted that wearing the sensor over tattoos was an issue and speculated that it could be challenging to use under long sleeve shirts.
- **Compatibility with PPE:** Two evaluators said that the compatibility of the product with other PPE exceeded their expectations, and five evaluators said that it met all their expectations. Most evaluators did not have any, nor did they foresee, issues with this aspect of product usability and thought it would integrate well with PPE. They stated it is small and did not have any snag points that would be a concern. One evaluator mentioned that sensor position cannot be adjusted once their PPE is on.
- **Wearer Interface:** Four evaluators said that it met most of their expectations while the other three said that it met only some of their expectations. Most evaluators found that the haptic alert could be felt but questioned whether it would be noticed during an emergency response situation. One evaluator said they did not notice any alerts while they performed activities. Another thought that it would be better if the alert had an adjustable setting. Two of the evaluators mentioned they would not be concerned if they could not feel the haptic alert as long as there was someone from command monitoring it. Two evaluators disliked that the app does not provide them with an ability to see their trends. One evaluator also mentioned they would have liked it to have alerts triggered by heart rate.

4.4.3 Deployability

The Kenzen Device received a deployability score of 3.0. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Scalability:** Evaluators' scoring of this criterion for this product differed widely depending on their experience and opinions of this functionality. Two evaluators said that this product met all their expectations in regard to its ability to be scalable, two said that it met most of their expectations, two said that it met only some of their expectations, and one said that it met none of their expectations. Those rating it higher noted that an unlimited number of users could be added if desired, but that cost of the product would be a limiting factor to consider. Other evaluators mentioned that it takes a bit of time to get a user profile set up, and while additional wearers could be added, they couldn't all be viewed on one dashboard. They also pointed out there is no capability to have multiple agencies in one dashboard. One evaluator reported this action could not be performed even with vendor support.
- **Software Compatibility:** One evaluator stated that the compatibility of the product software with multiple platforms exceeded their expectations. Five evaluators stated that it met all their expectations, and one stated that it met only some of theirs. Evaluator comments on this criterion were very few. Overall, the evaluators believed the product would function fine on the platforms they use.

- **Third-party Software Integration:** This criterion was another where the evaluators scores varied widely. Two evaluators said that the ability to support third-party software integration met all their expectations, two said that it met most, one said that it met only some, and two said that it met none of theirs. This scoring variability appears to be based on the evaluators' priority on the capability to use an API, a functionality that does not exist in the product at this time. An evaluator noted that the vendor said that they could probably provide this capability, but it is not usually done. Other evaluators expressed concerns that the data ownership and access to the data is only through the vendor. One evaluator noted that the system does have the capability to integrate weather data from an external internet source.

4.4.4 Maintainability

The Kenzen Device received a maintainability score of 3.8. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Cleaning/Decontamination:** Two evaluators indicated that the Kenzen Device exceeded their expectations, three evaluators said that it met all their expectations, and two said that it met most of their expectations. Evaluators generally agreed that it was very easy to clean and liked that spare straps with the product, should they be needed. One evaluator noted that they used a lot of isopropyl alcohol to clean it, and it did not damage the sensor; they also mentioned that it is a positive that soap and water can be used as well. One evaluator expressed a concern that cleaning solutions could possibly enter and damage the interior of the device through its opening for environmental measures. (The device's IP67, which indicates it is watertight up to one meter of water, challenges this assumption, however.)
- **Durability:** One evaluator mentioned that the product's apparent durability exceeded their expectations, and six evaluators said that it met all their expectations. Evaluators thought the product seemed quite durable. One evaluator noted that it has an IP67 rating, which means it is dust tight and can be immersed in water up to one meter. Another evaluator mentioned that the straps would probably wear out, but that would be acceptable and that they are a replaceable component.
- **Battery Type:** One evaluator said that the battery type in the Kenzen Device met all their expectations, and six evaluators said that it met most of their expectations. The concern that nearly every evaluator expressed is that the battery is not hot swappable and/or that the device cannot use other power supplies. A discharged sensor would need to be taken out of service for recharging, and a faulty battery would require that a sensor be out of service for repairs. One evaluator mentioned they did not like the way a full charge was indicated (by the color of an LED), and another did not like that the charging power supply was an alternating current plug since it would require multiple outlets.
- **Customer Support:** One evaluator indicated that the customer support options stated for the product exceeded their expectations, four evaluators said that it met all their expectations, and two evaluators said that it met most of their expectations. Evaluators noted that the smartphone app provides support contact information. (Customer support is available by phone, email, and internet portal.) The vendor's stated response time was within 24 hours. Some evaluators did not think that was an acceptable time, while others thought it would depend on what the issue was. One evaluator noted that there is a fee for customer support.
- **In-House Maintenance:** Most evaluators noted that in-house service or calibration isn't needed for the Kenzen Device nor would most desire it. One evaluator did express an interest in having some capability to make repairs on faulty sensors.

4.4.5 Affordability

All criteria in the Affordability category are "information only." These criteria did not contribute to the product's overall score, but the NUSTL team still recorded responder comments regarding these criteria:

- **List Price:** There were multiple comments from the evaluators concerning the Kenzen Device pricing. Some evaluators thought the price was reasonable although at least one of them was not confident that the pricing information from the vendor was firm. Evaluators commented on the pricing structure as well. One did not like that pricing was split between the sensor and services, while another would have preferred if the sensors accounted for a larger part of the costs (that is, that service would not have been such a large portion). One evaluator, who thought the costs were a bit high, wanted pricing options to reduce costs for bulk quantity purchases.
- **Additional and Recurring Costs:** Some evaluators thought that these expenses were reasonable; however, others disagreed. One evaluator who deemed the data services cost too high also mentioned that the need for smart phones and cellular service are additional costs to consider. Another evaluator did not think the subscription cost was appropriate, while one other said that the training cost is too high.
- **Contract Listing:** Evaluators noted that they would be able to purchase the product only through the vendor, as the vendor did not mention a contract listing option. Evaluators would prefer to have multiple ways to purchase the product.

4.5 Slate Safety, Band V2

The Slate Safety Band V2 uses an armband-mounted sensor to capture the wearer's physiological data. It was one of three armband products in this assessment. The product measures the wearer's heart rate, heart rate limit value, core body temperature, exertion level, calories burned, distance traveled, responder down detection, and GPS location. The sensor has an SOS tap alert feature that allows the wearer to signal command when they require assistance.

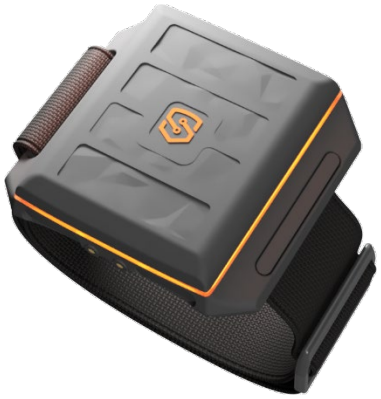


Figure 4-5 Slate Safety Band V2

Image Credit: Slate Safety

Data is wirelessly transmitted in one of three ways: using the Verizon cellular network, Bluetooth 5.3, or an optional 2.4 GHz gateway. The sensor switches between these networks based on availability. If none of these options is available, it stores data until a connection is established. Data is ultimately stored on a cloud server. The Band V2 command dashboard is a web portal accessed through an internet browser. The dashboard provides multiple views including a screen for multiple wearers' real-time data sorted by recent notification and then stoplight status (i.e., green, yellow, or red colors based on thresholds). Other dashboard features include charts to see trends, maps with locations of wearers and real time measurements, and individual user details.

The dashboard permits authorized users to establish threshold values for individual users or a team. Alerts are displayed on the dashboard and can also be sent to designated phones as text messages. The sensor provides haptic and stoplight indication LED alerts to wearers; vibration intensity and duration as well as light color signify different alert levels. Wearers also have an ability to push out an alert to command by tapping and holding the sensor until it vibrates. The product has System and Organization Controls II compliance. Customizable usernames further protect the privacy of individuals being monitored. Data sharing is accomplished by first downloading data that will be sent.

According to the vendor, the UL1642-certified rechargeable Lithium-ion battery in the sensor will provide 24 hours of continuous monitoring on a single charge (100 hours if GPS is off). The sensor charges with a USB cable or an optional multiple unit charger; the charging time is 3.5 hours.

The product sensor sells for $495. A monthly software service fee of $15 per device is also required. Additionally, gateways, storage cases, multi-chargers, replacement straps and onsite support are available for purchase.

The Slate Safety Band V2 received an overall assessment score of 4.3. Evaluator comments provided throughout the assessment are reported below, grouped by SAVER category. In each category, the criteria are listed according to their order of importance as assigned by the physiological monitoring systems focus group (see Table 2-1).

4.5.1 Capability

The Slate Safety Band V2 received a capability score of 4.3. Evaluator feedback on evaluation criteria related to this SAVER category included:

- Health Status Alerting: The Band V2 received the highest score possible in regard to ability to provide alerts to command: all seven evaluators said that it exceeded their expectations. Evaluators liked the real-time alerts provided by the product. They noted that someone would not need to monitor the dashboard all the time but could rely on alerts sent by text message. During assessment activities, evaluators noticed haptic alerts from the sensor and thought they were suitable for the operational environment. They liked the ability to transmit an SOS tap alert to command. One evaluator also commented that the prioritization of alerts on the dashboard was beneficial. The only negative comment was made by one evaluator when they said that alerts from this system could be overwhelming.
- Physiological Measures: Five of the evaluators said that the measures provided by the Band V2 met all their expectations; two evaluators said that it met most of their expectations. While evaluators noted that the system provides important measures, most said that they would like to have respiratory rate, blood oxygen saturation, and ECG data as well. They liked that the system provided GPS location. One evaluator pointed out that the sensor may not work over tattoos, which could be an issue for many firefighters.
- Remote Sensor Platform: One evaluator stated that this product exceeded their expectations regarding this criterion, and six evaluators said that it met all their expectations. Most evaluators commented that it worked well transmitting data over a cellular network during the assessment. One evaluator reported that they lost the cellular connection at one point, but when cellular connection resumed, the sensor reconnected, and their data showed on the dashboard. The evaluator thought this was good and also appreciated that they did not need to carry a separate device to relay the data.

- **Data Privacy:** Five evaluators stated that the Band V2 met all their expectations concerning data privacy, while two evaluators said that it met most of their expectations. Evaluators noted that there is not any need to include personally identifiable information of users for system functionality. An evaluator who scored this lower pointed out that the encryption is not provided by the vendor but is left up to the user. Another evaluator raised the issue of there being no mention of compliance with HIPAA requirements or NIST standards with regard to privacy.
- **Data Sharing:** Three evaluators said that the ability to share data using this product exceeded their expectations, and four evaluators said that it met all their expectations. Evaluators mentioned that although this feature was already incorporated into the product through an API, but they would require someone with appropriate expertise to use it. They also noted that data can be easily exported into an Excel file which can be sent to others and liked that the data ranges can be user specified.
- **Profiles or Baselines:** Four evaluators said that the ability to create profiles or baselines for individual wearers with this product exceeded their expectations, while three evaluators stated that it met all their expectations. When using the dashboard, evaluators found it easy to configure profiles and baseline thresholds for individual users. They also found it easy to switch a sensor between user profiles. Evaluators mentioned that the positive implication for this capability is that sensors can be easily shared among the staff and thus save the organization time and money.
- **Location Services:** Location of the wearers is available through GPS data. Evaluators indicated that solution was good for outdoor locations. Some of the evaluators expressed a need for indoor location tracking to include three dimensional and underground, but others did not think it was as necessary. An evaluator noted that the location was not available indoors once the GPS signal is lost. One evaluator said the map associated with the command interface was user friendly, but another evaluator disliked that the dashboard did not have an option to view all the wearers on the map.

4.5.2 Usability

The Slate Safety Band V2 received a usability score of 4.3. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Accuracy:** One evaluator said that the perceived accuracy of this product exceeded their expectations, and six evaluators said that it met all their expectations. Evaluators found the apparent accuracy of the Band V2 to be acceptable and comparable to the finger pulse oximeter and contactless thermometer values.
- **Battery Life:** Two evaluators stated that the battery life of Band V2 exceeded their expectation, while five evaluators said that it met all their expectations. Evaluators found the battery life was acceptable even with GPS data on (which they said wouldn't always be needed). They noted, however, that the charging time would require them to have extra sensors to ensure they could be used by all staff between shifts. They pointed out that having a hot-swappable battery would resolve this issue.

- **Comfortable Fit:** Six evaluators said that the comfort of wearing Band V2 sensor met all their expectations; one evaluator said that it met most of their expectations. Most evaluators commented that it had a perfect fit and was not noticeable while being worn. Some evaluators noted the adjustability of two separate straps for comfortable sizing as a good feature. Others noticed that the strap was made from a Nomex material, which would be good for firefighting applications. While most evaluators liked the strap of this product, not all of them did. One evaluator mentioned that while the Band V2 was not uncomfortable, they found it bulky and noticeable to wear.
- **Command Interface:** Five evaluators mentioned that the Band V2 interface exceeded their expectations, one evaluator said that it met all their expectations, and one evaluator said that it met most of their expectations. Evaluators found the interface intuitive and easy to use, so much so that one said they did not think any training would be needed. They also liked the different options for viewing data (including data for multiple users, data history and trends, maps, and individual pop ups). They commented favorably on the stoplight colors used for alerts, the ability to customize names for groups of individuals as well as the individuals themselves, the red bubbles used for SOS tap alerts, threshold control settings, and prioritization of alerts within the dashboard and text message alerts. One negative comment provided by an evaluator was that they found it hard to obtain historical data for a specific time period.
- **Ease of Donning and Activation:** Four evaluators stated that the ability to quickly put on the Band V2 and begin monitoring exceeded their expectations, and three evaluators said that it met all their expectations. Evaluators noted it was very easy to put on and start monitoring. They liked that the device automatically begins transmitting data when donned and does not require the user to push a power button. Evaluators also liked that the sensor did not need to pair with another device to transmit data over a cellular or Wi-Fi network.
- **Compatibility with PPE:** Two evaluators said that the compatibility of the product with other PPE exceeded their expectations, and five evaluators said that it met all their expectations. Most evaluators did not find any challenges to wearing the sensor with PPE. One mentioned this specific sensor's benefits of being low-profile, lightweight, and insensitive to sensor orientation when worn. Another evaluator, however, said it was a little bulkier than they would have liked.
- **Wearer Interface:** Five evaluators said that the wearer interface exceeded their expectations, and two said that it met all their expectations. Evaluators noted that haptic alerts were strong enough to be felt with gear on and while performing activities. However, one evaluator mentioned they did not feel the alerts while performing the Stair Climb activity. One evaluator mentioned that they could hear the vibration of sensors on other evaluators around them. Another evaluator liked that the sensor vibrated not only for alerts but also for when it was safe to return to work. Most evaluators appreciated the SOS tap alert feature that transmits the need for assistance to command.

4.5.3 Deployability

The Slate Safety Band V2 received a deployability score of 4.3. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Scalability:** Four evaluators said that this product exceeded their expectations regarding its ability to be scalable; the other three stated that it met all their expectations. An evaluator noted that the system permits unlimited wearers to be added to the dashboard, while up to only 10 at a time are displayed on the screen in grid view. Evaluators mentioned, as described in the results for ease of donning and activation, that adding users was as easy as applying a charged sensor. An evaluator also noted that the process to exchange sensors at shift changes or similar switches is through a simple drop-down menu on the command interface. One evaluator believed that the reconfiguration of sensors between users would be challenging since the system/command dashboard could only manage one at a time. Another evaluator mentioned it would be easy to scale up and scale down the number of users without needing to have a profile set up in the system. One of the evaluators liked how the command interface indicated whether a user was wearing their sensor with a data connection by color code: green for connected or gray for not connected.
- **Software Compatibility:** Three evaluators stated that the compatibility of the product software with multiple platforms exceeded their expectations, three evaluators said that it met all their expectations, and one said that it met most of their expectations. An evaluator mentioned that the command interface is web-based and easily accessible through internet browsers. One evaluator thought the system should have a mobile app, and another evaluator noted that the vendor said this feature is in development.
- **Third-party Software Integration:** On the ability to support third-party software integration, two evaluators said that the product exceeded their expectations, four evaluators said that the product met all their expectations, and one said that it met most of their expectations. Some evaluators mentioned that there is an API which permits the data to be streamed on other software platforms, but one evaluator noted this functionality was not demonstrated during the assessment and thus gave it a lower score.

4.5.4 Maintainability

The Slate Safety Band V2 received a maintainability score of 4.3. Evaluator feedback on evaluation criteria related to this SAVER category included:

- **Cleaning/Decontamination:** Three evaluators indicated that the Band V2 exceeded their expectations, and four evaluators said that it met all their expectations. Evaluators found that it was easy to clean the sensor. They noted that the sensor has an IP68 rating making it dust tight and suitable for immersion in water during cleaning. Evaluators liked that, according to the vendor, the sensor is machine washable.
- **Durability:** Six evaluators stated that the product's apparent durability exceeded their expectations, and one evaluator said that it met all their expectations. The high scores were attributed to the degree of water resistance (IP68 rating, which indicates protection against continuous immersion in water) and apparent robustness. A couple of evaluators referred to the five year expected lifetime of the sensor as a positive, while one said they thought it should be longer given its cost. One evaluator speculated that the straps would wear out but noted they are easily replaceable at minimal cost.
- **Battery Type:** Four of the evaluators said that the battery type in the Band V2 met all their expectations, and the other three evaluators said that it met most of their expectations. Evaluators mentioned that the rechargeable batteries were a good approach, but several said they would like to have some type of alternate power supply as well. One of the evaluators considered the lack of power options as a tradeoff for the high IP rating. One evaluator liked the docking stations used to recharge the sensors.

- **Customer Support:** One evaluator indicated that the customer support stated for the product exceeded their expectations, and six evaluators said that it met all their expectations. Three of the evaluators cited the vendor's providing support through a website chat. One evaluator noted, however, that there was no vendor-provided information about specific hours that their support is available.
- **In-House Maintenance:** Evaluators noted that in-house service or calibration is not needed for the Band V2 nor would most of them have desired it. One evaluator noted the sensor only has a one year warranty.

4.5.5 Affordability

All criteria in the Affordability category are "information only." These criteria did not contribute to the product's overall score, but the NUSTL team still recorded responder comments regarding these criteria:

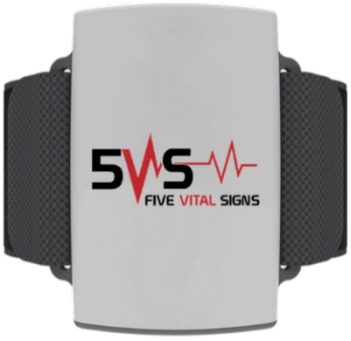
- **List Price:** Some evaluators thought the price of the Band V2 system was reasonable. Others believed that it was too costly, especially for smaller departments or those with tight budgets. A couple of evaluators would have preferred flat pricing without a subscription component for software access.
- **Additional and Recurring Costs:** Some evaluators considered the monthly software subscription cost of $15 per device to be too expensive. However, one of them pointed out that the software was the product's best feature.
- **Contract Listing:** Evaluators noted that the vendor did not provide any information about contract options.

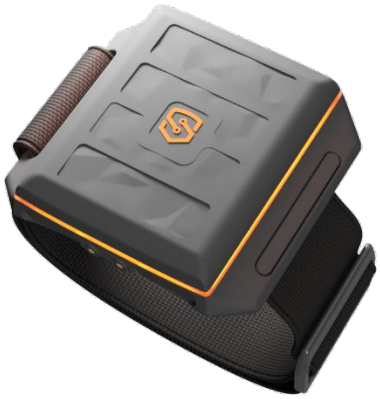
5.0 SUMMARY

Physiological monitoring systems are worn by first responders and collect and relay real-time physiological data to remote command displays during incident responses to monitor the health status of staff. In November 2022, NUSTL, in conjunction with PNNL, conducted a SAVER assessment of physiological monitoring systems at the Orange County Fire Training Center in New Hampton, NY. The SAVER team selected and acquired five physiological monitoring systems for the assessment based on market research and recommendations from a SAVER focus group on this technology. Seven first responder evaluators assessed the capability, usability, deployability, and maintainability of five commercially available physiological monitoring systems against a set of 25 criteria.

Table 5-1 summarizes the advantages and disadvantages of each product as identified by the evaluators. This summary table focuses on the criteria that had more significant differences between the scores across the five products and those criteria that the evaluator focus group had given greater weight. Individual responder agencies that intend to purchase physiological monitoring systems should carefully research the capabilities and features of available instruments to identify the product best suited to their operational needs.

Table 5-1 Advantages and Disadvantages

Manufacturer/Product	Advantages	Disadvantages
 Empatica Embrace Plus **MSRP: $40.40–$64.00 per user each month + phone and data service costs** **Overall Score: 3.1**	• Stores two days of data • Long battery life • Quick and easy charging • Easy to clean • Access to command interface via web portal • Configurable usernames • Reliable and good accessibility to customer support	• Lacks alerting to user or command • Experienced connection issues • Unable to share sensor between staff • Temperature and heart rate data may be inaccurate • Operator must refresh portal for current data
 Equivital eq02+ LifeMonitor and Black Ghost **MSRP: ~$1000/sensor** **Overall Score: 4.1**	• Suitable level of alert details • Data transmission via handheld radio possible • Well organized and intuitive command interface • Hot-swappable battery • Data sharing appears relatively easy • Data export to other software • Includes two-lead electrocardiogram and heat strain index • Automated 15 second refresh rate	• Lack of alerts to wearer • Harness may have limited lifetime • Donning takes more time • Donning requires privacy • Must be worn before incident responses • Software installation on a command device is necessary
 Five Vital Signs Detect-C **MSRP: ~$1000/sensor** **Overall Score: 3.4**	• Does not require a separate on-body device • API available for integration purposes • Easy to apply and activate • Comfortable to wear • Configurable usernames • Data simultaneously accessible by multiple users	• Haptic alerts not noticeable during activities • Dashboard alerts initially unclear • Unintuitive user interface • Short battery life when used for real-time monitoring • Questionable accuracy for body temperature • Data sharing not straight-forward

Manufacturer/Product		Advantages	Disadvantages
 Kenzen Kenzen Device		• Noticeable haptic alerts • One minute refresh rate • Accuracy appears good • Configurable usernames • Easy to clean	• Does not alert on heart rate • Requires a smartphone for transmission • Unable to view multiple users simultaneously in command interface • Short battery life • Sensor exchange between users is time consuming • No data sharing functionality • Measures only heart rate and body temperature data • Problematic to wear over tattoos
MSRP: $350/user per year with additional $2500/agency yearly for data services + phone and data service costs	**Overall Score: 3.2**		
 Slate Safety Band V2		• Noticeable haptic alerts during activities • Text message alerts • Wearer and create alert, “Tap” alert • No additional on-body device needed • Multiple data views in command interface • Alert prioritization in dashboard • API for software integration • Easy data export • Simple profile and baseline functionality • Easily changes users • IP68 rating • Automated activation • Configurable usernames	• Long charging time (3.5 hours to full charge) without other power options • Cannot simultaneously reconfigure multiple sensors • User must provide data encryption • No smartphone app currently
MSRP: $495 per sensor plus $15 monthly service fee per sensor	**Overall Score: 4.3**		

6.0 ACKNOWLEDGEMENTS

NUSTL thanks the assessment evaluators for their valuable time and expertise. Their insights and recommendations will assist responder agencies making procurement decisions and guide the planning and execution of future SAVER projects. Appreciation is also extended to those fire departments that provided evaluators who participated in this SAVER assessment.

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NUSTL also thanks the OCFTC, where the assessment was held, for the access to the facilities, supplies and equipment, and support personnel. This permitted the assessment to be successfully conducted.

7.0 REFERENCES

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APPENDIX A. EVALUATION CRITERIA DEFINITIONS

Capability

- **Health Status Alerting** refers to the user interface providing alerts to remote command staff when physiological measures of the wearer exceed or fall below agency-defined threshold values (also known as out-of-tolerance (OOT) conditions).
- **Physiological Measures** refers to what sensor measurements are reported by the system.
- **Remote Sensor Platform** refers to the ability of sensors to transmit data to a remote platform, rather than to a device on the wearer's body (such as a smartphone).
- **Data Privacy** refers to the need for system compliance with agency data privacy standards.
- **Data Sharing** refers to the ability to transmit data to other agencies (e.g., hospitals, EMS, paramedic), if desired.
- **Profiles or Baselines** refers to creation of profiles or baselines for different wearers to adjust (and save their individual) thresholds for out-of-tolerance alerts.
- **Location Services** refers to the ability of the system to provide the location of the wearer in a critical incident. Note this was identified as for information only.

Usability

- **Accuracy** refers to the ability to produce reliable measurements of physiological signs.[1]
- **Battery Life** refers to the ability for the battery to last throughout a critical response or duty shift (depending on the agency's preferred use case).
- **Comfortable Fit** refers to availability of sensors in different sizes or adjustable for comfortable fit.
- **Command Interface** refers to the ease of use or intuitiveness of the display and controls for command staff.
- **Ease of Donning and Activation** refers to need to put on sensors quickly and easily initiate monitoring.
- **Compatibility with PPE** refers to the ability of sensor to be optimally worn without interfering with other pieces of personal protective equipment.
- **Wearer Interface** refers to the ability for wearers to receive out-of-tolerance alerts but receive minimal real-time updates on physiological measurements (to prevent distractions) during a critical incident response.

Deployability

- **Scalability** refers to the ability to add additional wearers to the software platform when additional responders arrive on the incident scene after monitoring has already started.
- **Software Compatibility** refers to the system's ability to be accessed on various platforms (e.g., tablet, mobile phone, computer, and to run on a variety of desktop and mobile operating systems (e.g., Mac OS, Linux, Windows, iOS, Android) that may be used by incident command.

[1] Accuracy is based on the evaluators' impressions rather than laboratory testing.

- **Third-party Software Integration** refers to the ability to readily share and use data collected from system sensors with third-party software (e.g., incident management or situational awareness platforms).

Maintainability

- **Cleaning/Decontamination** refers to the ability to withstand cleaning and decontamination after being worn by one or more users or in the event of being exposed to contaminants during an incident.
- **Durability** refers to the ability to withstand wear, environmental conditions, and damage.
- **Battery Type** refers to system power source options.
- **Customer Support** refers to the technical support or customer service being available to the purchasing agency.
- **In-house Maintenance** refers to regular recalibration and repairs that can be completed "in-house" by the purchasing agency.

Affordability

- **List Price** refers to the unit price or the manufacturer's suggested retail price (MSRP).
- **Additional and Reoccurring Costs** refers to any costs associated with the use of the system or its services, not including the list price.
- **Contract Listing** refers to any contracting vehicles where the vendor or associated contract is listed.

APPENDIX B. ASSESSMENT SCORING FORMULA

The overall assessment score for each product was calculated using the product's averaged criterion ratings and category scores. An average rating for each criterion was calculated by summing the evaluators' ratings and dividing the sum by the number of responses.

Category scores for each product were calculated by multiplying the average criterion rating by the criterion weight assigned by the focus group, thus resulting in a weighted criterion rating. The sum of the weighted criterion scores was then divided by the sum of the weights for each criterion in the category as seen in the formula and example below:

Category Score Formula

$$\frac{\sum(Average\ Criterion\ Rating \times Criterion\ Weight)}{\sum(Criterion\ Weights)} = \frac{Category}{Score}$$

Category Score Example [ii]

$$\frac{(4.3 \times 4) + (5 \times 4) + (4 \times 3) + (4.5 \times 3) + (4.5 \times 3)}{4 + 4 + 3 + 3 + 3} = 4.5$$

To determine the overall assessment score for each product, each category score was multiplied by the percentage assigned to the category by the focus group. The resulting weighted category scores were summed to determine an overall assessment score as seen in the formula and example below:

Overall Assessment Score Formula

$$\sum(Category\ Score \times Category\ Percentage) = \frac{Overall\ Assessment}{Score}$$

Overall Assessment Score Example

$$\underline{Capability} \quad \underline{\text{Usability}} \quad \underline{Affordability} \quad \underline{Maintainability} \quad \underline{Deployability}$$

$$(4.0 \times 33\%) + (4.2 \times 27\%) + (4.2 \times 20\%) + (3.8 \times 13\%) + (4.5 \times 7\%) = 4.1$$

ii Examples are for illustration purposes only. Formulas vary depending on the number of criteria and categories assessed and the criteria and category weights