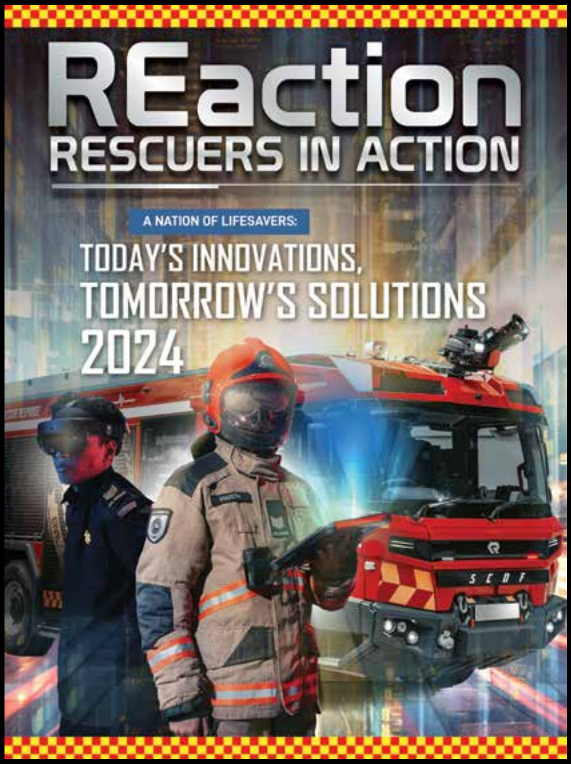
REaction

RESCUERS IN ACTION

A NATION OF LIFESAVERS:

TODAY'S INNOVATIONS, TOMORROW'S SOLUTIONS 2024



REaction

'REaction — Rescuers in Action' is SCDF's annual technical publication that aims to be a platform for thought-provoking discussions by sharing knowledge and case studies.

The publication provides an array of articles covering a myriad of subjects, as we envision it to be a repository of knowledge for both academic and practising readers in the emergency services fraternity. We hope that you have gained new insight and found REaction beneficial to you.

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EDITOR'S FOREWORD

As we continue our journey toward the Singapore Civil Defence Force's (SCDF's) Transformation 2030 — Prepared, Even for the Unexpected — we are proud to present this year's edition of REaction, themed: Today's Innovations, Tomorrow's Solutions. In an unpredictable operating environment, our ability to adapt and innovate has never been more crucial. By anticipating and addressing the challenges of tomorrow, we remain steadfast in our vision of being a world-leading life saving force.

SCDF's Transformation 2030 sets the tone for this edition. The first article outlines our strategic thrusts to continue building a nation of lifesavers. These key initiatives pave the way for an array of groundbreaking innovations that are changing the day-to-day of our frontliners. For example, the Automated Medical Store optimises frontline medical logistics and ensures operational readiness across our fire stations. An article on Armoury, a digital platform that streamlines equipment management, provides insights into the collaborative and iterative design thinking process behind our innovations. These solutions ultimately allow our frontliners to focus on their core mission of saving lives.

This edition also features cutting-edge technology shaping our frontline operations. The newest addition to our fleet, the Electric Pump Ladder, underscores our dedication to a green future. Additionally, marine search and rescue operations have been enhanced using artificial intelligence and video analytics. We illustrate our strategic approach to ensuring our technology meets the demands of our operational landscape through our acquisition of HazMat Sensors,

Training also takes centre stage in this edition. We delve into evidence-based interventions that elevate our operational readiness. One research study demonstrates the effectiveness of a virtual reality game-based intervention in enhancing stress response and performance among firefighting trainees. Another article highlights the development of SCDF's Responders Functional Fitness Training Programme. It showcases how the programme improves our firefighters' ability to meet the physical demands of firefighting whilst minimising the risk of injury.

We hope that you will find this edition an inspiring and insightful read. As we foster a culture of continued improvement, we are not just adapting to change; we are driving it. On this note, we would like to express our appreciation to the authors and contributors of REaction 2024. Stay safe and keep well!

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SCDF'S TRANSFORMATION 2030: PREPARED, EVEN FOR THE UNEXPECTED

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EDITORIAL PREVIEW

Since 2015, the Singapore Civil Defence Force (SCDF) has been on a transformation journey to build a nation of lifesavers, involving the community as responders to supplement SCDF's resources. As the organisation approaches 2025, it aims to reassess and revitalise its priorities for future success.

The vision statement "Prepared, Even for the Unexpected" emphasises the critical importance of preparedness and anticipatory action for SCDF, its partners, and society at large. The desired outcomes for 2030 include future-ready operations, a connected SCDF and a resilient society. These reflect a proactive shift towards risk reduction, enhanced collaboration and community-driven preparedness.

As SCDF progresses towards 2030, the transformation represents a bold leap towards a future defined by preparedness, connectedness and resilience. The framework embodies a commitment to innovation, collaboration and community engagement, positioning SCDF as a beacon of inspiration and excellence in emergency response and public safety.

INTRODUCTION

Since 2015, the Singapore Civil Defence Force (SCDF) has embarked on a bold transformation journey with the vision of building a nation of lifesavers. This vision involves mobilising the community as a network of responders to supplement SCDF's limited resources and meet the escalating demand for emergency services. As SCDF approaches 2025, it is time to reassess and revitalise its priorities for the next phase of organisational success.

TRANSFORMATION 2030 FRAMEWORK

The new transformation framework for 2030 is designed to build upon and advance existing plans while aligning with the Ministry of Home Affairs' (MHA's) strategic priorities and the Home Team Transformation 2030 plan. The framework focuses on three key drivers, five key directions and three desired outcomes, as depicted in Figure 1.

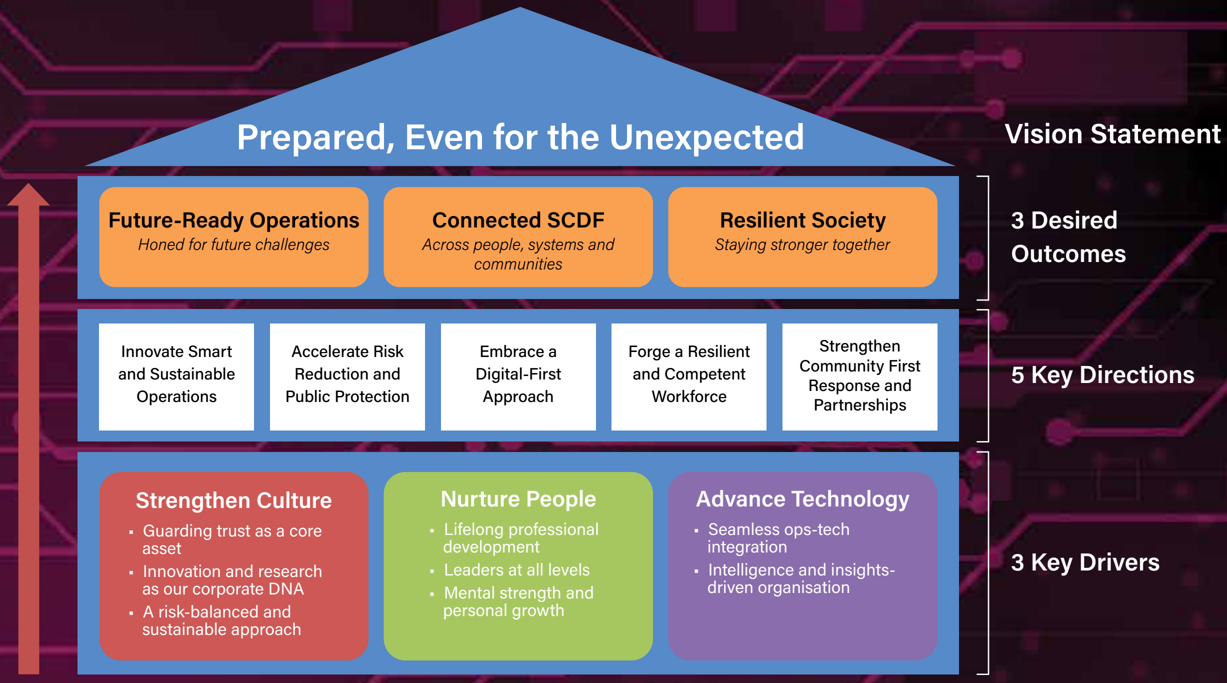

Figure 1: Transformation 2030 Framework

KEY DRIVERS

Key drivers are cross-cutting factors that fuel the key directions and support attaining the desired outcomes. They are:

- **Strengthening culture.** SCDF will continue to build a robust culture and identity anchored in its core mission of saving lives and property, while also building strong public trust and generating operational impact. SCDF will also foster a culture of risk balancing, innovation and research to enhance its capabilities and safety.

- **Nurturing people.** SCDF will nurture our people as our most valuable asset, providing lifelong opportunities for professional development, equipping them with relevant competencies, and valuing their diverse strengths and perspectives. SCDF will also prioritise the holistic well-being of its people, encompassing physical, mental, emotional and social aspects.

- **Advancing technology.** SCDF will embrace technology as a fundamental enabler of efficiency and agility to become an intelligence- and insights-driven organisation. This will allow SCDF to harness data and leverage advanced analytics for organisational decisions and operational outcomes. SCDF will also connect people, systems and communities through technology to enhance collaboration and resilience.

KEY DIRECTIONS

Key directions are strategic thrusts that guide the development of actionable initiatives and are anchored by one or more major flagship projects. They are:

- **Innovating smart and sustainable operations.** SCDF will innovate and enhance its operational capabilities to meet the dynamic and diverse needs of the community, optimising resources and responding faster and smarter. SCDF will also adopt and drive sustainability efforts in the domain of emergency response, such as the electrification of emergency vehicles, more efficient use of firefighting media, and reduction of incident environmental impacts.

- **Accelerating risk reduction and public protection.** SCDF will leverage smart fire safety systems and smart building management systems to enhance its early warning and response capabilities, as well as reduce fire safety non-compliances. SCDF will also leverage the Fire Research Centre to develop cutting-edge fire science knowledge and drive innovative fire safety solutions to better protect the population from new and emerging risks.

- **Embracing a digital-first approach.** SCDF will adopt a digital-first mindset and approach, transforming its processes, systems and platforms to harness data and technology for better outcomes. SCDF will also uplift its technology literacy and develop a core of highly competent ops-tech officers to drive the operations-technology nexus.

- **Forging a resilient and competent workforce.** SCDF will equip its workforce with the most updated and relevant skills and competencies to succeed professionally and develop individually. SCDF will also nurture leaders at all levels and foster a supportive and inclusive work environment that promotes mental strength and personal growth.

- **Strengthening community first response and partnerships.** SCDF will strengthen its role as a community advocate and partner, creating an inclusive whole-of-society ecosystem that enhances community connectivity and resilience. SCDF will also deepen its engagement with existing networks of community first responders (CFRs), the private sector and global partners. This way, safety becomes everyone's responsibility.

DESIRED OUTCOMES

The desired outcomes are the three core areas that represent SCDF's envisioned future state in 2030. They are:

- **Future-ready operations.** SCDF will move from a response-centric approach to a proactive risk detection and monitoring approach, reducing the occurrence and extent of incidents. SCDF will also respond swiftly and effectively to incidents, supported by data analytics, smart systems and purpose-built robots. SCDF will also prioritise high-acuity cases and enhance patient outcomes through evidence-based care. An example is shown in Figure 2.

Figure 2: Use of augmented reality to enhance operational capabilities

- **Connected SCDF.** SCDF will be intrinsically connected across systems and communities, enhancing collaboration and coordination. SCDF will leverage a central data analytics engine, SCDF's Intelligent Core (iCore), to aggregate and harness data for anticipatory operations, fire safety management and community building. SCDF will also network its responders, machines, appliances, systems and infrastructure to optimise sensemaking, command and control. Figure 3 illustrates this.

Figure 3: Use of cell broadcast technology to disseminate public emergency alerts

- **Resilient society.** SCDF will foster the growth of a resilient society fortified by cutting-edge emergency response capabilities and community-driven preparedness. SCDF will also proactively emphasise public education and emergency readiness skills, using technology and innovation to create realistic and engaging scenerios (Figure 4). Additionally, SCDF will support and empower CFRs and partners to drive ground-up initiatives and expand their roles beyond firefighting and medical emergencies.

Figure 4: Public education to train and empower citizens to be CFRs

VISION STATEMENT

The SCDF Transformation 2030 vision statement "Prepared, Even for the Unexpected" encapsulates the critical importance of preparedness and anticipatory action for SCDF, its partners, and the wider society. The vision sets the tone for a call to action, emphasising the need for readiness and adaptability in facing unforeseen challenges. It is an assertion that SCDF will be ready for all crises. It also rallies our partners and wider society to not only be ready and prepared for identifiable emergencies but also to build up our joint preparedness in overcoming unforeseen challenges.

CONCLUSION

As SCDF charts its course towards 2030, the transformation journey is not merely a response to external forces, but a bold and visionary leap towards a future where preparedness, connectedness and resilience form the bedrock of SCDF's identity. The refreshed transformation framework embodies a commitment to innovation, collaboration and community engagement. It sets the stage for SCDF to become a beacon of inspiration and a model of excellence in emergency response and public safety.

ARMOURY: HOW SCDF AND OGP CO-CREATED A DIGITAL SOLUTION FOR EQUIPMENT CHECKS

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EDITORIAL PREVIEW

In a groundbreaking collaboration, the Singapore Civil Defence Force (SCDF) and Open Government Products (OGP) have co-created a digital solution, Armoury, to address the challenges of manual equipment checks. With approximately 140,000 checks conducted annually, the manual process was not only inefficient but also prone to data loss, human error and inaccessibility.

The journey to Armoury's creation involved rigorous design thinking, empathising with SCDF officers, and iterative prototyping. The result is a software as a service tool that enables seamless team collaboration, real-time tracking and user-centric reporting. Since its launch in August 2023, Armoury has achieved a 92% completion rate, recorded over 48,000 submissions, and resolved over 11,000 issues, garnering a 4.5 out of 5 satisfaction rating.

The success of Armoury has transformed SCDF's operational readiness and serves as a testament to the power of innovation and collaboration in the public sector. This article offers insights into the co-creation journey, key takeaways, and the future of digital transformation for SCDF and OGP.

THE PROBLEM: MANUAL AND INEFFICIENT EQUIPMENT CHECKS

Every day, Singapore Civil Defence Force (SCDF) officers conduct checks on approximately 400 emergency vehicles and vessels, manually accounting for their equipment and operational readiness. This equates to roughly 2,800 checks per week and over 140,000 checks per year, largely done using pen-and-paper checklists.

Manual accounting is not only susceptible to physical damage and data loss — where the records could be misplaced. It also limits the accessibility and utilisation of critical information that could be gleaned from data collated. This information provides insights into the operational readiness of Singapore's fleet of emergency appliances. Human error is also inevitable in the manual process.

In the past, SCDF had explored using technology to resolve the issues faced in manual accounting. The radio frequency identification (RFID) system was introduced. While scanning tagged equipment was fast and efficient, the system proved unsuitable for SCDF's rugged operating environment, as the RFID tags were subjected to frequent wear and tear. SCDF then tapped on free-to-use digital forms. While these cloud-based forms allowed easy access to data, the experience was not user-friendly — officers had to scroll and individually input hundreds of items during each appliance check. These solutions were primarily tailored for frontline users, resulting in data that was siloed and inaccessible to other personnel. Consequently, this made data analysis at the Force level challenging.

THE SOLUTION: ARMOURY, A DIGITAL CHECKLIST FOR EQUIPMENT CHECKS

Enter Armoury — a software as a service tool designed to resolve tracking and compliance issues. Its conception has the potential to replace any existing workflow involving manual checklists, with the possibility of data collation and analysis based on records of the digital checks.

Key features include:

- Seamless team collaboration with multiple users able to input into one checklist simultaneously.
- Restricted user access with permissions tied to Singpass accounts.
- Real-time tracking and monitoring of critical data, stored securely in the government cloud.
- Real-time data analytics and user-centric reporting tools.

With Armoury, the status of each piece of equipment (e.g., available, sent for servicing, condemned, pending replacement) is tracked during each check. The data is then stored in a secure database for future reference and further analysis, such as an overview of equipment prone to disrepair. As a web application, it is compatible with mobile devices — whether personal or workplace-issued — minimising the need to purchase additional equipment. Its intuitive user interface and dashboard highlight outstanding issues and appeal to SCDF officers, allowing them to focus on important information and urgent actions. The mobile compatibility also allows commanders to get a quick overview of the equipment readiness status of the units under their respective charge. Figure 1 shows an example of the Armoury interface.

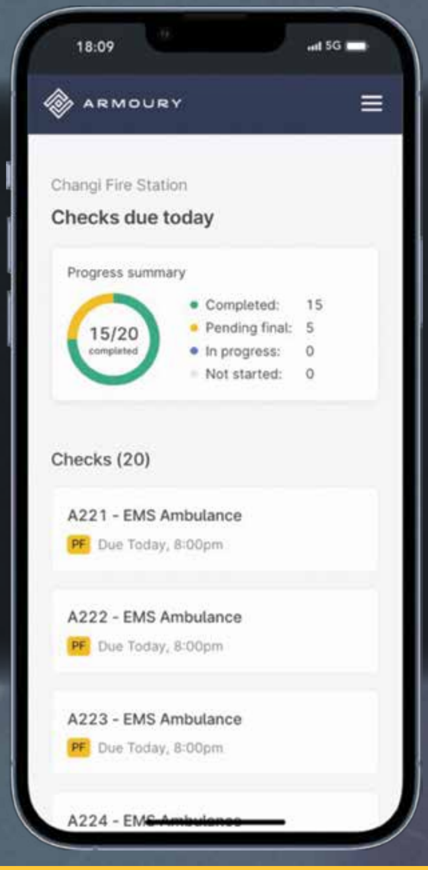

Figure 1: An example of the Armoury interface for equipment checks and tracking of the operational readiness of their emergency vehicles

THE PROCESS: CO-CREATING WITH DESIGN THINKING

Armoury was born out of a hackathon organised by Open Government Products (OGP) in 2023, where SCDF sponsored a problem statement on equipment and operational readiness checks. A team of OGP officers, with the help of SCDF domain experts, applied design thinking principles to understand the problem, ideate solutions, prototype, and test them with real users.

Design thinking is a human-centred approach to innovation that emphasises empathy, collaboration, experimentation and iteration. The team followed these steps:

- **Empathise:** The team conducted user research by interviewing and observing SCDF officers who perform equipment checks daily. They uncovered their pain points, needs and context.
- **Define:** The team synthesised their findings and defined the problem statement and user persona. They also identified key assumptions and hypotheses to be tested.
- **Ideate:** The team brainstormed possible solutions and selected the most promising one based on feasibility, desirability and viability. They also mapped out the user journey and features of the solution.
- **Prototype:** The team built a low-fidelity prototype using paper sketches and digital tools. They also prepared a list of questions and scenarios to test the prototype with users.
- **Test:** The team returned to the users and asked them to try out the prototype. They collected feedback and observed how the users interacted with it. Based on the test, the team validated or invalidated their assumptions and hypotheses.
- **Iterate:** The team analysed the feedback and refined the prototype accordingly. They repeated the testing and iteration process until they achieved a satisfactory level of user satisfaction and usability.

The result was Armoury, a digital checklist that addresses user needs and solves identified problems effectively and efficiently.

THE OUTCOME: A SUCCESSFUL ROLLOUT AND POSITIVE FEEDBACK

After the hackathon, the team continued to work on Armoury, improving its features and functionalities, and preparing it for deployment. They also engaged SCDF officers and stakeholders for change management, communicating the benefits and changes of using Armoury, and providing training and support.

In August 2023, Armoury was officially launched and progressively rolled out to all fire stations in Singapore. Figures 2 and 3 show examples of scenarios in which Armoury is used. Since then, it has received positive feedback from users and has resulted in significant improvements in the equipment checking process. Some of the achievements include:

- A 92% completion rate of checklists
- Over 48,000 submissions recorded
- Over 11,000 issues reported and resolved
- A 4.5 out of 5 satisfaction rating
- A 5 out of 5 ease of use rating

Figure 2: Firefighters using Armoury as part of their operational readiness checks

Figure 3: Paramedics using Armoury as part of their operational readiness checks

Beyond direct improvements to equipment and operational readiness checks, Armoury has empowered SCDF officers to take stronger ownership in designing solutions and innovating workflows. User feedback sessions and design workshops for the development of Armoury engaged officers, and it was through one of these workshops that SCDF and OGP realised the possibility of integrating features of Pulse[1] — a medical store inventory management web application — with Armoury. This resulted in a secondary module for the consumable inventory management in ambulances.

Moreover, Armoury leveraged existing infrastructure to deliver a mobile web-based solution with lower hosting costs and infrastructure expenses without the need for additional equipment purchases and maintenance. In addition to cost efficiencies, Armoury has also contributed to significant time savings for SCDF, with an estimate of at least 37,686 man hours saved annually.

From an auditing perspective, Armoury has facilitated a transformative shift towards proactivity within SCDF by providing a comprehensive dashboard of all equipment across 23 fire stations and three specialist units. This enables SCDF's Operations Department, Logistics Department, and Emergency Medical Services Department to proactively monitor and manage equipment status and compliance in real time. Armoury has also enabled SCDF to make data-driven decisions based on analytics and insights generated from the digital checks. For example, SCDF can identify equipment prone to faults and plan for preventive maintenance or replacement. SCDF can more effectively monitor the operational readiness of its fleet and ensure that any issues are promptly addressed.

Armoury won the Biggest Moneysaver Award at OGP's Hack for Public Good 2023, and the Gold award (Project category) at SCDF Lifesavers' Innovation & Technology Awards 2023. It was featured at SCDF's Transformation Townhall, where the product team shared their experiences in designing Armoury and how design thinking was put into practice.

The Armoury product team at SCDF's Transformation Townhall

[1] The platform was named "Pulse" in reference to its primary users, who are paramedics and emergency medical technicians responsible for saving lives (pulse) during emergency calls.

THE LEARNING: SIX KEY TAKEAWAYS FROM THE COLLABORATION

Armoury is not merely a product, but also a story of innovation, collaboration and transformation in the public sector. SCDF and OGP have learnt valuable lessons from their co-creation journey, which can be summarised into six key takeaways:

1. **Boots on the ground.** The product team and the policy team should always be on the ground, talking to users and understanding their processes, pain points and needs. This helps validate or invalidate assumptions, empathise with users, and design solutions that fit their context and preferences.
2. **Start small, do one thing well.** The product team should focus on solving one specific problem or user group at a time, rather than trying to address all possible scenarios or requirements. This helps avoid scope creep, prioritise features, and deliver value faster. For Armoury, the team focused on fire engines as the first use case, before expanding to other types of vehicles and equipment.
3. **Build, measure, learn, repeat.** The product team should adopt an iterative approach, where they build prototypes, test them with users, measure the results, learn from the feedback, and improve the product accordingly. This helps ensure that the product is user-centric, data-driven, and constantly evolving. For Armoury, the team went through several rounds of prototyping, user testing, and refinement based on insights gathered from the ground.
4. **Dare-to-try and tenacious spirit.** Users and domain experts should have the courage and perseverance to experiment with new ideas and technologies, even if they are not fully polished or perfect. They should also be willing to share their feedback and suggestions, and be open to change and improvement. For Armoury, the ground officers who initiated using FormSG to digitise their checklists were invited to be early adopters and champions of the product.
5. **Supportive environment.** The organisation and leaders should create a supportive environment and a safe space for innovation, where the product team, the policy team, users and domain experts are empowered to collaborate, communicate and co-create solutions. They should also align on the problem and common goal, and provide the necessary resources and guidance. For Armoury, SCDF headquarters departments and frontline units were aligned on strategic goals and user needs, and committed to solving the problem together.
6. **Communicate change timely.** The product team and the policy team should communicate changes and benefits of the new product or process to users and stakeholders in a timely and sensitive manner. They should also provide avenues for feedback, queries and support. This helps build trust, confidence and adoption among users and stakeholders. For Armoury, the team used a Telegram group to communicate changes and address questions, and involved key stakeholders in testing and feedback sessions.

The Armoury project team at OGP's Hack for Public Good 2023

The Armoury project team receiving the Gold award (Project category) at SCDF Lifesavers' Innovation & Technology Awards 2023

CONCLUSION

Armoury is only the beginning of a new chapter in SCDF's digital transformation. SCDF and OGP will continue to enhance Armoury to support other types of checklists. We are also exploring new solutions for other challenges, such as fynder, a digital platform for asset sharing and loaning, which was prototyped in the 2024 hackathon. fynder aims to maximise resource usage and create efficiencies through resource sharing among government agencies.

SCDF and OGP hope that their story will inspire other public officers and agencies to embark on their own innovation journeys, and to co-create solutions that will benefit the public and the nation.

AUTOMATED MEDICAL STORE – REVOLUTIONISING LOGISTICS AT THE FRONTLINE

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EDITORIAL PREVIEW

With the growing trend of companies adopting automation for logistical support, the Singapore Civil Defence Force (SCDF) team from Ang Mo Kio Fire Station explored automation for their medical store through advanced technologies and data analytics. This article addresses the challenges Emergency Medical Service (EMS) personnel face in managing medical stores and how automation can alleviate their workload. The Automated Medical Store leverages technologies such as video analytics and ultra-sensitive weight sensors to enable EMS personnel to withdraw items quickly — simply enter, take what they need, and exit the store. Withdrawal data is shared with SCDF's third-party logistics provider, ST Logistics, which monitors stock levels and replenishes items as needed. This automated replenishment system prevents stock shortages and ensures the station remains operationally ready.

INTRODUCTION

In 2023, the Singapore Civil Defence Force responded to 246,832 Emergency Medical Service (EMS) calls, averaging 676 EMS calls daily (Singapore Civil Defence Force, 2024). This figure is shared with 92 ambulances across the island. Each ambulance uses medical supplies during calls. To ensure they are constantly equipped, each fire station maintains its medical stores so the ambulance can return and replenish medical supplies.

Paramedics manage medical equipment and disposable supplies at the fire stations daily. At present, dispensing and managing medical disposable supplies at fire stations is labour-intensive and time-consuming.

CURRENT SITUATION

There are currently almost 180 different types of medical dispensable items in the store. The quantity of medical items used per shift varies depending on the number and type of emergency calls handled by the crew. For example, responding to a cardiac arrest case requires a range of supplies, including intravenous (IV) cannulas, automated external defibrillator pads, airway devices like oropharyngeal airways or laryngeal mask airways, a bag valve mask, suction catheters, IV saline bottles, and alcohol swabs. In addition, essential drugs such as adrenaline and amiodarone are required.

Responding to trauma cases necessitates additional medical supplies such as bandages, tapes, and pain-relieving medications like tramadol and penthrox. It is important to note that these medications are controlled items requiring additional verification during withdrawal.

All withdrawals of medical supplies are presently recorded either in an online form or a logbook. Individual store in-charge then compiles the data to ensure it tallies with physical quantities left in the medical store. On average, the crew takes up to 20 minutes to withdraw items from the medical store. The process involves retrieving the medical store key from the watch room, unlocking the store, selecting and recording the items required, then locking up the medical store and returning the keys to the watch room. During busy shifts, with more medical supplies used, paramedics might request off-run timing from the ops centre to allow the crew to return to the fire station and restock the ambulances. This ensures that they are well-supplied for the next shift.

A stock take is conducted at least once a month to verify that physical stock counts correspond with the final list and to remove expiring items from the inventory. Paramedics also need to order medical dispensable supplies from the Integrated Logistics Management System when stock levels are low. This laborious process is in addition to their primary role of responding to medical calls during their 12-hour shifts.

Upon an initial indentation request, it takes approximately two to three weeks for items to be delivered to the fire station. The entire indentation process involves two levels of approval: first from the Commander Fire Station, followed by a second approval from headquarters. Occasionally, delays in the approval process can impact delivery times and affect the availability of medical supplies at the station. This prompts the need for contingency measures such as borrowing from other stations to ensure adequate supplies.

CONCEPTUALISATION

With the rising trend of companies adopting automation for logistical and retail support, the Ang Mo Kio Fire Station project team envisioned automating the complex task of managing medical dispensable supplies. The team sieved out case studies where automation was implemented successfully around the world. For instance, Amazon developed its cashier-less shopping technology, Just Walk Out, which allows shoppers to check out items from a store without paying at a register (The Business Times, 2024). Amazon is rolling out this technology to other third-party stores this year while it continues to use Dash Carts — its smart shopping carts that can log shoppers' items and charge them upon leaving the stores.

With these examples in mind, the team collaborated with SCDF's logistics and research partners, ST Logistics and Home Team Science & Technology Agency (HTX), to explore if automation features can be introduced into how medical supplies are managed within a fire station medical store. This led to the proposal of the Automated Medical Store (AMS), a smart logistics solution aimed at improving inventory management in medical stores. AMS is designed to facilitate a "grab and go" automated checkout for dispensable items in an unmanned medical store (Figure 1). Additionally, it incorporates data analytics to notify our logistics partner to deliver and replenish medical supplies when inventory levels are low. AMS also aims to provide trend analysis capabilities for accurate stock forecasting and replenishment planning.

Figure 1: Concept of withdrawing medical supplies from AMS

DEVELOPMENT

AMS uses facial recognition technology to allow paramedics quick and secure access to the medical store. By combining ultra-sensitive weight sensors and facial recognition cameras, users can withdraw medical supplies and leave the store seamlessly. This addresses the currently time-consuming process of restocking an ambulance between shifts.

The AMS backend system then triggers notifications when stock balances reach predefined threshold levels and provides alerts for expiring items. As most medical items are perishable, overstocking infrequently used items would result in unnecessary wastage. AMS aims to collect indentation data from various fire stations to more accurately distribute medical supplies across fire stations based on usage patterns.

Automation in this aspect is especially valuable given the diverse inventory of medical supplies. It eliminates the need for our paramedics to perform physical stock takes of our medical inventory. This helps our paramedics focus on operational readiness and improve their medical expertise through training instead of being preoccupied with logistical matters.

The implementation of AMS aims to reduce the time taken to withdraw medical supplies to under five minutes and minimise the time ambulances are off-run for restocking. Such outcomes will translate to an increased availability of ambulances responding to medical emergencies.

IMPLEMENTATION

AMS was developed, and a six-month pilot trial was conducted at Punggol Fire Station in 2022. The trial included installing ultra-sensitive weight sensors and facial recognition cameras on the shelves of the medical store (Figure 2). Medical items were then placed in standardised individual bins on these shelves.

Figure 2: Pilot AMS trial in Punggol Fire Station

The facial recognition cameras would scan and identify the user to initiate the indenting process. At the same time, ultra-sensitive weight sensors on each bin recorded data whenever an item was removed or returned. Video analytics was introduced to co-relate these two data points. This allowed users to collect items from the shelves and leave the medical store without filling out logbooks or online forms. The ultra-sensitive weight sensors chosen were also robust enough to be installed in a refrigerator for drugs requiring low-temperature storage.

The pilot trial was generally well-received by users at Punggol Fire Station, who applauded the elimination of the tedious process of withdrawing medical supplies. More importantly, the pilot trial gathered constructive feedback from users and highlighted areas of improvement to enhance the user experience of AMS.

AREAS FOR IMPROVEMENT

A major issue that surfaced from the pilot trial was the accuracy of the weight sensors used. The load cells performed well with heavier items but were less reliable with lighter ones, leading to inaccuracies in recorded quantities. This required users to notify the project team to make back-end adjustments to actual quantities. There were also cases where the system inaccurately recorded withdrawal data even when no items were taken, or when items were removed and then placed back into the bin. Since many items in the medical store are lightweight, such as gauze, IV cannulas and drug ampoules, improving the sensitivity of the load cells is essential.

Users also shared that scanning their faces at individual shelves before taking items was cumbersome. This was a hassle, especially when users had to withdraw multiple items at once.

Further collaboration with HTX was arranged to incorporate several design modifications and tweaks to backend logistics services. With that, an improved version of AMS was on the horizon.

NEW AND IMPROVED – AN UPGRADED AMS

The new version introduced a mobile application to verify the identity of users entering the store. Overhead surveillance cameras were also added in the medical store to track the location of up to four users simultaneously. Additionally, the ultra-sensitive weight sensors were upgraded for improved accuracy and, together with a backend material matrix, can accurately track inventory quantities (Figure 3). The surveillance camera footage was used with machine learning tools to improve the tracking of inventory withdrawals. All inventory withdrawal records are stored on a cloud server and displayed in the AMS mobile application for user transaction acknowledgement.

Figure 3: The upgraded AMS featuring shelves with upgraded weight sensors and surveillance cameras

Using the withdrawal data collected, inventory levels can then be monitored in real-time. When items require replenishment, a restock prompt will be triggered. The task of restocking medical supplies in AMS is outsourced to ST Logistics, a third-party logistics company engaged by SCDF. ST Logistics was engaged to monitor the expiry dates and quantities of medical supplies at each AMS store and replenish the inventory where required.

THE FUTURE OF AMS

AMS is currently only in operation at Punggol Fire Station. Given the project's success in improving logistical efficiency and enhancing operational readiness, AMS was assessed to be suitable for implementation across all Fire Stations with medical stores within SCDF. It will be introduced to Sengkang Fire Station by the end of 2024 and subsequently to all Fire Stations with medical stores by 2026.

Following the successful implementation of AMS to manage medical supplies, the SCDF Logistics Department is also exploring using similar automation processes to manage firefighting consumable supplies.

The AMS represents a revolutionary concept that utilises available technology in an innovative way to enhance operational processes for our frontliners. It also highlights the importance of collaborative efforts between our frontliners and strategic partners like HTX in harnessing new technology to keep SCDF relevant in an ever-changing digital landscape.

REFERENCES

1. Singapore Civil Defence Force. (2024, February 21). *Emergency Medical Services, Fire & Enforcement Statistics 2023.* Retrieved from https://www.scdf.gov.sg/docs/default-source/scdf-library/amb-fire-inspection-statistics/scdf-annual-statistics-2023.pdf

2. The Business Times. (2024, April 18). *Amazon to push cashierless shopping tech into more third-party stores, while backing off itself.* Retrieved from https://www.businesstimes.com.sg/companies-markets/amazon-push-cashierless-shopping-tech-more-third-party-stores-while-backing-itself

SMART AND SUSTAINABLE PUMP LADDER

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EDITORIAL PREVIEW

The Singapore Civil Defence Force (SCDF), as a Home Team Department under the Ministry of Home Affairs, is dedicated to advancing the national sustainability agenda outlined in the Singapore Green Plan 2030 under the GreenGov.SG initiative. Within this framework, SCDF is committed to ambitious carbon abatement targets, aiming to reach peak carbon emissions by 2024 and net-zero emissions by 2045.

INTRODUCTION

The electric pump ladder (EPL), as shown in Figure 1, is the latest addition to the Singapore Civil Defence Force (SCDF) fleet and is the first electric emergency vehicle in the Association of Southeast Asian Nations (ASEAN) region. It was launched on 3 April 2024 at the Milipol Asia-Pacific – TechX Summit (MAP-TXS) 2024. The EPL, developed in collaboration with the Home Team Science and Technology Agency (HTX), embodies cutting-edge firefighting technology with its electric drive and pumping capabilities. This vehicle not only prioritises the safety of responders and the community but also aligns with SCDF's commitment to zero- and low-emission vehicles. It marks a significant step towards a sustainable and environmentally responsible future.

Figure 1: The SCDF EPL

Launch of the SCDF EPL during MAP-TXS 2024 on 3 April 2024 by Mr K Shanmugam, Minister for Home Affairs and Minister for Law, and Mrs Josephine Teo, Minister for Communications and Information and Second Minister for Home Affairs

KEY CAPABILITY

The vehicle is equipped with a pump capable of discharging from its 2,000-litre water tank and 400-litre foam tank. It operates solely on electricity and features a battery capacity that allows continuous operation for up to one hour. To extend its range, the onboard Energy Backup Unit provides additional power for up to six hours, matching the operational capability of a conventional diesel pumper.[1]

POWERING DIFFERENTLY

With a charging capacity of up to 132 kW, the EPL can rapidly recharge its built-in batteries. This enables seamless short-range, emission-free operation, even with frequent use in urban environments like Singapore. When the vehicle comes to a stop, the engine automatically shuts down, with the lighting and equipment powered directly by the batteries. This significantly reduces noise levels at incident sites, which helps reduce stress for both responders and nearby residents. Besides delivering power, the EPL's electric drive operates emission-free, ensuring no fuel combustion during operation.

The transition from a combustion engine to an electric one represents a complete drive concept transforming the architecture of the firefighting vehicle, which yields numerous positive effects. This new concept enables a lower centre of gravity and a more balanced axle load distribution, resulting in exceptional cornering stability and reduced driving risks. Manoeuvrability is crucial for emergency vehicles, particularly in urban settings. With the EPL, engineers have pushed the boundaries of what is achievable. No other vehicle with comparable extinguishing and transport capacities offers such compact dimensions or an equally small turning radius (12.5 m in diameter). This is shown in Figure 2.

Figure 2: The SCDF EPL tackling a narrow space

[1] A conventional diesel pumper emits approximately 1 gramme of greenhouse gases per kilometre travelled. These emissions include carbon monoxide, hydrocarbons, nitrogen oxides, and particulate matter.

SAFETY FIRST

Engineered from the ground up, the EPL embodies innovation at every level while prioritising responder and community safety, as well as inclusivity. The EPL delivers both ergonomic and tactical advantages — it reduces physical strain on responders and enhances operational success. It minimises lifting strain, lowers removal heights and includes an electric ladder-lowering device. With just 260 mm between the road surface and the cabin floor in operation mode, it has never been easier to enter or exit a firefighting vehicle. First, the EPL eliminates the need for steps or stairs, reducing the risk of injury and long-term stress on responders. Second, the design features street-level entry, reducing injuries to responders when entering and exiting the vehicle with heavy equipment. Finally, by also repositioning the pump room in the EPL, additional equipment compartments are created at the rear of the vehicle, resulting in increased storage space at a low height and reduced lifting of heavy equipment.

SIMPLIFYING COMMUNICATION

The cockpit and crew cabin were also redesigned to improve communication. The cockpit features a rotating driver and commander seat, and the rear cabin is not separated from the cockpit to ensure the greatest possible interaction between the commander and responders. This is especially helpful during deployments at major events or when more time is needed to deliberate for complex situations.

The EPL is at the centre of its own communication system. It features intuitive, easy-to-use touchscreens with Internet-of-Things capabilities. This enhances firefighting effectiveness and responder safety, as pump operators can now have sight of situations. They can now control water or foam discharge using a handheld device, as opposed to the conventional vehicle, where pump controls are only operable from the rear of the vehicle. This is exemplified in Figure 3.

Figure 3: SCDF personnel controlling the EPL systems with a handheld device

BRILLIANCE ALL AROUND

A clear view around the vehicle is a basic requirement for a successful and safe operation. The integrated high-performance light mast and LED strips, with their powerful luminosity, ensure shadowless illumination of the operating environment. The ground contour lightings further enhance the safety of responders when operating in dark environments. In addition, the cornering lights make it easier to see pedestrians when driving. This increases the safety of pedestrians and helps reduce the risk of accidents on the way to the emergency scene. Figure 4 captures the EPL's all-around illumination.

Figure 4: Exterior of the EPL with its all-round illumination

RETHINKING OPERATIONS

Equipped within the EPL, the battery-powered Modular Firefighting Machine (MFM) is the latest addition to SCDF's suite of robots. Capable of carrying a payload of up to 625 kg and discharging water, the MFM will assist responders in delivering heavy firefighting equipment and penetrating risky areas during a fire. Another new solution customised and equipped within the EPL is the Mobile Equipment Carrier. It reduces response time significantly during road traffic accidents by allowing quicker deployment of heavy rescue tools so responders only need to make a single trip from the EPL to the incident site.

CONCLUSION

In 2024, the EPL will undergo an operational trial at Punggol Fire Station, marking the beginning of a groundbreaking era in firefighting technology. Subsequently, three additional units of the EPL are scheduled to commence operational trials at three other fire stations from 2026. The insights gained from these trials will play a pivotal role in shaping the future of not only the EPL but also SCDF's entire fleet of electric emergency vehicles. The development of the EPL underscores SCDF's unwavering commitment to delivering top-tier emergency response services while championing a greener, more sustainable future.

STRESS MANAGEMENT USING VR: HARNESSING STRESS AS A SUPERPOWER

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EDITORIAL PREVIEW

The Singapore Civil Defence Force, together with the National University of Singapore, embarked on a study on the use of virtual reality (VR) game-based intervention with real-time biofeedback for stress management and performance in firefighting trainees during their 22-week training regimen. The VR game developed by Kana (previously known as Stressjam) consists of three levels that require trainees to overcome obstacles, such as climbing ropes from mountain tops to steep cliffs, diving down and swimming underwater, and taming buzzing wasp nests. Trainees perform these actions while monitoring their heart rate variability (provided as a colour-coded scale during gameplay) and regulating their stress levels. It was found that the trainees reported a lower level of perceived stress (compared to their counterparts who were not exposed to the game) and showed a significant improvement in their stress mindset after the game. Moreover, the increase in the root mean square of successive differences during gameplay suggested a positive physiological response. The significant improvement in the final exercise assessment (when trainees took on the role of duty officers) indicated that such VR game-based training is a promising tool for enhancing performance in high-stress professions.

A GAME-CHANGER: ENTER THE WORLD OF VR TRAINING

Imagine battling fires, saving lives, and managing stress all at the same time. It is no small feat, but for the brave firefighters of the Singapore Civil Defence Force (SCDF), it is just another day on the job. With constant pressure and high stakes, stress management is no longer a luxury — it is a necessity. This sparked an exciting collaboration between the National University of Singapore and SCDF: a virtual reality (VR) game designed to help firefighters manage stress more effectively.

What Is the Game About?

The VR game, Kana VR, was developed by Kana to create a thrilling yet educational experience. Trainees see themselves scaling mountain peaks, diving underwater, dodging lava, and taming buzzing wasp nests. Sounds like an action-packed adventure? But there is a twist — these trainees need to regulate their stress levels to succeed. They do this by monitoring their heart rate variability (HRV), presented as a colour-coded scale during the game. Kana VR is more than a high-octane game; it is a science-backed intervention to improve stress management skills. While playing, trainees receive real-time biofeedback, allowing them to see how their stress levels fluctuate and to control them effectively. This instant feedback helps them understand and manage their physiological and psychological responses to stress. They have only one superpower — their stress system!

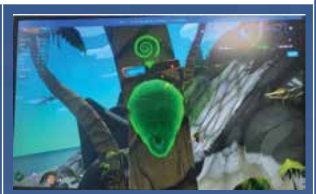
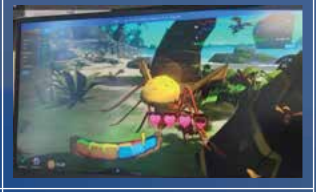
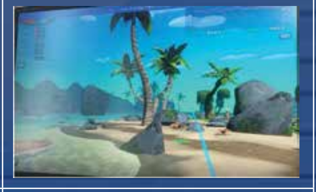
So, Does It Work?

Jerčić and Sundstedt showed how individuals who enhanced their emotional regulation using biofeedback in serious games achieved notable success [1]. They found that players who were more attuned to their emotions and who honed their emotional regulation skills were better at controlling arousal, which led to improved performance, quicker reaction times, and sharper attention during decision-making tasks. Similarly, a study by Maarsingh et al. highlighted the positive impact and appeal of Kana VR in fostering a healthier stress mindset among its users [2]. Trainees benefit from continuous updates about their arousal levels while engaging in a highly immersive game. This ongoing feedback helps them better recognise stress indicators and apply coping strategies. Additionally, incorporating biofeedback into the game boosts both engagement and the trainees' sense of self-efficacy as they develop effective stress management skills [3].

Bringing Kana VR to Singapore!

We were excited to bring this immersive training approach to Singapore for the first time [4]. Our proof-of-concept study explored if Kana VR with biofeedback training can enhance the stress mindset among SCDF officers and enhance training performance. Table 1 describes the components inside the Kana VR Game.

Table 1: The Adventure Begins — Inside the Kana VR Game

Components	Description	Screenshots
Story and Narrative	Players are on an exotic island where they overcome various obstacles to save the island from problems associated with a volcano. The player should overcome various elements of the island by engaging their stress system. Some challenges can be overcome by increasing their stress system, as indicated by the orange portion of the scalebar, others by calming down, as indicated by the blue portion of the scalebar. A player can progress through the game and achieve its goal by managing their stress level, measured through real-time HRV as indicated on the top left and right corners of the screen.	  
Game Mechanics	The game space consists of a jungle island with temples and other ancient buildings. A non-player character provides instructions for the next step. Several static and dynamic objects are available, including gemstones to collect, balls to pick up and wasps to avoid or kill. The player can move around the game space using the trigger button on the controllers. Permissible actions include picking and interacting with objects as well as swimming and climbing movements. There are levels of gameplay, with increasing challenges.	  
Feedback	Real-time feedback is displayed on the top of the screen as a stress meter. Their root mean square of successive differences (RMSSD) scores are continuously tracked for more than 60 seconds, which produces the stress range displayed to the participant in-game. The average value for the previous 60 seconds is fed back to the participant and serves as a baseline. At the end of the game, a scoreboard illustrates the player's total points, percentage of gemstones collected, stress average, stress range, time played and grades for specific tasks.	 

THE GAME PLAN

Recruited participants were trainees who undertook the same Section Commander Course (SCC) training and assessment and were randomly assigned into controls (received no Kana VR, n=13), placebo (received Kana VR but without real-time biofeedback, n=15) and intervention (played Kana VR with real-time biofeedback, n=19). The duration of the Kana VR gameplay was about 40 minutes and was administered between weeks 3 and 12 of the 22-week SCC. The HP Reverb G2 was used for this study as VR hardware (Figure 1). The stress mindset measure (SMM) tool was adopted to evaluate stress mindset among trainees pre- and post-gameplay [5-6]. Data from in-game performance scores, real-time heart rate measurements and perceived stress were collected to understand the trainees' stress management and the potential impact of VR-based training.

Figure 1: Participants undergoing the VR-based training with facilitators at the SCDF Civil Defence Academy

THE RESULTS ARE IN: LOWER STRESS, BETTER MINDSET

PSS

The Perceived Stress Scale (PSS) is a 10-item questionnaire to assess an individual's stress levels over the past month. Each question is rated on a Likert scale from 0 (never) to 4 (very often). Responses are reverse-coded and then totalled to generate a score ranging from 0 to 40 [4]. Given that daily activities and life events affect perceived stress, the survey was administered monthly to track participants' stress levels throughout the course. Participants from the control and placebo groups had similar overall PSS profiles, with an initial increase in perceived stress over the early stages. This was subsequently maintained over the remaining training period (Figure 2). Notably, participants from the intervention group had an overall significantly lower ($P<0.05$) level of perceived stress compared to the control and placebo groups from week 7 onwards.

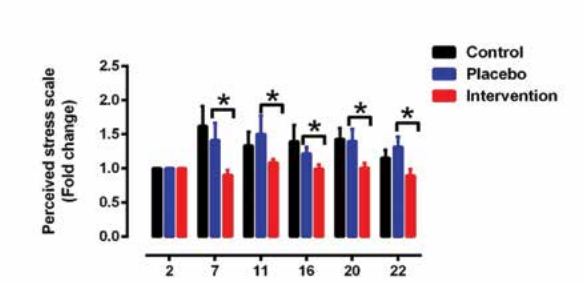


*Figure 2: PSS survey data from participants throughout the 22-week training regimen. *Significantly different from the respective comparison group (2-way ANOVA, Tukey's multiple comparison post-hoc test).*

SMM

We employed the SMM to gain further insight into participants' stress responses. Participants in the intervention group completed the eight-item SMM using a Likert scale ranging from 0 (strongly disagree) to 4 (strongly agree) immediately before and after gameplay. To calculate the final SMM score, we reverse-scored the odd-numbered items, summed the scores for all eight questions, and then divided this total by eight. SMM was administered pre- and post-gameplay at weeks 3 and 12 of the training regimen. While there were no observable differences in stress mindset between pre- and post-gameplay at their respective weeks, the pre-game stress mindset was found to have significantly increased (P<0.05) at week 12 compared to the baseline response at week 3 (Figure 3). This suggests that the effects on stress mindset acquired from the gameplay take time to develop.

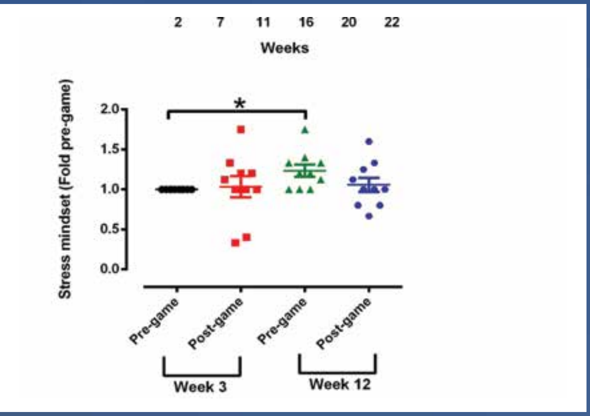


Figure 3: Stress mindset survey

HRV

To determine physiological response, the Kana VR sensor was attached to the trainee's chest to capture HRV throughout the gameplay. In this study, only participants from the intervention group used the sensor. Hence, HRV was only measured in this group. HRV was then utilised to calculate the root mean square of successive differences (RMSSD) that measured the variability of heart rate intervals. For adults, a healthy RMSSD range generally falls between 15 and 95, depending on lifestyle factors. Some game tasks required players to maintain specific RMSSD values, encouraging them to consciously manage their physiological and stress responses. The biofeedback measurements during the gameplay significantly increased (P<0.05) at week 12 compared to week 3. This validated participants' improved ability to cope with stress during the second VR intervention (Figure 4).

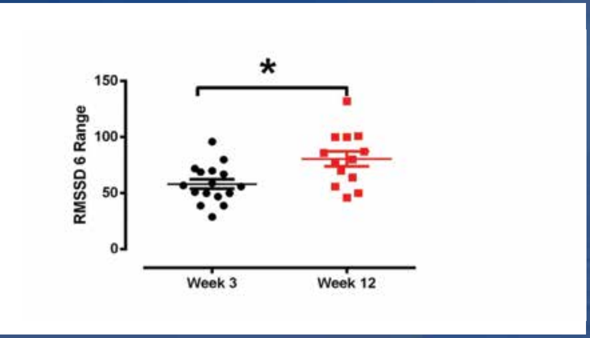


*Figure 4: Biofeedback (RMSSD) measurements during VR gameplay at weeks 3 and 12. Data is presented as mean +/- SEM. *Significantly different to week 3 within the intervention group (Student's unpaired t-test).*

REAL-WORLD IMPACT

The ultimate test for these trainees came during their final exercise assessment at the end of the programme. It is a simulated scenario where trainees will take on the role of the Duty Officer who commands the operations and provides instructions to the various sections. The instructors will assess the trainees out of 100 points. The results were promising — those who had trained with Kana VR performed significantly better than their peers who had not. Based on the participants' role as duty officers, the intervention group had significantly higher scores (P<0.05) (~15%) in the final exercise assessment when compared to the control group. This was not observed in the placebo group.

CONCLUSION — UNLEASHING THE POTENTIAL

Training approaches often overlook the stress inherent in crisis situations. Preparing first responders emotionally for difficult situations improves both short-term coping and long-term well-being. SCDF plays a crucial role in delivering emergency response and public safety services throughout Singapore. SCDF personnel frequently encounter emergencies that may evoke intense negative emotions associated with stress. Therefore, there is a pronounced need for effective methods that focus on emotion-regulation skills. Our exploratory study suggests that VR game-based training is a powerful tool for enhancing performance in real-world, high-stress situations. This innovative stress management approach can revolutionise training for first responders not just in Singapore, but globally. By integrating immersive and evidence-based training approaches such as Kana VR, individuals can be better prepared for the rigours of their demanding roles. This leads to healthier, more resilient, and more effective emergency responders.

REFERENCES

1. Jerčić, P., Sundstedt, V., Practicing emotion-regulation through biofeedback on the decision-making performance in the context of serious games: A systematic review. *Entertainment Computing* 2020, 29, 75-86.

2. Maarsingh, B. M.; Bos, J.; Van Tuijn, C. F. J.; Renard, S. B., Changing Stress Mindset Through Stressjam: A Virtual Reality Game Using Biofeedback. *Games Health* J 2019, 8, (5), 326-331.

3. Houzangbe S, C. O., Gorisse G, Richir S., Fear as a biofeedback game mechanic in virtual reality: effects on engagement and perceived usability. FDG '18: Proceedings of the 13th International Conference on the Foundations of Digital Games 2018, 1-6.

4. Imran, M.A.D.B.; Goh, C.S.Y.; V, N.; Shanmugham, M.; Kuddoos, H.; Leo, C.H.; Rai, B. A Virtual Reality Game-Based Intervention to Enhance Stress Mindset and Performance among Firefighting Trainees from the Singapore Civil Defence Force (SCDF). *Virtual Worlds* 2024, 3, 256-269.

5. Crum, A. J.; Salovey, P.; Achor, S., Rethinking stress: the role of mindsets in determining the stress response. *J Pers Soc Psychol* 2013, 104, (4), 716-33.

6. Crum, A. J.; Akinola, M.; Martin, A.; Fath, S., The role of stress mindset in shaping cognitive, emotional, and physiological responses to challenging and threatening stress. Anxiety Stress Coping 2017, 30, (4), 379-395.

This study was also published in Imran, M. A. D. B., Goh, C. S. Y., V, N., Shanmugham, M., Kuddoos, H., Leo, C. H., & Rai, B. A Virtual Reality Game-Based Intervention to Enhance Stress Mindset and Performance among Firefighting Trainees from the Singapore Civil Defence Force (SCDF). In Virtual Worlds, 3(3), 256-269.

THE DEVELOPMENT OF SCDF RFFT PROGRAMME – UPKEEPING FRONTLINE OPERATIONAL FITNESS

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EDITORIAL PREVIEW

Firefighting is a demanding job requiring significant strength, endurance and resilience. The Responders Functional Fitness Training (RFFT) programme was co-developed by the Singapore Civil Defence Force and Home Team Science and Technology Agency to enable firefighters to meet these physical demands. More specifically, the programme was designed to improve firefighters' physical fitness and reduce injury risks by incorporating exercises mimicking real-world tasks. They target key muscle groups, mainly in the lower back and lower limbs. Throughout a 12-week training intervention study, the RFFT programme improved lower body strength and cardiorespiratory endurance. While agility and muscular power showed minimal changes, the Individual Physical Proficiency Test saw positive trends. To improve the RFFT going forward, we suggest embracing technology, such as wearables (for instance, smartwatches and heart rate monitors), to enable more precise feedback and accurate data collection. Moreover, refining RFFT to include a broader range of plyometric exercises could yield a more comprehensive impact on firefighters' physical fitness.

INTRODUCTION

Firefighting is a physically challenging occupation that exposes individuals to substantial physiological strain. Fireground tasks, such as fire suppression, equipment carriage and rescue operations, demand significant muscular strength and endurance alongside cardiorespiratory endurance (Elsner & Kolkhorst, 2008). In addition, firefighters don heavy protective gear in thermally hostile environments such as burning structures, increasing energy demands, adding stresses to the cardiovascular system, and subjecting firefighters to further physiological strain (Bruce-Low et al., 2007; Del Sal et al., 2009; Elsner & Kolkhorst, 2008). To ensure operational safety and success, firefighters need to have sufficiently high levels of physical fitness to cope with the occupational stresses of firefighting.

Firefighters are also at a higher risk of morbidities and mortalities. For example, sudden cardiac events have been attributed to the physiological and psychological strains of firefighting (Jeung et al., 2022). Cardiac arrests are a leading cause of on-duty firefighter mortality, responsible for approximately 45% of on-duty firefighter deaths in the United States (Haller & Smith, 2019; Kahn et al., 2015). This poses a major health concern for firefighters. Additionally, firefighters are prone to developing musculoskeletal disorders due to the need to frequently perform repetitive movements and carry out strenuous activities such as dragging and lifting.

To ameliorate the risks of injuries and mortality, regular physical fitness training has been recommended by the National Fire Protection Association (2000). Improving fitness has benefits beyond allowing firefighters to meet their occupational demands and complete their operations. Higher levels of physical fitness would ensure firefighters have sufficient strength and endurance — both muscular and cardiorespiratory — to withstand the extreme physical workload and carry out their duties safely, while also conferring cardioprotective effects and reducing risks of developing metabolic syndrome (Baur et al., 2012; Strauss et al., 2021). This is especially important as cardiovascular risk factors, combined with physical strain, precipitate cardiac events, a serious concern for firefighters. Thus, there is a need to explore strength and conditioning programmes to sufficiently prepare Singapore Civil Defence Force (SCDF) firefighters to face the fireground safely and optimally.

RESPONDERS FUNCTIONAL FITNESS TRAINING PROGRAMME (RFFT)

Keeping fit is a challenge for SCDF responders because they often work odd hours and long shifts. Conventional fitness programmes may not be suitable to address the specific needs of firefighting. Thus, SCDF and the Home Team Science and Technology Agency developed a fitness programme called the RFFT programme, which aims to enhance the physical and work performance of SCDF responders. The RFFT programme was designed with SCDF's operational constraints, training frequency and timings, and firefighter readiness in mind to ensure training safety and effectiveness.

The RFFT programme comprises exercises that match biomechanical movements and functional activities during operations to fix deficits and prevent injury mechanisms such as overexertion and overuse (Abel et al., 2015). The RFFT programme is based on the physical demands and skills of urban firefighting, as defined by a functional job analysis. The programme has three main types of exercises: heart rate zone (HR zone) training, AMRAP (as many rounds/reps as possible), and job-specific training. HR zone training aims to improve a person's aerobic capacity based on HR Zone 3, as shown in Figure 1. AMRAP is a circuit training that involves performing

HEART RATE ZONES

Zone	Intensity	% of *Heart Rate Max
1	VERY LIGHT	50 - 60%
2	LIGHT	60 - 70%
3	**MODERATE**	**70 - 80%**
4	HARD	80 - 90%
5	MAXIMUM	90 - 100%

*ESTIMATED HEART RATE MAX = 220 - AGE

Figure 1: Heart rate zones — RFFT targets Zone 3

a series of exercises for a fixed time or number of rounds/reps with little rest in between. Job-specific training is a functional training that involves performing tasks that simulate real firefighting scenarios, such as hose dragging, ladder climbing and casualty evacuation, with rest periods in between.

The RFFT programme also includes functional exercises that target different muscle groups and movement patterns, such as squats, lunges, push-ups, pull-ups, planks, and kettlebell swings. These exercises help increase core stability, balance, coordination and mobility, as well as prevent injuries.

The RFFT programme is flexible and adaptable. It can be done in various locations, such as fire stations, gyms or outdoor areas with little or no equipment. The programme also allows for customisation and progression, based on firefighters' fitness levels and goals.

EFFICACY STUDY ON RFFT

A study was conducted to assess the effectiveness of the 12-week RFFT intervention on physical fitness and the Individual Physical Proficiency Test (IPPT) of firefighters from 22 fire stations. The study design is shown in Figure 2.

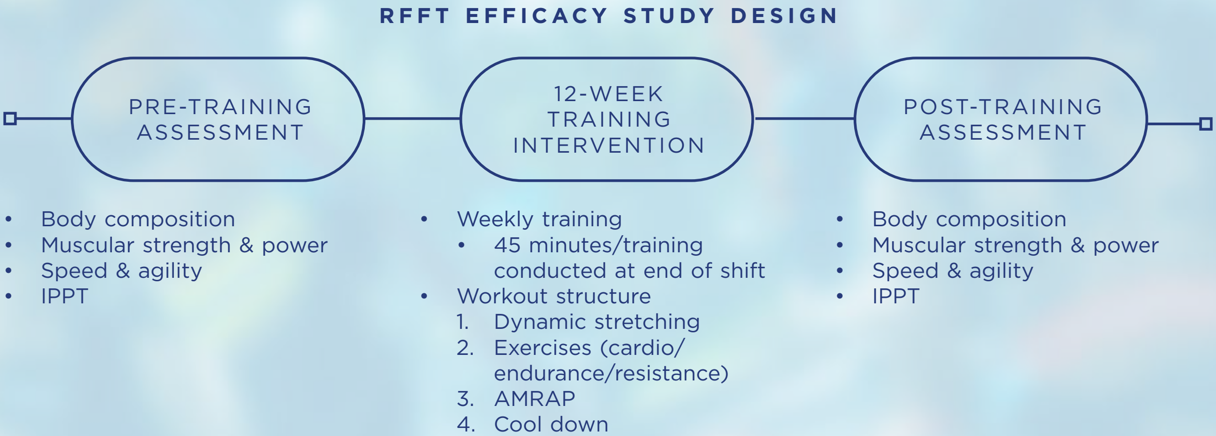


Figure 2: Study design of RFFT 12-week programme study

METHODS

A total of 49 firefighters participated in this study {age: 27.3 ± 7.24 years [mean ± standard deviation (SD)]}. The study utilised a pre-post-study design, where participants were required to undergo the 12-week RFFT programme with pre-training and post-training assessments. The pre- and post-training assessment consisted of fitness evaluation (see section below) and IPPT. Statistical analysis was performed using JASP (version 0.18.3), and data was tested for normality using the Shapiro-Wilks test. Where appropriate, paired samples t-tests and Wilcoxon signed-rank tests were conducted to determine the effect of RFFT on a series of fitness evaluation components and IPPT stations.

FITNESS EVALUATION

Muscular power, speed and agility, lower limb strength, and grip strength were assessed at the Emergency Responders' Fitness Conditioning and Enhancement Lab (EXCEL). Muscular power refers to the ability to exert maximal force in the shortest time. This was assessed using the EZEJUMP system, where participants performed three countermovement jumps on the jump mat (Markovic et al., 2004). Speed and agility refer to how fast the body moves and reacts in response to a stimulus, such as changing direction. This was assessed using the Swift Performance NEO timing gates and the agility t-test (Raya et al., 2013). Muscular strength refers to the ability to generate force and overcome resistance, and was assessed at the lower limb and forearm. Lower limb strength was assessed using the BIODEX multi-joint dynamometer using the isokinetic protocol to determine the torque produced during knee joint flexion and extension (Tuominen et al., 2023). Forearm strength was assessed using the J-tech grip strength dynamometer (Rhea et al., 2004). Figure 3 summarises the evaluation and the respective equipment used.

FITNESS EVALUATION

Figure 3: Components assessed during fitness evaluation and the respective equipment used

IPPT

The IPPT consists of push-ups, sit-ups and a 2.4 km run. The number of push-ups (per minute) and sit-ups (per minute), and the time to complete a 2.4 km run were recorded. The maximum rate of oxygen consumption attainable during physical exertion (VO2max) was estimated using the 2.4 km run time with the following formula (Trinh, 2019):

$$VO_2 \ max \ (mL/kg/min = 76.775 - (2.543 * Run \ Time \ [min])$$

TWELVE-WEEK TRAINING INTERVENTION

Participants were required to complete the weekly RFFT sessions during their shifts at their respective fire stations for a total of 12 weeks. Examples of the weekly training sessions are shown in Figures 4 and 5.

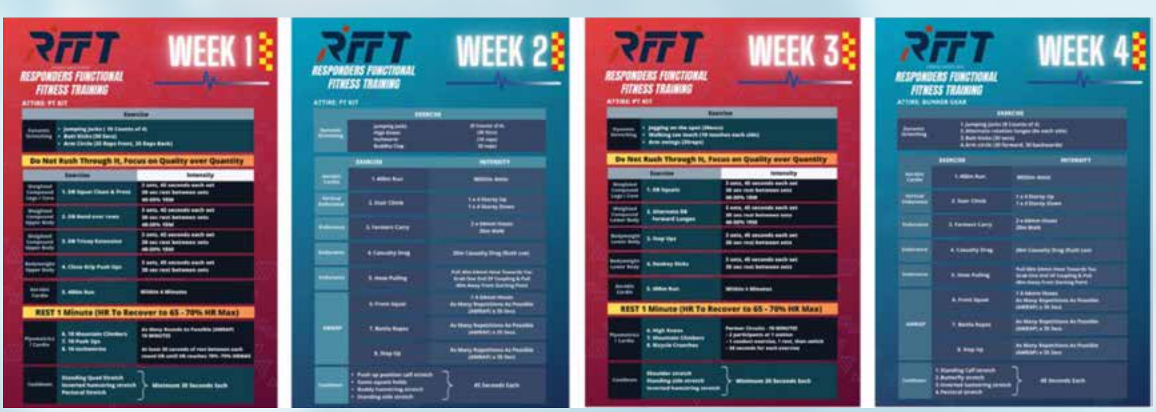


Figure 4: Examples of RFFT programmes for week 1 to week 4

Figure 5: Firefighters performing the weighted front squat with firefighting hoses

RESULTS AND KEY FINDINGS

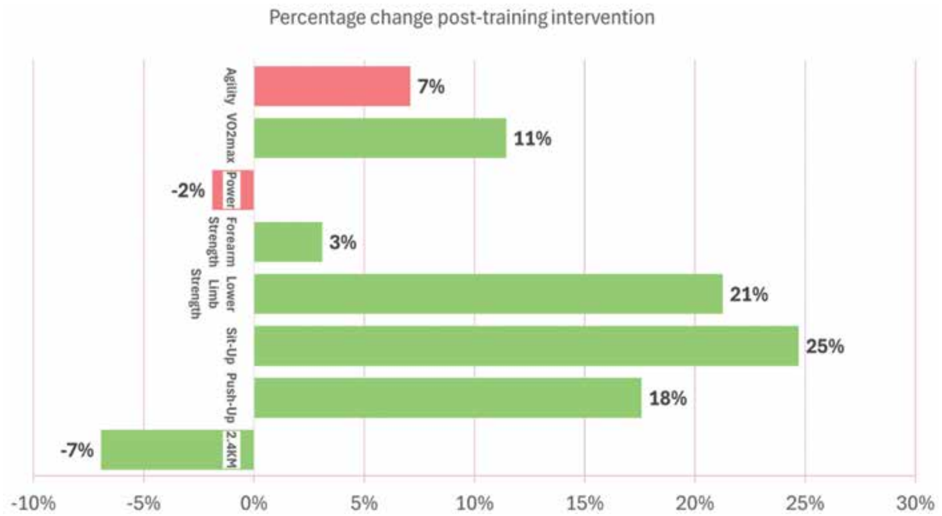
Thirty-three firefighters did not attend the post-test assessment and were considered drop-outs. This amounted to a participant attrition rate of 68%.

Table 1 shows the participants' age, height, weight and BMI by sex. Figure 6 depicts the results of the pre- and post-test fitness evaluation in terms of percentage change following the 12-week intervention. Overall, the results indicated significant differences in agility and lower limb strength (p=.042, p=<.001), while the other fitness evaluation components were not significantly different (p>.05) (Table 2).

Table 1: Participant's demographic information

Time	*n*	*Gender*	*Age*	*BMI*
Pre	49	4F, 45M	27.3 ± 7.24	24.1 ± 3.69
Post	16	1F, 15M	26.3 ± 6.03	24.0 ± 3.80

Note. Results are reported as Mean ± SD.



Note. Green bars indicate a desirable change, while red bars indicate a less desirable change.

Figure 6: The percentage change in IPPT and performance parameters post the 12-week intervention

Table 2: Statistical analysis of pre- vs post-trial results

Components	Pre-Trial	Post-Trial	Change	*p*
Agility	13.70 ± 2.22	14.61 ± 2.60	0.90 ± 1.62	**.042***
VO_2max (estimated)	45.07 ± 6.20	49.15 ± 3.76	3.53 ± 9.17	.209
Muscular Power^	12.68 ± 3.19	12.44 ± 3.13	-0.24 ± 1.62	1
Forearm Strength	43.46 ± 8.08	44.61 ± 7.90	1.15 ± 3.37	.192
Lower Limb Strength	160.58 ± 46.89	193.21 ± 43.64	42.67 ± 62.21	**<.001***
Sit-ups	35.44 ± 7.13	42.36 ± 7.50	6.92 ± 12.43	.067
Push-ups	39.50 ± 9.27	45.57 ± 11.94	6.07 ± 15.40	.259
2.4km run	12.47 ± 2.44	10.86 ± 1.48	-1.61 ± 5.42	.209

Note. Paired t-test was used to analyse normal data, while Wilcoxon signed-rank test was used to analyse non-normal data, as represented by ^.

Overall, our findings indicate that the RFFT may be helpful in maintaining physical fitness, especially in terms of IPPT performance, cardiorespiratory endurance and muscular strength. To further improve the effectiveness of the training programme, workout intensity, frequency, as well as elements of plyometric and agility work may be increased to ensure the training remains holistic. However, operational constraints and safety should be considered while refining and incorporating changes to the current programme design.

LIMITATIONS

There were a few limitations in this study. The decentralisation of the study meant that participants were spread across fire stations, which made it challenging to track training frequencies, intensity, and progress. This resulted in lower compliance levels and higher drop-out rates. In addition, the data acquisition tools used resulted in an onerous and manual self-reporting process, which may have also further contributed to the poor compliance levels and dropouts.

FUTURE RESEARCH WORK

Continuous refinement of the training programme is recommended to ensure the relevancy of the training to operational demands and to maintain its efficacy. Centralised training should be considered for future studies to ensure more consistency and ease of progress tracking. Using technology to complement the training may also improve its efficacy. Leveraging wearables to allow real-time heart rate monitoring reduces self-reports and may lead to better training adherence levels to the target HR zone. The development of mobile applications may also help in progress tracking, dissemination of RFFT information, and relevant resources.

CONCLUSION

A consistent physical training programme for the SCDF can foster cohesion and minimise training hazards, using scientific research-based evidence to enhance training outcomes. Applying science and technology to our training can improve our firefighters' performance, making sure they are physically ready to handle physiological challenges of the job without jeopardising safety.

SCDF will further improve the existing RFFT programme to comprehensively address additional issues, such as heat adaptation, wearing full personal protective equipment with self-contained breathing apparatus, etc.

REFERENCES

1. Baur, D. M., Christophi, C. A., & Kales, S. N. (2012). Metabolic syndrome is inversely related to cardiorespiratory fitness in male career firefighters. The Journal of Strength & Conditioning Research, 26(9), 2331-2337.

2. Bruce-Low, S. S., Cotterrell, D., & Jones, G. E. (2007). Effect of wearing personal protective clothing and self-contained breathing apparatus on heart rate, temperature and oxygen consumption during stepping exercise and live fire training exercises. Ergonomics, 50(1), 80-98.

3. Del Sal, M., Barbieri, E., Garbati, P., Sisti, D., Rocchi, M. B., & Stocchi, V. (2009). Physiologic responses of firefighter recruits during a supervised live-fire work performance test. The Journal of Strength & Conditioning Research, 23(8), 2396-2404.

4. Elsner, K. L., & Kolkhorst, F. W. (2008). Metabolic demands of simulated firefighting tasks. Ergonomics, 51(9), 1418-1425.

5. Haller, J. M., & Smith, D. L. (2019). Examination of strenuous activity preceding cardiac death during firefighting duties. Safety, 5(3), 50.

6. Jeung, D. Y., Hyun, D. S., Kim, I., & Chang, S. J. (2022). Effects of emergency duties on cardiovascular diseases in firefighters: a 13-year retrospective cohort study. Journal of Occupational and Environmental Medicine, 64(6), 510-514.

7. Kahn, S. A., Woods, J., & Rae, L. (2015). Line of duty firefighter fatalities: an evolving trend over time. Journal of Burn Care & Research, 36(1), 218-224.

8. Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. The Journal of Strength & Conditioning Research, 18(3), 551-555.

9. National Fire Protection Association. (2000). NFPA 1583: standard on health-related fitness programs for firefighters. National Fire Protection Association, Quincy, MA.

10. Raya, M. A., Gailey, R. S., Gaunaurd, I. A., Jayne, D. M., Campbell, S. M., Gagne, E., ... & Tucker, C. (2013). Comparison of three agility tests with male servicemembers: Edgren Side Step Test, T-Test, and Illinois Agility Test. Journal of Rehabilitation Research & Development, 50(7), 951-960.

11. Rhea, M. R., Alvar, B. A., & Gray, R. (2004). Physical fitness and job performance of firefighters. The Journal of Strength & Conditioning Research, 18(2), 348-352.

12. Strauss, M., Foshag, P., Jehn, U., Brzęk, A., Littwitz, H., & Leischik, R. (2021). Higher cardiorespiratory fitness is strongly associated with lower cardiovascular risk factors in firefighters: a cross-sectional study in a German fire brigade. Scientific Reports, 11(1), 2445.

13. Trinh, C. M. (2019). Predicting VO2max from 1-and 1.5-mile runs. In International Journal of Exercise Science: Conference Proceedings (Vol. 2, No. 11, p. 8).

14. Tuominen, J., Leppänen, M., Jarske, H., Pasanen, K., Vasankari, T., & Parkkari, J. (2023). Test– retest reliability of isokinetic ankle, knee and hip strength in physically active adults using Biodex system 4 pro. Methods and Protocols, 6(2), 26.

USE OF VIDEO ANALYTICS TO ENHANCE MARITIME SEARCH AND RESCUE OPERATIONS FOR SCDF

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EDITORIAL PREVIEW

A marine search and rescue (SAR) operation can be likened to searching for a needle in a haystack, traditionally relying on manual sighting approaches. While Singapore Civil Defence Force's (SCDF) marine specialists are trained to conduct such operations using systematic search patterns, manual sighting has a high possibility for human error. Moreover, the current speed at which SAR can be performed is limited by the nature of operation, which is usually resource intensive, involving the deployment of multiple vessels and manpower. Given the widespread use of artificial intelligence (AI) for land-based object detection, such as human counting, security and vehicle tracking, the SCDF Marine Division has partnered with HTX's (Home Team Science and Technology Agency) Sense-making and Surveillance Centre of Expertise (CoE) and Marine Systems CoE in a proof of concept (POC) on possible applications for marine SAR operations. The POC aims to explore the use of AI-based video analytics to improve the efficiency of SAR operations by achieving reliable real-time detection of search targets.

INTRODUCTION

Every year, the Singapore Civil Defence Force (SCDF) Marine Division responds to several water rescue incidents. The Maritime and Port Authority of Singapore (MPA) is the incident manager of all marine SAR operations, activating resources from related agencies such as the SCDF Marine Division and Police Coast Guard to support operations. Over the years, several technologies have been deployed by the Marine Division to enhance the efficiency of SAR operations, including seaborne electro-optic sensors (SEOS), remotely operated vehicles (ROV) and sonars. However, the use of such technologies in SAR operations is time consuming and ineffective, as it relies heavily on the operator to control and interpret the images to detect the search target. As a result, there is a need to explore and integrate advanced technologies, such as video analytics (VA), to automate target detection and recognition. This will reduce the reliance on human operators and enhance the overall effectiveness of marine SAR operations. By incorporating AI in VA to process video feeds from various sources available on board the vessels, the technology can aid rescuers in detecting anomalies (e.g. life rafts, life buoys, or individuals) that could indicate search targets.

TYPES OF SAR INCIDENTS

SAR scenarios in local waters often involve man overboard (MOB) incidents, where individuals fall off a vessel or seaside structure and are at risk of drowning. Additionally, marine emergencies such as vessel collisions or ship fires can lead to individuals falling or escaping into the waters, resulting in mass MOB situations. In such cases, immediate witnessing and reporting of the incident to port authorities can significantly enhance the chances of survival for the missing person(s).

SAR incidents may be broadly categorised into time-critical or prolonged types of operations. During the initial period following the last sighting, the chance of locating and rescuing individuals in distress is the highest, with the likelihood of survival decreasing over time. If the missing person at sea cannot be located, the operation may be extended for up to seven days to cover a wide area in a prolonged SAR operation. Prolonged SAR operations are manpower and logistically intensive because the casualty could drift far away from the last known location or become submerged underwater. The Basic Task Force in a marine SAR operation consists of one Rapid Response Fire Vessel and one Marine Rescue Vessel. Additional vessels, such as Heavy Rescue Vessels (HRV) and Heavy Fire Vessels, may be activated to support the operation. In addition, the Marine Division can deploy a Rigid Hull Inflatable Boat and jet skis to facilitate shallow water rescue operations (Figure 1).

Figure 1: SCDF Marine Division's Rigid Hull Inflatable Boat deployed during SAR operation

CURRENT SEARCH METHODS

Depending on the nature of incident, the rescue team formulates a search plan by determining the search area where the missing person(s) would likely be found. This assessment is based on the last known position, time elapsed and possible drift due to water currents. Once the search area has been determined, rescuers execute a systematic search pattern to thoroughly scan the area. During a SAR operation, the vessel's crew must maintain a proper lookout for possible targets by manually sighting the water surface and utilising video feeds from onboard cameras or sonar images (Figure 2). In a prolonged SAR operation, additional equipment, such as ROV or sonar equipment, may be deployed for underwater search. This comprehensive approach maximises the chances of locating missing individuals.

Figure 2: SCDF marine specialists manually sighting during a SAR operation

VA FOR MARINE SAR

In a proof of concept (POC), two main capabilities are being explored to integrate VA into SAR operations. The first application aims to assist in locating drifting targets during time-critical operations where timely identification of man-in-water is paramount for a successful rescue. By leveraging VA, the systems could potentially detect and track individuals in the water more quickly and accurately than human observers. The second application explores the use of VA in underwater search and recovery during prolonged operations to analyse sonar or video data to identify potential targets. This could reduce rescuer fatigue and improve overall efficiency by allowing human operators to focus on verifying and responding to VA-identified targets rather than manually scanning large volumes of data. Deep learning network is a method applied to train the VA by analysing how a target and, in this use case, a person may look like. The project team used synthetic data, created to resemble the appearance of individuals in water, as training examples to address the lack of actual images. The synthetic data was superimposed into camera footage obtained onboard SCDF vessels to train the VA to identify potential search targets. Images obtained at sea can be of poor quality due to poor lighting. Therefore, the project team utilised image enhancement techniques on colour and contrast to improve the quality of the footage for improved accuracy.

INTEGRATING VA FOR SURFACE SEARCH

The man-in-water detection utilises live video footage from the SEOS installed on all SCDF vessels. A SEOS is a type of camera system designed for marine environments to capture visual images in varying light and weather conditions. The project team conducted trials using life-sized mannequins floating at a distance to validate the concept. Two types of camera footage were utilised from the SEOS: RGB camera and forward-looking infrared (FLIR) camera. While RGB cameras capture and produce images resembling what the human eye sees (Figure 3), FLIR is a type of thermal imaging technology that creates a visual representation by detecting infrared radiation, allowing rescuers to see during night conditions (Figure 4). The VA prototype was tested at various distances from SCDF vessels. These trials aimed to assess the effectiveness of the AI models in detecting and identifying objects of interest, simulating real-world SAR scenarios. The use of both RGB and FLIR camera footage allowed for comprehensive testing of the AI models across different visual environments, contributing to the refinement and optimisation of the detection capabilities for diverse operational conditions.

Figure 3: VA object identification with RGB camera

Figure 4: VA object identification with FLIR camera

INTEGRATING VA FOR UNDERWATER SEARCH

Prolonged SAR operations may extend the search below the water surface because a drowned victim may initially sink to the seabed. However, changes in various factors, such as body composition and water conditions, can influence whether the drowned victim remains submerged or resurfaces over time. Underwater search is currently conducted with sonar equipment such as side-scan sonar (SSS) and multibeam sonar.

The SSS is an equipment deployed from a moving vessel. It emits acoustic signals reflected off the seabed and other underwater objects. As the vessel moves slowly across the search area with the SSS, the returning signals reflected from objects are generated into a sonar image portraying the seabed, which rescuers manually monitor for possible search targets (Figure 5). Sonar image examples of some objects of interest, a sunken vessel and a person, are shown in Figures 6 and 7, respectively. By integrating VA into live sonar images, an AI model can be trained to identify objects of interest during a SAR operation. Upon detection, the system can be programmed to alert the operator and point the rescuer to the location of detection for further investigation. The application of VA would alleviate the burden on rescuers and enhance the efficiency and accuracy of the search process, ultimately contributing to more timely and successful outcomes.

Figure 5: SCDF marine specialists monitoring sonar images from the SSS during a SAR operation

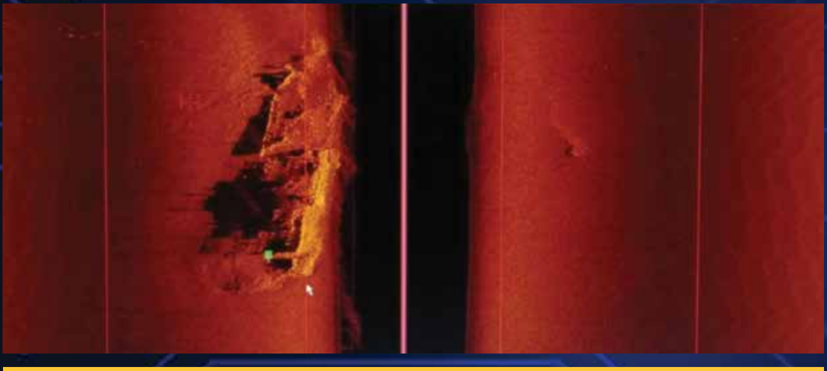

Figure 6: Sonar scan of the seabed with a sunken vessel detected

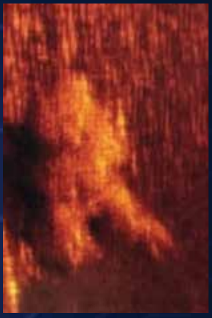

Figure 7: Sonar detection of a human target

An ROV is a highly manoeuvrable underwater vehicle that can be used to investigate the seabed while being operated by a rescuer at the water surface. The HRV is equipped with the Seamor Chinook, a ROV model that can be deployed during SAR operations (Figure 8). The operator will navigate the ROV using the multibeam sonar and RGB camera equipped on the vehicle (Figure 9). The multibeam sonar is a type of forward-looking acoustic imaging system that enables the operator to effectively navigate the ROV in local waters that are usually murky or have low visibility to detect search targets. The ROV is typically deployed to further investigate potential search targets identified by the SSS, or if the search has been narrowed down to a specific location.

Figure 8: SCDF's ROV — Seamor Chinook

Figure 9: Rescuers operating the ROV with sonar imaging and RGB camera

FUTURE OF SAR OPERATIONS WITH ARTIFICIAL INTELLIGENCE

The project team has successfully concluded the initial phase of trials, during which valuable insights and feedback were gathered to enhance the AI model. Operator inputs were actively sought throughout the trials to ensure that the development aligned with SCDF's specific operational requirements, aiming to bolster operational capabilities. As a notable example, a map-based graphical user interface (GUI) will be implemented in the second phase of the POC. It will display the geographical locations of potential targets, thereby improving mission planning and visualisation. This GUI will also be made accessible on a wireless tablet on board SCDF vessels, empowering rescuers to monitor SAR operations without being confined to a fixed station, thereby enhancing flexibility and responsiveness during critical operations.

The integration of VA technology will weave into future technologies currently being explored by the SCDF Marine Division. For example, VA can be applied to camera footage of Unmanned Aerial Vehicles (UAV), which holds significant promise to enhance the efficiency and effectiveness of marine SAR operations. With similar RGB and thermal cameras equipped on the UAV, rescuers can do a rapid aerial scan to identify potential person(s) in distress across vast expanses of water in a short time. Once a target is identified, the UAV can deploy an inflatable life buoy to provide immediate assistance while piloted resources make their way to provide further assistance. By harnessing VA in conjunction with these advanced technologies, SCDF aims to improve its SAR capabilities during marine emergencies and enhance overall operational effectiveness, especially during the time-critical phase of operations.

ENHANCING HAZMAT RESPONSE: SCDF'S AND HTX'S SCIENTIFIC APPROACH TO SENSOR EVALUATION AND PROCUREMENT

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EDITORIAL PREVIEW

In today's complex operating environment, swift detection and early warning of incidents involving Hazardous Materials (HazMat) are crucial. These incidents can lead to severe health risks, property damage and environmental contamination. Recently, the Singapore Civil Defence Force (SCDF) has been leveraging the Internet of Things and fixed HazMat sensors strategically deployed across the island. These sensors provide 24/7 monitoring for early warning of potential HazMat incidents.

A thorough procurement evaluation process is required for the cost-effectiveness of solutions to meet operational needs. Thus, it is necessary to design tests to fully understand HazMat sensors' capability, performance and limitations, and instil confidence when using them during operations. SCDF collaborates with the Home Team Science & Technology Agency in the procurement evaluation process using scientific methods. This article will cover two such examples:

- Evaluating performance of an infrared standoff sensor: Unveiling the testing methodology designed to validate the vendor's technical claims on sensitivity and instilling confidence in the sensor's capabilities.
- Optimising deployment of an electronic nose grid: Exploring the utilisation of scientific models to determine the optimal coverage for maximising efficiency of the sensor network.

These efforts underscore SCDF's commitment to innovation and safety. SCDF will continue to enhance HazMat response capabilities through cutting-edge sensor technologies to mitigate emerging risks and protect public safety effectively.

INTRODUCTION

In today's complex industrial and environmental landscapes, the swift detection of Hazardous Materials (HazMat) is critical in incidents involving chemical, biological, radiological or explosive agents. Accidents involving HazMat can lead to severe health risks, property damage and environmental contamination. Due to the dynamic nature of HazMat incidents, timely detection and early warning of HazMat plumes is essential for rapid response.

SUITE OF SCDF'S HAZMAT SENSORS

Traditionally, the Singapore Civil Defence Force (SCDF) deployed responders with handheld sensors after a reported HazMat incident. In recent years, SCDF has been leveraging the Internet of Things and fixed HazMat sensors. Deployed strategically across the island, these fixed HazMat sensors proactively monitor for potential HazMat incidents and, upon detection, alert SCDF at the earliest possible time. This enhances real-time monitoring and detection of HazMat, reduces response time, and provides a more accurate assessment, thus improving overall public safety.

SCDF deploys both standoff and point source sensors for 24/7 HazMat monitoring. Standoff sensors are advanced instruments capable of detecting and identifying substances from far, without direct sampling or exposure. These devices typically employ techniques such as infrared spectroscopy, Raman spectroscopy or laser-based methods to analyse the spectral signatures of HazMat from long distances of up to 5 km with a wide area of coverage. Point source sensors are designed to detect, identify and quantify specific HazMat within proximity. These sensors analyse samples directly from the source, providing accurate and detailed readings of the HazMat. When used in combination, these sensors provide early warning of potential incidents and continuous monitoring of plume spread during an incident.

To implement such a comprehensive monitoring capability is expensive. Therefore, during procurement, it is necessary to ensure that the sensors meet operational needs cost-effectively. With a plethora of sensors available in the market, selecting the right one involves thorough assessment. Compounding this challenge is the rarity of HazMat incidents, making real-world testing difficult. Often, agencies rely on technical specifications and vendor claims that may not accurately reflect the sensors' performance under actual operational conditions. To overcome this problem, SCDF works closely with the Home Team Science & Technology Agency (HTX) Chemical, Biological, Radiological, Nuclear and Explosives (CBRNE) Centre of Expertise to evaluate the procurement of new sensors. The procurement process includes literature review, laboratory testing and field testing.

EVALUATING PERFORMANCE OF AN INFRARED STANDOFF SENSOR

SCDF recently procured new standoff sensors for maritime use. Deploying standoff chemical sensors on ships or near our shores presents unique challenges over typical land deployments. The harsh local marine environment, with factors such as saltwater corrosion, humidity and constant motion, can adversely affect the performance of these instruments. Rigorous testing under simulated marine conditions is thus necessary to ensure their reliable operation, ruggedisation, and suitability for maritime applications. The process safeguards both personnel and the environment from potential chemical threats.

To ensure that the sensors delivered are satisfactory, SCDF approached HTX CBRNE to conduct a joint field test to evaluate the technical specification provided by the original equipment manufacturer as well as calculation and simulation by subject matter experts.

Objective:

To evaluate the performance and capabilities of a standoff chemical detector, specifically on its ability to detect and identify tracer gas releases from an external source at varying distances, through a Sea Acceptance Test (SAT) in the actual maritime environment.

Experimental Setup:

Two ships, *HRV821* and *MRV811*, from SCDF Marine Division were involved.

The first ship, *HRV821*, acts as a source, performing controlled tracer gas release (Sulfur Hexafluoride, SF_6). The second ship, *MRV811*, carried the standoff sensor, which continuously monitored and attempted to detect the tracer gas plumes released from *HRV821* at distances of 1 km and 2 km.

Key Considerations:

1. Environmental factors: Account for varying maritime conditions such as wind speed, humidity and sea state, which can influence gas plume behavior and detector performance.
2. Ship motion: Both ships experienced constant motion due to waves and currents, affecting the standoff sensor's line-of-sight stability and gas releases.
3. Path interference: Potential interfering factors like sea spray, atmospheric aerosols, and infrared radiation from the sun can affect the detector's ability to accurately identify the tracer gas.
4. Safety protocols: Implement strict safety measures, including personal protective equipment and emergency response plans, to mitigate risks associated with tracer gas handling and potential leakage.
5. Data collection: Continuously monitor, record and log data from the IR detector, as well as environmental conditions, gas release parameters, and ship positions/orientations for comprehensive analysis.
6. Calibration and control: Establish baseline measurements and perform calibration checks before and after each test to ensure accurate and reliable results.

Detecting a gas plume in the air by the standoff sensors requires temperature differences between the gas plume and the background environment (Figure 1). The reported reading is usually based on the transmittance/signal differences between the two (e.g. gas plume concentration reading minus background concentration reading). At the same time, the minimum area that the gas needs to occupy is determined by the arc angle (as shown in Figure 1). As the arc angle is constant, a further gas plume will need to occupy a larger area for effective detection. This can be seen in Figure 1, where the detector's viewing area at 2 km is larger than at 1 km.

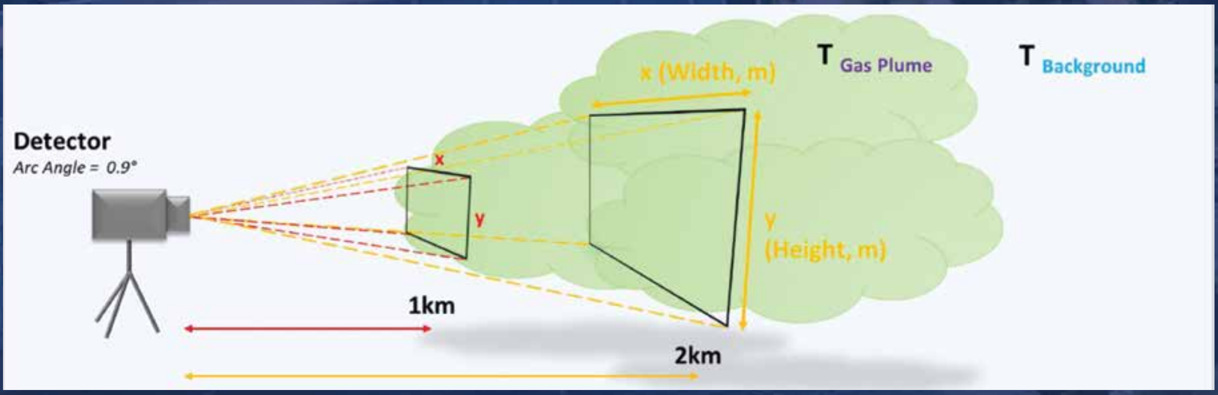

Figure 1: Simplified example of gas plume detection when there is a temperature difference between the background and gas plume at varying distances. While the arc angle is constant, the viewing area at 2 km (rectangle with dimension in yellow) is much larger than the viewing angle at 1 km (rectangle with dimension in red). Hence, a larger gas plume is needed for effective detection at a larger range.

While manufacturers can estimate the minimum gas release required to trigger a reading at various distances, these estimates often assume ideal conditions that do not account for real-world variables such as release rate, gas density, wind speed, wind direction, humidity, etc.

Using past release data provided by SCDF for a similar test and the manufacturer's recommended amount as a reference, HTX CBRNE ran several simulation cases with variations to the total mass released, release rate, wind speed and wind direction. The simulation results were assessed to ascertain if the suggested tracer gas release is sufficient to produce a detectable reading at the target distance (i.e., 1 km and 2 km). In general, the probability of successful reading increases when the minimum detection limit is met and most of the viewing area is filled up. This is shown in Figure 2, where the detection probability is higher for the case on the left as the required gas concentration is met and most of the viewing area is filled.

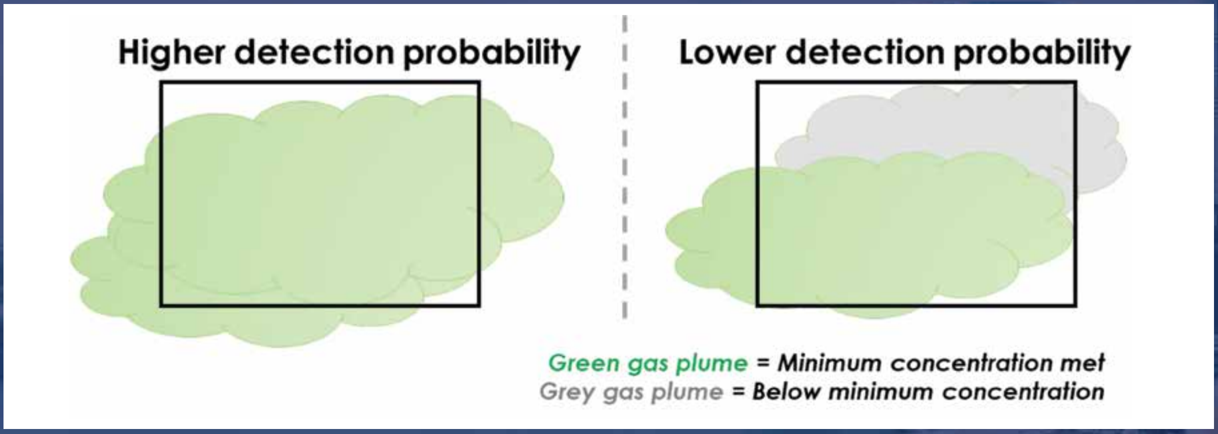

Figure 2: Example of two scenarios with different detection probabilities — an almost fully covered viewing area (left) versus a viewing area around 50% covered (right).

The initial recommendation from the manufacturer was 0.18 kg and 0.72 kg for detection at 1 km and 2 km, respectively. However, after the simulation analysis, we found that the amount required was 60 times and 30 times more, respectively. This finding allowed SCDF to prepare for a larger gas release and review the safety measures for conducting such releases at sea. During the SAT, it turned out that HTX's predictions were closer to the mark, and the higher release amount allowed the team to address significant challenges such as the unpredictable sea state, constant motion of both vessels and higher humidity levels at sea.

This field test shed light on how the standoff chemical detector performs under real maritime conditions, pinpointing its limitations and areas for improvement. By understanding these factors, the effectiveness of the standoff detector in safeguarding ships, their crews and coastal areas against chemical hazards can be significantly enhanced. SCDF's experience with field testing, combined with HTX CBRNE's simulation expertise and vendor's product knowledge, enabled experimental parameters design and significantly contributed to the trial's success. Furthermore, the detector's successful validation and stress testing in the local environment notably boosted SCDF's confidence in the equipment's performance and effectiveness in protecting maritime assets and coastal regions.

OPTIMISING THE DEPLOYMENT OF AN ELECTRONIC NOSE GRID

Ensuring public safety from chemical threats involves not only evaluating sensor performance but also optimising sensor placement. HTX CBRNE devised a methodology to enhance coverage efficiency by predicting worst-case scenarios, identifying affected regions, and refining sensor placement through machine learning.

By conducting a statistical study through simulations with detailed input, the methodology estimates the potential impact area. Weather data is analysed with factors like wind speed, direction and temperature, while the source term is derived from the worst probable scenario. Simulations are carried out for each weather category with the source term, and the results are combined with probability to generate an impact heatmap. Examples of such contour maps are shown in Figures 3A-3C.

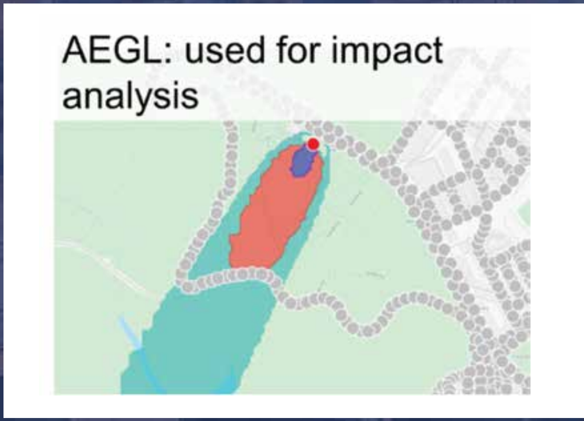

Figure 3A: Acute Exposure Guideline Levels (AEGL) illustrates the potential impact of a source release.

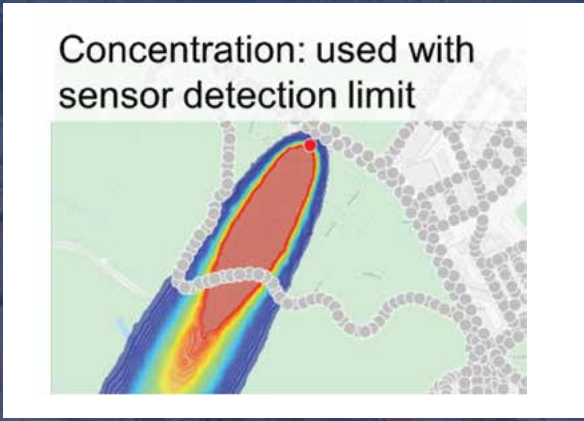

Figure 3B: Concentration contour plot of a source release. This information, combined with the sensor's lower detection limit, aids in identifying optimal sensor placement locations.

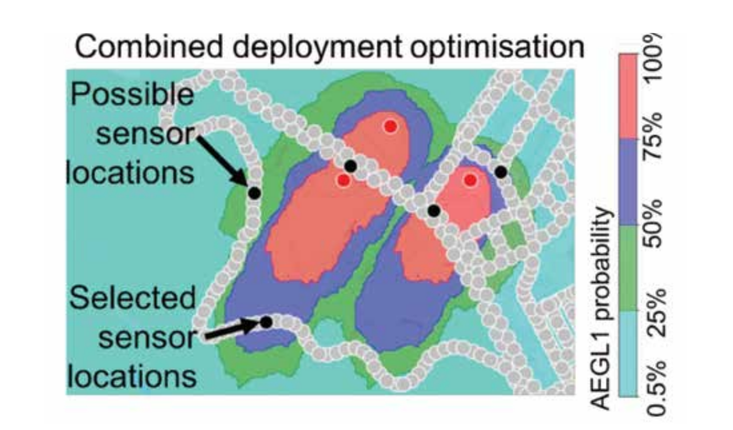

Figure 3C: Example of possible sensor deployment scenario. The background contour represents the probability of an area being affected by AEGL 1 in the event of a chemical leak. Grey dots indicate potential sensor locations, while black dots highlight sensor locations the algorithm selects for optimal coverage and detection efficiency.

To identify optimal sensor locations, the study employs a machine-learning technique called differential evolution. This algorithm considers factors such as potential sensor locations, available sensor quantity, detection limits and heatmap data to optimise detection efficiency across various release scenarios. It can be adapted to different chemical release scenarios, prioritising more hazardous substances and facilitating sensor placement optimisation across different sites.

CONCLUSION

In conclusion, sensors are indispensable in SCDF's HazMat operations. They enable early detection, informed decision-making and effective response strategies. As technology continues to evolve, SCDF remains committed to investing in and harnessing cutting-edge sensor innovations. These advancements not only enhance our capability to provide early warning capabilities but also contribute significantly to SCDF's overarching goal of saving lives and protecting property. By continually pushing the boundaries of sensor technology, SCDF remains ready to handle emerging challenges and safeguard the community against hazardous threats.

HOW SEARCH AND RESCUE TEAMS FIND SURVIVORS AFTER EARTHQUAKES

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Following a disaster, such as the earthquake in Turkey and Syria in February 2023, every second counts. Urban Search and Rescue (USAR) teams must act quickly and efficiently within the first few hours and days following the disaster to save entombed victims as quickly as possible.

RAPID SEARCH AND RESCUE

In the early hours after a major disaster, when many areas need checking, emergency teams conduct rapid searches to maximise the opportunities for saving lives. Rescuers usually finish searching at a site within a few hours, then move to the next area. They can use this stage to identify zones where a deeper search would be worthwhile. Specially trained search and rescue dogs (K-9 teams) are employed to move quickly in the rubble to sniff out signs of life. Indeed, these trained dogs detect live human scent, even when a victim is buried deep in rubble.

FULL SEARCH AND RESCUE

This phase of operations, also called a technical search, locates and rescues deeply trapped survivors. The search and rescue of entombed victims requires the involvement of search and rescue specialists with very specific USAR equipment to detect and locate victims, communicate with them, and then extract and rescue them.

USAR teams often use victim location dogs, but they also use electronic victim search equipment with:

1. Seismic sensors or acoustic sensors.
2. Ultra-wideband (UWB) rescue radar, also called ground penetrating radar (GPR).
3. USAR search cameras.

These three technologies complement each other and allow rescue teams to go faster.

LIFE DETECTORS WITH SEISMIC OR ACOUSTIC SENSORS — SEARCH

Seismic detectors (also called listening devices) are designed to detect and locate the position of conscious buried survivors under the rubbles following a collapse. Ultra-sensitive seismic sensors use seismic technology to detect the smallest sounds or vibrations caused by survivors buried under rubble (scratching, hitting, shouting, etc.) and help pinpoint their location.

Figure 1: LEADER seismic detectors in use on the field

What Is Seismic Technology?

Seismic detectors, like wave receivers, sense vibrations that resonate and circulate in the different materials of the collapsed building and amplify them via a control box. The technical search specialist can listen via audio headsets and view the audio signal via a bar graph on the control box for vibrations made by victims under the rubble.

How to Use Seismic Sensors?

1. First, the team leader deploys the seismic sensors by placing them on the surface of the rubble in the same line.
2. Then, a long whistle sounds to demand total silence. One of the rescuers hits the ground with a heavy metal bar, and an interpreter asks out loud, “Is anyone there? We are the rescue team.”

3. They listen in total silence and wait for the victim's response (scratching, hitting, shouting, etc.) to help locate them.
   3.1. If no response or vibrations are detected, rescuers continue through the zone to be covered, repeating the same method. The objective is to map the zone by identifying the location of buried victims.
   3.2. If the sensors receive a signal (represented by sounds in the audio headset and via an active bar graph on the control box), the intensity of the signals received by each sensor is compared. It is then necessary to focus on the sensor with the strongest signal and gradually bring the two others closer in a triangle until they all display the same intensity. The position of the victim is identified when all sensors have a signal at the same intensity.

Figure 2: Illustrations of how to use LEADER seismic sensors to find a victim under rubble

LIFE DETECTORS WITH UWB RADAR — SCAN

One of the latest innovations in victim location equipment is the UWB radar detector. This radar detector is designed to detect and locate the position of entombed victims following a collapse. It uses UWB technology, a highly sensitive stabilised band, to detect the movements of a buried victim. It can detect the smallest movements — even the breathing of an unconscious person.

Figure 3: LEADER UWB radar sensor in use on the field

What Is UWB Technology?

UWB is a radio modulation technique based on the transmission of very short impulses. The UWB sensor is a transmitting/receiving device with an ultra-sensitive sensor producing electromagnetic waves that can pass through construction materials. It can scan and probe through 50 cm of dense concrete or any other construction material, such as bricks, asphalt, sand, wood, tiles, plastic, plaster and glass, to detect the movement of buried victims. It should be noted, however, that electromagnetic waves cannot pass through metal surfaces and damp surfaces, such as clay and water.

How to Use the UWB Rescue Radar?

The UWB sensor must be placed in contact with the rubble by a rescuer and regularly moved according to a virtual search grid so that the radar can survey below the surface. The objective is to map the zone by identifying the location of buried victims. During this time, a second search and rescue specialist monitors the progress of the remote wireless control box in real time.

The UWB detector scans the ground by sending waves that pass through building materials. If these waves return with a gap in length, this indicates that there is movement, and it may be a buried victim. When the UWB radar sensor detects a movement under the rubble, the screen displays an icon indicating the depth at which the movement is found, as well as the frequency of the movements (strong or weak) to determine whether it is a human. This means survivors can be detected very quickly in real time. Its high sensitivity and the stability of its signal allow detection with precision down to 1 m. Strong and irregular movements, such as the movement of a conscious victim’s arm up, are detectable up to 30 m in free field conditions; regular weak movements, such as the chest movements/breathing of a victim, even if unconscious, are detectable up to 10 m in free field conditions.

SEARCH CAMERAS

Once the survivor is detected and located, a second step involves visually verifying that it is a human with a search camera. Equipped with a microphone and speaker module, it can also be used to communicate with the person to determine their assistance needs.

What Is a Search Camera?

A victim search camera is a miniature camera (47 mm in diameter for LEADER models) designed to slide into very narrow spaces such as cracks, gaps, and standard 51mm holes drilled by USAR teams to inspect behind a wall or inside a confined space. The USAR search camera is connected to a control box with an extra-large colour screen to inspect the area or confined space and identify potential survivors.

Types of Search Camera

The search and rescue camera is designed to be used anywhere you cannot see. For this purpose, it can be fastened to two mounts: the extendible telescopic pole version or the cable reel version.

Extendible Telescopic Pole Version

Search cameras are most often used with a telescopic pole (which can be extended 3–4 m), allowing the user to inspect:

- Confined spaces by simply inserting the camera through a gap or hole.
- Inaccessible areas at height by inserting a camera through a window or gap in the wall.
- Behind walls — the camera (47 mm in diameter) is inserted into a hole (with a standard diameter of 51 mm), which has been previously drilled by USAR teams (using a corer or drill) to view the cavity where the survivor is located.

Cable Reel Version

Reel-mounted cable versions are also available. These are equipped with tens of metres of cable. The search camera is used to inspect very deep areas such as cavities, crevasses, pipes, and very deep wells in very damp or underwater environments.

In addition, there are several types of search cameras available with this version to cover different types of situations:

- **Colour search camera for visual search and communication with the victim — CAM.** The colour search camera provides the ability to visually inspect inaccessible or confined, difficult-to-access spaces. Once the victim is located, it is also possible to communicate with them through the microphone and speaker built into the camera head.
- **Thermal imaging search camera to locate victims by detecting hotspots and to communicate — TIC.** The USAR thermal imaging camera provides the ability to locate survivors by detecting hotspots (the heat of a victim's body). The TIC supplements and accelerates searches to focus on hotspots and contrasts in temperature to find survivors or their heat signatures in dark, confined spaces, dusty environments, smoky areas, etc. Fitted with a microphone and speaker, the camera head can be used to communicate with the victim.
- **Waterproof search camera for visual searches in extreme situations — RD90.** The waterproof search camera provides the ability to inspect inaccessible or difficult-to-access confined spaces such as crevasses, cavities, wells, etc., and allows searches in very damp or underwater environments up to tens of metres deep.

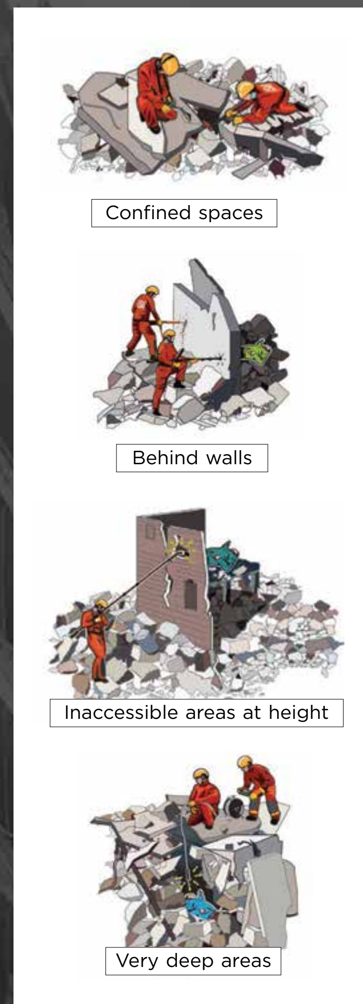

Figure 3: Spaces search cameras allow rescuers to inspect

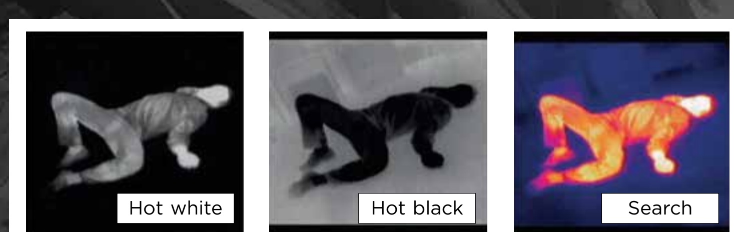

Figure 4: Colour modes of TIC: hot white, hot black and search (multicolour)

THE LEADER MULTISEARCH: 5-IN-1 MULTIFUNCTIONAL USAR SYSTEM

For over 20 years, LEADER has designed cutting-edge USAR equipment to help search and rescue teams rescue entombed victims even more quickly and efficiently. LEADER is the only manufacturer to offer a complete range of USAR equipment using all the technologies commonly used in USAR operations. The life detector LEADER MULTISEARCH is the only USAR system to combine up to five peripherals on the same control box:

- **Victim Location and Detection**
  - Peripheral SEARCH. Seismic sensors are used to listen to the sounds or vibrations of entombed victims.
  - Peripheral SCAN. UWB rescue radar is used to detect the movements of buried victims, whether conscious or unconscious.
- **Visual Location and Communication**
  - Peripheral CAM. USAR colour search camera is used to locate victims and communicate with them.
  - Peripheral TIC. USAR thermal imaging search camera is used to locate victims through a visual search for hotspots in rubble in very dark, dusty, smoky environments, etc.
  - Peripheral RD90. USAR waterproof search camera is used to locate victims in very damp environments or underwater to a depth of 90 m or 180 m.

The MULTI-APP box is the heart of the LEADER MULTISEARCH system. Depending on operational needs in the field, it connects up to five interchangeable peripherals (SEARCH, SCAN, CAM, TIC, RD90) to allow rescuers to be ever more efficient and to go ever faster in the search for buried victims.

Thousands of LEADER devices are used by an extensive number of search and rescue teams worldwide (INSARAG, SUSAR, etc.). These robust and effective devices are tried and tested around the world and have continued to prove themselves recently during the earthquake in Turkey and Syria.

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DIOXINS — THE MOST HAZARDOUS SUBSTANCE IN STRUCTURE FIRE ENVIRONMENTS

Sean Scott
Briana Scott

Post-structure fire settings, especially those where plastics, synthetic materials, or household products made with polyvinyl chloride (PVC) have burned, are where extremely hazardous and carcinogenic chemicals are created. One chemical in particular, dioxin, some consider to be the second most toxic chemical known to man, second only to radioactive waste.

INTRODUCTION

Not only is dioxin extremely toxic to all life, it is also known to the World Health Organization as a member of the so-called Dirty Dozen — a group of dangerous chemicals also referred to as persistent organic pollutants or POPs.

POPs are chemicals of global concern due to their potential for long-range transport, persistence in the environment and atmosphere, ability to bio-magnify and bioaccumulate in ecosystems, as well as their significant negative effects on human health and the environment. Bioaccumulation is the accumulation of chemicals in organisms from the surrounding environment through skin absorption (by contact with contaminated surfaces, clothing and equipment), ingestion and inhalation.

The most commonly encountered POPs are unintentional by-products of many industrial processes, especially chlorinated dibenzo-p-dioxins (CDDs) and dibenzofurans.

CDD’s are highly toxic compounds that are created during combustion processes, especially structure fires where PVC, plastics, paper and other chlorinated materials burn. The most toxic form of CDD is 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD or 2,3,7,8-TCDD), better known as dioxin.

Over 350,000 residential structure fires occur in the US each year; in the UK, about 640 fires occur per million people (Image courtesy of Mark Doyle)

What Are Dioxins and How Are They Created?

Dioxins are formed when products containing carbon and chlorine burn, especially plastic, paper, pesticides, herbicides or other products where chlorine is used in the manufacturing process. Dioxins do not typically exist in materials before they are burned. They are especially prevalent in structure fires and wildfires.

Residential garage fires typically consume large quantities of plastics, PVC and synthetic materials

Residential structure fires can create immeasurable amounts of dioxins as well as other hazardous substances

Depending on the ambient temperature in a fire, dioxins can be adsorbed or chemically bound to smoke particles or remain in a vapour phase. Adsorption is when particles bond with one another, similar to how a magnet bonds with iron, rather than being absorbed like a sponge absorbs liquids.

Dioxin can enter your body if you inhale contaminated particulate, have skin or eye contact with contaminated soot, ash or other materials, or eat contaminated food. Since ultra-fine smoke particulate matter generated in fires is often less than 3 μm in size (half the size of a red blood cell), inhalation of dioxin-laden particulate can easily bypass the lungs and enter the bloodstream.

HUMAN HEALTH RISKS OF EXPOSURE TO DIOXIN

Many adverse health effects have been well documented in scientific literature regarding dioxin. “TCDD is considered the most toxic man-made substance and the fifth most toxic naturally occurring compound known to man. 2,3,7,8-TCDD is a potent toxicant in animals and has the potential to produce a wide spectrum of toxic effects in humans” (Environmental Protection Agency, 1997c).

SOME STARTLING FACTS ABOUT DIOXIN

1. Scientists say the toxicity of dioxin is exceeded only by radioactive waste. Short-term exposure to high levels of dioxins may result in skin lesions, such as chloracne. Long-term exposure is linked to a vast array of diseases and ailments, including impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions.

Dermal absorption of toxic chemicals is of major concern to firefighter health (Images courtesy of John Nee and Glenn Preston – Boston Fire Department)

Other adverse health effects may include cardiovascular disease, diabetes, cancer, porphyria, endometriosis, early menopause, reduced testosterone and thyroid hormones, altered immunologic response and altered metabolism.

Diseases which have been linked to dioxin seem endless. Ingesting dioxin can also result in congenital malformations, spontaneous miscarriages, and a fatal, slow-wasting syndrome similar to AIDS. Dioxin is strongly suspected of contributing to the pathology of the urinary and haematological systems, growths in the colon, gallbladder complications, multiple myeloma, and lung, larynx and prostate cancer.

According to researcher Joe Thornton, “Dioxin’s health effects include endocrine disruption, reproductive impairment, infertility, birth defects, lowered sperm counts, impaired neurological development, damage to the kidneys, and metabolic dysfunction. There is no evidence that there is a safe level of dioxin exposure below which none of these effects will occur.”

2. Dioxin is an endocrine-disrupting chemical that can threaten the development of newborns. The endocrine system is a series of glands that produce and secrete hormones that the body uses for a wide range of functions, including respiration, metabolism, sensory perception, sexual development and growth.

   The US National Toxicology Program and the Environmental Protection Agency have determined that dioxin is a proven human carcinogen. In July 2009, the US Institute of Medicine published a report that showed evidence of an association between exposure to dioxin and soft-tissue sarcoma, non-Hodgkin's lymphoma, chronic lymphocytic leukaemia, Hodgkin's disease, prostate cancer, multiple myeloma, as well as cancers of the larynx, lungs, bronchi and trachea.

3. Dioxin is on the Special Health Hazard Substance List because it is a teratogen. A teratogen is any agent that causes an abnormality following foetal exposure during pregnancy. Pregnant women and their developing infants are extremely vulnerable to the effects of dioxin.

4. Dioxin is genotoxic and a known mutagen. A mutagen is a physical or chemical agent that causes a mutation, which is a change in the DNA of a cell. Dioxin alters the genetic structure of living cells. The effect dioxin has on cell structures and genes can be passed down to future generations. In 2012, a scientific study found that dioxin affects not only the health of an exposed rat but also unexposed descendants through a mechanism of epigenetic transgenerational inheritance.

   When dioxin binds to an intracellular protein known as the aryl hydrocarbon receptor (AHR), the AHR can alter the expression, or function, of certain genes. The resulting cellular imbalance leads to a disruption in normal cell function and adverse health effects. The genetic effects of dioxin may skip a generation and reappear in the third or subsequent generations.

5. Dioxin is hepatotoxic (toxic to the liver), nephrotoxic (toxic to the kidneys), and embryotoxic (toxic to embryos).

6. Dioxin causes birth defects and spontaneous miscarriages.

7. Dioxin is neurotoxic. Neurotoxicity is a form of toxicity in which a biological, chemical or physical agent has an adverse effect on the central and/or peripheral nervous system.

8. The International Joint Commission, comprised of the United States and Canadian governments, has publicly stated that zero exposure to dioxin is the only safe level. There is no permissible exposure limit set by the National Institute for Occupational Safety and Health.

9. Dioxin is bioaccumulative and becomes more concentrated with repeated exposure. Once internalised, they accumulate in body tissues, mainly body fat, resulting in chronic lifetime exposure (Schecter et al., 1994).

10. When calculating human exposures, dioxins are so toxic that they are measured in picogrammes — that is, trillionths (0.000000000001) of a gramme. Dioxin, even in picogrammes, is associated with severe health damage that can shorten the lives of people exposed to it.
11. In 1999, the Agency for Toxic Substances and Disease Registry set a minimal risk level for dioxins and related compounds of 1 pg (1 trillionth of a gramme) toxicity equivalence per kilogramme of body weight per day.
12. In certain animal species, dioxin is so harmful that it can cause death after a single exposure.
13. No antidote for dioxin toxicity is known. Symptomatic and supportive care is the only known therapy.

MORE IMPORTANT FACTS ABOUT DIOXIN

1. Dioxin was a key ingredient in Agent Orange, which was used as a defoliant in the Vietnam War.
2. Half-life estimates for dioxin (the time required for dioxin to decrease by half) on surface soil range from nine to 15 years, whereas the half-life in subsurface soil may range from 25 to 100 years.
3. Dioxins persist in the environment for a long time because they do not dissolve in water.
4. Photolysis (the decomposition of molecules by the action of light) is considered to be the most important degradation mechanism of gaseous dioxins in the atmosphere. However, laboratory evidence indicates that when dioxins interact with particles, photodegradation is reduced to insignificant levels.
5. The only known way to completely destroy dioxin is by incinerating it at temperatures over 1,550°F (843°C).
6. Burning 1 kg (2.20 lb) of wood produces as much as 160 μg of total dioxins.
7. Barry Commoner, a professor at Washington University, stated, “Many toxic chemicals are linked with a specific illness, such as lead and brain damage, or asbestos and mesothelioma. Others are linked with several illnesses. Dioxin is tied to such a large number of diseases because it is a cancer enhancer. Dioxins intensify cancers which other toxins begin. They greatly enhance the activity of the enzyme system that converts most environmental carcinogens into active agents. In effect, dioxin influences tumour production by enhancing the activity of carcinogens. This is why dioxin has different effects on different people. For example, if a group of workers has already been exposed to chemicals which cause Hodgkin’s disease, dioxin will speed up the process and they will have an increased rate of Hodgkin’s disease progression. The human body tends to store dioxin in fatty tissue, and when people take in dioxin through food or air, it ends up stored inside their cells.”

FIREFIGHTERS ARE AT THE GREATEST RISK OF EXPOSURE TO DIOXIN

Thirty years ago, firefighters were most frequently diagnosed with asbestos-related cancers. Today, the cancers are more often leukaemia, lymphoma, myeloma, oral, digestive, respiratory and urinary cancers. It is no coincidence that these are the same types of cancers known to be caused by exposure to dioxin.

Although firefighters wear state-of-the-art personal protective equipment (PPE), toxic chemicals often find their way through where they can be inhaled, ingested, or absorbed by the skin. Exposure to dioxin is likely one of the primary causes, or at least a contributing factor, for the high number of cancers, diseases and fatalities among men and women in the fire service.

FIRE INVESTIGATORS

Fire investigators typically spend hours, and sometimes days, inside fire-damaged structures. They sift through smouldering debris and ash searching for the cause and origin of fires. Oftentimes, PPE is regarded as cumbersome and not worn. Here, investigators are exposed to dioxin and a myriad of other toxins in the ash as well as in the airborne particulate matter.

Fire investigators are exposed to toxic chemicals, gases and particulate matter that can cause sickness, disease and even death (Image courtesy of Central Fire Protection District – Santa Cruz County)

TURNOUT AND TEXTILE CONTAMINATION

Currently, there are no scientifically proven methods to clean textiles contaminated with dioxin. In fact, the only known way to destroy dioxin is by incinerating it at temperatures over 1,500°F (843°C). Dioxin is not water soluble, nor does it decompose when exposed to ozone or hydroxyls in the atmosphere.

If an attempt is made to clean smoke-damaged textiles that are contaminated with dioxin, heavy metals, or other toxic combustion by-products, samples of the articles should be analysed after the cleaning by a qualified independent third-party laboratory to see if the cleaning was truly successful. This is particularly important for clothing, where dioxin and other toxic combustion by-products can come in contact with the skin and be absorbed.

For those in the fire service, turnout coats, trousers and other protective garments are regularly exposed to high concentrations of toxic substances, including dioxin. Although some fire departments use industrial-grade washing machines and detergents to clean their gear, periodic testing should be performed to verify if these cleaning methods are effective or if hazardous substances, such as dioxin, remain embedded in the fabric after cleaning.

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