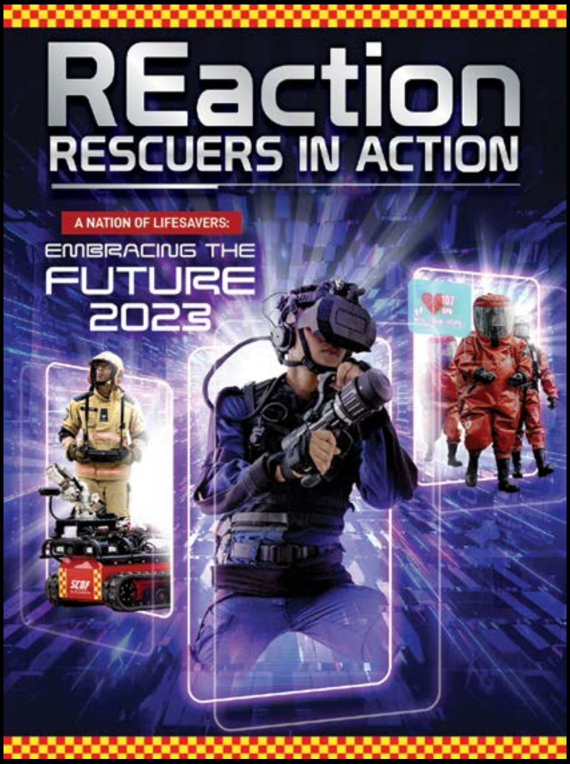
REaction

RESCUERS IN ACTION

A NATION OF LIFESAVERS:

EMBRACING THE FUTURE 2023



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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CONTENTS

EDITOR'S FOREWORD

Training, learning and innovation are key elements that form the cornerstone of all successful organisations. As our operating environment is constantly evolving, we need to continue transforming, sharpening and refining our capabilities and processes to meet emerging trends and challenges.

As part of our transformation journey, the Singapore Civil Defence Force (SCDF) continues to leverage science and technology to ensure the latest methods and technologies are adopted to optimise service and operational outcomes.

In this edition of REaction, we explore a spectrum of topics. These include test bedding smart applications and technologies to develop the next-generation smart fire station blueprint; and leveraging sensors and data analytics for integrated sensemaking.

Also featured are articles outlining SCDF's efforts in developing response strategies for incidents involving electric vehicles (EVs) as well as applying human factors and extended reality technologies to improve training effectiveness for our responders. Readers will also find a range of articles delving into firefighter safety and fitness, optimal work-rest cycles, equipment ergonomics, and enhanced heat resilience in emergency responders.

Underscoring SCDF's commitment to a greener future, there is also an article outlining SCDF's sustainability framework and sustainable practices to minimise waste and promote environmental conservation.

We hope that you will find the articles in this edition interesting and intriguing. On this note, we would also like to express our appreciation to the authors and contributors of REaction 2023. Stay safe and keep well!

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FUTURE-FORWARD: NEXT-GENERATION SENSEMAKING NETWORK IN SCDF

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EDITORIAL PREVIEW

The emergency response operating environment in the Singapore Civil Defence Force (SCDF) is typically uncertain and dynamic. Sensemaking[1] in such an environment requires SCDF to collect data from various sources, identify patterns and anomalies, and make informed decisions with adaptive strategies as crises unfold. SCDF has proactively capitalised on sensors, data analytics and artificial intelligence (AI) technologies to stay ahead of the evolving operational terrain and to enhance operational effectiveness.

As part of the SCDF Digital Transformation and Enterprise Architecture Study (DTS) roadmap,[2] the development of an intelligent core (iCore) was proposed. This article explores how iCore will further augment existing sensemaking capabilities and derive upstream data-driven insights to sharpen SCDF's policies across its organisational domains.

[1] Adapted from *Sensemaking: Framing and Acting in the Unknown* by Deborah Ancona, sensemaking refers to the process of structuring the unknown. This involves gathering data from the environment to first create a plausible understanding of the situation and then testing the understanding for refinement or abandonment. The nature of sensemaking is iterative — as the environment changes, new data will be gathered, applied, and tested. This leads to a continuously refined output.

[2] The DTS roadmap was published in REaction Technical Publication 2022 — "Digitally Transforming the Life Saving Force".

INTRODUCTION TO SCDF'S iCORE

iCore is envisioned to be the brain of SCDF's 24/7 sensemaking network (see Figure 1). It will harness data continually from multiple internal and external sources, and integrate processed and standardised datasets to serve as Single Sources of Truth (SSOTs). Then, it makes recommendations for SCDF to achieve various organisational outcomes.

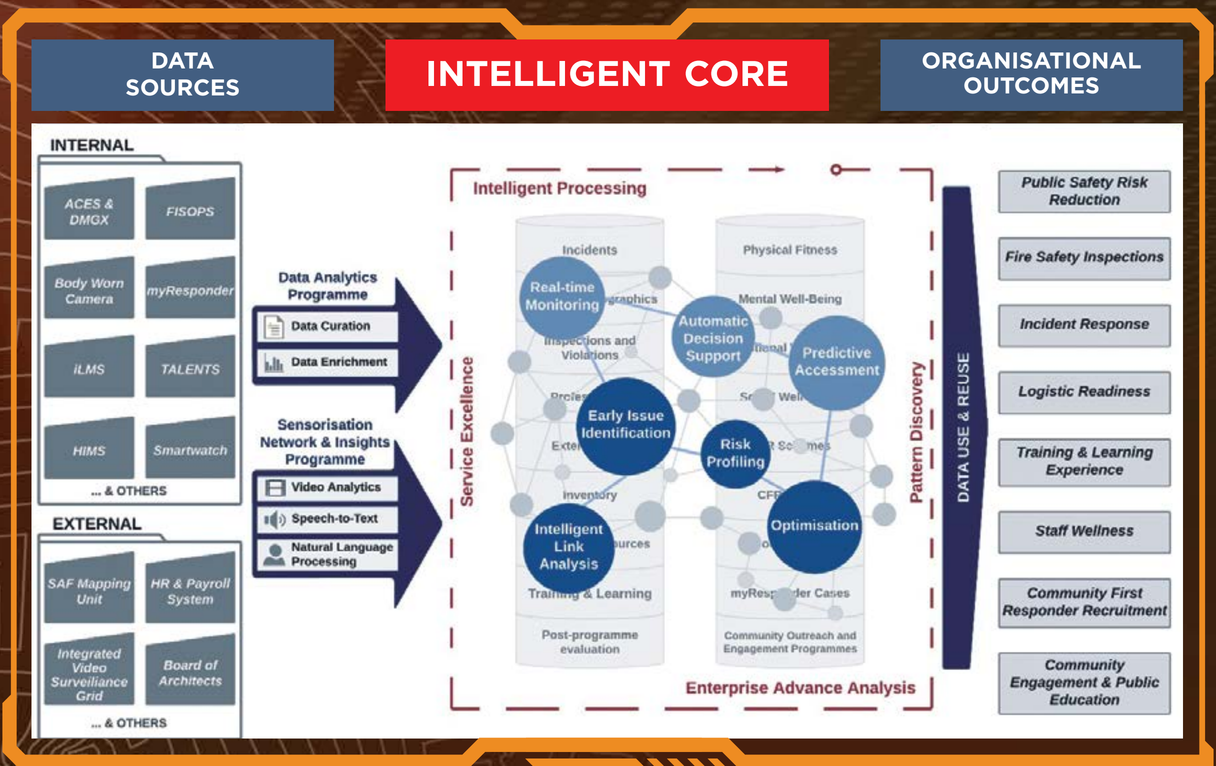


Figure 1. iCore is envisioned to serve as SCDF's brain to support sensemaking for improved organisational outcomes

As a critical centrepiece of our digital ambition, iCore will enhance the concept of operations (CONOPS) in SCDF's key organisational domains to achieve strategic business goals, as shown in Table 1 below.

Table 1. Strategic Business Goals enabled by SCDF's iCore

Operations	Regulations	Community
Sharpen incident response and achieve quicker reaction times	Risk-based management of the building Industry	Data-driven actions to encourage a greater degree of community participation
✓ Incident Response ✓ Logistic Response ✓ Training & Learning Experience ✓ Staff Wellness	✓ Public Safety Risk Reduction ✓ Fire Safety Inspections	✓ Community First Responder Recruitment ✓ Community Engagement & Public Education

ACHIEVING SCDF'S iCORE

The key components of iCore are the frontend network of sensors and the backend analytics engine, which will be developed in tandem under two key programmes, i.e., Sensorisation Network and Insights, and Data Analytics.

Sensorisation Network and Insights Programme

SCDF leverages various Internet of Things (IoT) sensors that are instrumental to its operations and public safety. The Sensorisation Network and Insights programme, which will be developed over the next five years, aims to establish two common core platforms to aggregate all sensors and external data feeds for SCDF:

a. *A Unified Monitoring Network* that enables anticipatory interventions by ingesting and making sense of different feeds. It flags out early warnings on potential fire safety non-compliances, alerting SCDF to address them and take pre-emptive measures. These include early detections of fire, hazardous materials incidents, road traffic accidents, and medical emergencies even before any 995 call is received.

b. *An Edge-Powered Mobile Command Post* that aggregates and streamlines sensor data[3] and external feeds to facilitate the consolidated review of information for sensemaking and operational command during incident response.

The programme will also leverage common backend infrastructure to catalyse information synthesis for sensemaking and enhanced decision-making. The various components and a summary of each platform are shown in Figure 2 below, as well as the ongoing sensor trials, including SCDF's Artificial Intelligent Sensemaking Platform (AISP).[4]

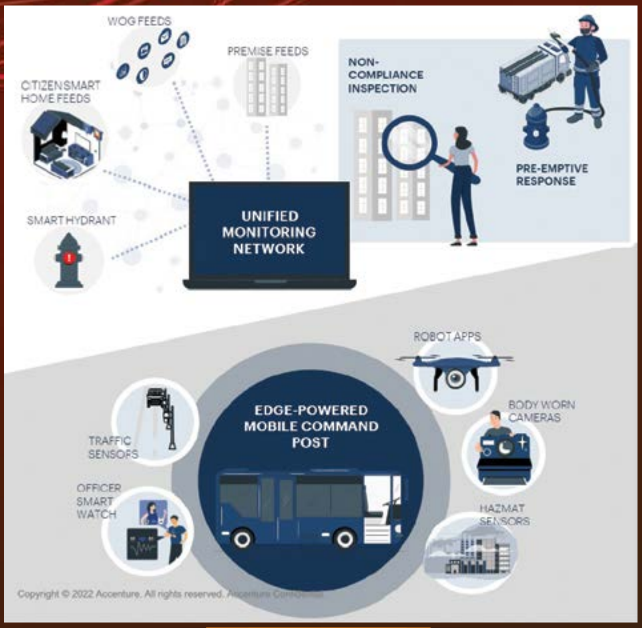


Figure 2. Sensorisation Network and Insights Programme — Unified Monitoring Network (top) and Edge-Powered Mobile Command Post (bottom)

Data Analytics Programme

Under the Data Analytics (DA) programme, suitable data sources will be identified, cleaned and transformed, allowing SCDF to integrate and converge curated data from a myriad of internal and external data sources.[5] These processed datasets, with a common data taxonomy, can then be fed through an Enterprise Data *Analytics Platform* for repeated use, designed to power and scale up analytics models. Actionable insights presented through analytics dashboards and visualisation tools will help realise the vision of a digital-to-the-core SCDF.[6]

3 Live video feeds via CCTVs in buildings and premises, cameras installed on SCDF appliances, body-worn cameras for frontliners, and Unmanned Aerial Vehicles (UAVs) can be used to enhance real-time situational awareness where possible.

4 AISP uses AI to amalgamate and summarise key information associated with each 995 call. It also analyses sensor data, including video feeds from official and open sources, expediently to make sense of, support, and recommend corresponding actions, preventing data overload for the Ops Centre as emergencies unfold.

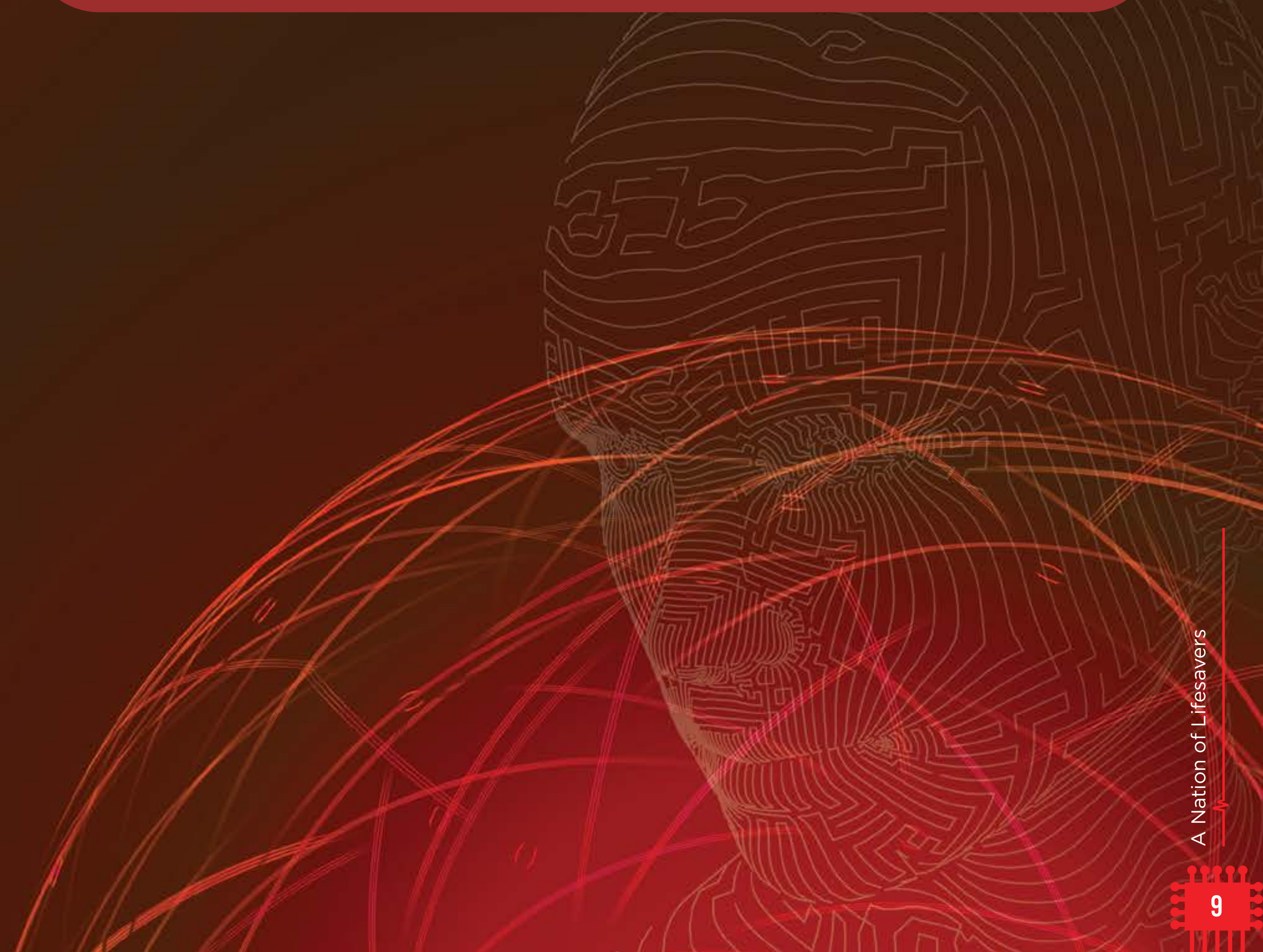
5 Sources include SCDF's internal standalone transactional systems, WOG, and commercial sources.

6 Required analytics capabilities vary with the complexity of use cases. Potential analytics include, but are not limited to, statistical modelling, non-probabilistic modelling, natural language programming, deep learning, optimisation, and network analysis.

A number of DA use cases have been identified to achieve the enhanced CONOPS in Table 1, and will be implemented through an AI Digital Factory approach over the next three to five years. This approach institutionalises a build-deploy-improve methodology across SCDF to ensure the agile, strategic implementation of analytics. This methodology, in close collaboration with Home Team Science & Technology Agency (HTX), GovTech and Institutes of Higher Learning (IHLs), will enable each use case to leverage previous data models, progressively coalescing into the iCore that will power SCDF's decision-making.

CONCLUSION

Given the proliferation of sensors and data, the development of the SCDF iCore will avail vast sources of information for holistic sensemaking and expedite the transformation of information into actionable insights. Acting as a force multiplier, it will enhance the management of public safety risks and drive SCDF's journey to becoming a data-driven upstream guardian of safety.



ELECTRIC VEHICLES: MODELLING FOR THE FUTURE

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EDITORIAL PREVIEW

The Singapore Green Plan 2030, or the Green Plan, is a whole-of-nation movement to advance Singapore's national agenda on sustainable development. The Green Plan charts ambitious and concrete targets over the next 10 years, strengthening Singapore's commitments under the United Nations 2030 Sustainable Development Agenda and Paris Agreement, and positioning Singapore to achieve its long-term net zero emissions aspiration by 2050.[1] The rapid adoption of electric vehicles (EVs) remains at the forefront of this decarbonisation shift.

1 Singapore Green Plan 2030 (2023). Available at: https://www.greenplan.gov.sg/.

INTRODUCTION

Global demand for EVs has significantly risen in recent years. According to the *Electric Vehicle Outlook 2022* report by the International Energy Agency (IEA),[2] global electric car sales hit a record high in 2021 despite supply chain bottlenecks and COVID-19. Compared to 2020, sales of EVs have nearly doubled to 6.6 million. The review of infrastructure is necessary to keep up with the increasing demand for safe and reliable EV charging services. This includes the incorporation of fire safety requirements locally, such as an emergency shut-off switch to the EV charging station when required. This aligns with Singapore's target to deploy 60,000 charging points by 2030, and for all vehicles to be of cleaner energy by 2040.[3]

RISK ASSESSMENT OF FIRES INVOLVING EVS

With the increasing uptake of EVs by the general population, there is a pressing need to understand the associated risks. Studies have shown that EV fires do not result in additional release of heat energy compared to Internal Combustion Engine Vehicle (ICEV) fires, both in terms of peak heat release rate and total heat released. Any difference in heat energy released is influenced by the size of vehicle (e.g., SUV or sedan) and the quantity of fuel carried (or state of battery charge) instead of the type of powertrain.

Thermal Runaway

However, lithium-ion batteries (LIBs) are subject to risk of thermal runaway when exposed to abnormal operating conditions (e.g., vehicle crash, external heat source, electrical overload).[4] Chemical reactions triggered within the battery could cause a build-up of toxic and flammable gases within, potentially leading to the rupture or venting of accumulated gases. Furthermore, unlike ICEVs, EV fires could result in jet flames[5] when venting of pressurised flammable gases occurs. This increases the likelihood of horizontal fire spread between adjacent vehicles.

Toxic Gas Release

While fires involving both ICEVs and EVs could release toxic gases,[6] studies showed that hydrogen fluoride (HF) was released in substantially larger quantities during an EV fire as compared to ICEV fires.[7] Known to be a highly corrosive and irritant gas, HF can severely irritate the eyes, skin and nasal passages when present in large amounts. High concentrations of HF can penetrate the lungs and pose life-threatening health effects or even death to those exposed near the incident site. These effects could be further exacerbated if the EV fire occurred within confined environments such as underground carparks, or if one faces prolonged exposure to HF. The amount of HF gas released by an EV fire involving a car utilising a 24kWh battery (relatively small by today's industry standards) is enough to fill around 20 five-room HDB flats at Acute Exposure Guideline Levels (AEGLs)-3[8] for 10 minutes, assuming there is no ventilation or dilution.

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2 EV sales leapt 55% in 2022 — here's where that growth was strongest. World Economic Forum. Available at: https://www.weforum.org/agenda/2023/05/electric-vehicles-ev-sales-growth-2022/.

3 Factsheet: Introduction of Electric Vehicles Charging Bill (2022) LTA. Available at: https://www.lta.gov.sg/content/ltagov/en/newsroom/2022/11/news-releases/introduction_of_EV_charging_bill.html.

4 Thermal runaway is defined as a state where heat generated within the battery cell exceeds heat dissipated, and the cell enters an uncontrolled state of increasing temperature until failure occurs.

5 This is a directional fire resulting from the combustion of pressurised release of gas and/or liquid.

6 These toxic gases could comprise organic compounds (polycyclic aromatic hydrocarbons), asphyxiant gases (e.g., CO, HCN) and irritant gases (e.g., HCL, SO_2).

7 Bisschop. R., Willstrand, O., Blomqvist, P., Temple, A., & Anderson, J. (2020). *Toxic Gases from Fire in Electric Vehicles*. Report 2020:90. Gothenburg: RISE Research Institutes of Sweden.

8 Acute Exposure Guideline Levels are used as guidance in dealing with rare, usually accidental, releases of chemical into the air. They are dictated by the severity of toxic effects caused by exposure, with Level 1 being the least and Level 3 being the most severe.

Reignition Risk

Following extinguishment of EV fires, the reignition risk of LIBs remains high due to "stranded energy" in the battery. Stranded energy or State of Charge (SOC) is the remaining energy inside any damaged battery modules or cells with no path to discharge.[9] In general, damaged EVs that retain an SOC above 30% are at risk of reignition.[10]

To date, there is a lack of operationally feasible methods for emergency responders to determine the SOC of a damaged battery. As a result, there is a possibility for LIBs to persistently reignite hours or even days after the fire is extinguished.

CAPABILITY DEVELOPMENT EFFORTS

Emergency Responder Guidebook

The Singapore Civil Defence Force (SCDF) adopts the Emergency Responder Guidebook to serve as a quick guide for responders to understand the risks involving EVs and how to deal with EV incidents. The guidebook contains information about different EV models, such as the layout of the high-voltage system, location of the emergency disconnects, and instructions on disabling the vehicle. This helps responders derive safe response measures by avoiding cutting into the high-voltage cables during extrication of casualties.

Fire Blanket

To enhance response to vehicle fires, SCDF's light fire attack vehicles (LFAV) are equipped with fire blankets. As LFAVs are not equipped with water tanks for immediate firefighting against ICEVs or EVs, the fire blanket serves to mount the initial fire suppression response. It prevents fire from spreading to adjacent vehicles or properties while firefighters source a water supply for water jets. In a thermal runaway situation, an EV fire is self-sustaining. Such fires are known to continue burning even without access to ample oxygen and can produce toxic fumes exceeding lethal concentrations if the fire occurs within a confined space. The fire blanket, while not a foolproof solution on its own, helps at the onset to contain flames, smoke, and toxic fumes when used in tandem with a water jet.

Figure 1. Use of fire blanket for car fires

9 Zhang, B., Bewley, R. L., Tanim, T. R., & Walker, L. K. (2022). Electric vehicle post-crash recovery—stranded energy issues and mitigation strategy. *Journal of Power Sources, 552*, 232239. https://doi.org/10.1016/j.jpowsour.2022.232239.

10 The SOC of a battery is a measure of available battery capacity, or how "full" it is. In an EV, the SOC of the battery pack is the equivalent of a fuel gauge.

Battery Fire Extinguishing System

With emerging technologies, SCDF does horizon scanning for systems and products to enhance its response readiness to EV incidents. One example that will be trialled is the Battery Fire Extinguishing System (BFES). Equipped with a piercing applicator, the BFES is designed to penetrate a burning EV battery compartment and introduce water directly for effective cooling. This method is said to help arrest the propagation of thermal runaway quicker and more efficiently than the external cooling of battery compartments. The BFES is envisaged to complement the fire blanket and provide direct cooling of the battery modules with water. Theoretically, this will inhibit any further thermal decomposition of the battery electrolyte, thus reducing the quantity of toxic gases generated.

Figure 2. BFES deployed on an EV

EV Extrication Robot

Singapore has many basement and multi-storey carparks. EV fires within these environments could result in a dangerous accumulation of toxic gases, especially within confined spaces. Further, a prolonged incident could also lead to a horizontal fire spread to other adjacent vehicles and threaten the structural stability of the building. As such, there is a need for the public to be evacuated from the building until the affected EV is removed and toxic gases are reduced to a safe level.

Figure 3. EV Extrication Robot

In this regard, SCDF identified a need for an EV Extrication Robot to remove EVs from tight spaces, as it would be too dangerous to deploy tow trucks in such hazardous conditions. It is envisioned for the EV

Extrication Robot to be heat-resistant, highly manoeuvrable, and capable of swiftly moving vehicles away. As it would take time for such an EV Extrication Robot to be deployed at the scene, SCDF will first deploy the fire blanket and BFES to contain the situation.

INTER-AGENCY COOPERATION

While SCDF as an emergency response force is constantly working towards enhancing its operations when dealing with EV incidents, there is also collaborative effort between various agencies at the national level to study the challenges and develop solutions to resolve such issues. The inter-agency Community of Practice (COP) was jointly formed to facilitate information exchange, feedback, alignment, and joint work on investigation and clarifications on safety and EV regulations. SCDF is engaging multiple agencies to streamline processes, develop safety protocols, and ensure safety is met at all junctures of the workstream. One of the collaborative studies is the usage of water-containing pods, where the EV will be fully submerged in a pod for a suitable duration before it is transported to a facility for safe battery discharge. SCDF is currently working together with other agencies, through the COP, to develop guidelines for pounds and workshops to ensure the safe management of damaged EVs.

Slated for Q3 2024, SCDF will be working together with the Land Transport Authority for an electric bus (E-bus) fire burn test to determine the characteristics of E-bus fires. The results of the burn test will provide SCDF with the information needed to formulate its concept of operations when tackling an E-bus fire, as well as to understand the associated risks of a larger vehicular platform and battery capacity compared to smaller EVs. Proposed solutions are cross-referenced with other nations to ensure that we remain in line with best practices from all over the globe. SCDF is working towards better handling of incidents involving EVs as Singapore moves towards becoming a greener city.

CONCLUSION

While cases of EV fires have been rare in Singapore, it is still vital that precautions are taken to manage the associated risks created by such fires. This is especially so given the rising numbers of EVs and E-buses on the roads in recent times and in the future. Inter-agency collaboration is the first step to ensure that the various agencies and stakeholders have a common understanding of the risks posed by EV fires as well as developing management strategies. The collaboration will enhance EV incident management in Singapore by taking a lifecycle approach to ensure a thorough and well-coordinated management between SCDF and other stakeholders in the ecosystem.

ENHANCING PRE-HOSPITAL EMERGENCY CARE IN SINGAPORE THROUGH QUALITY MANAGEMENT FRAMEWORK

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EDITORIAL PREVIEW

In the last two decades, the Emergency Medical Services (EMS) Department in the Singapore Civil Defence Force (SCDF) saw tremendous growth and advancement in multiple areas. One of these areas was the increased emphasis on clinical compliance, which led to the creation of the clinical audit team in HQ SCDF in 2014. The drive to continuously improve patient outcomes and paramedic performance led SCDF to transition towards total quality management, similar to what healthcare institutions do in Singapore and internationally. Holistic and proactive approaches have been used to optimise resources, ensure patient and personnel safety, and improve clinical standards and service delivery.

This article brings the reader through the journey of how the clinical audit team in the EMS Department evolved to adopt quality management (QM) in 2023, with the overall objective of enhancing the quality of pre-hospital emergency care for the public. The challenges faced in implementation and the innovative methods to overcome these challenges are also outlined.

INTRODUCTION

In the 1970s, Singapore's Emergency Ambulance Service (EAS), under the Singapore Fire Brigade, was staffed by nurses and midwives seconded from hospitals. The EAS and Singapore Fire Service eventually merged with SCDF in the late 1980s. Under SCDF, EAS underwent a significant transformation. SCDF incorporated modern equipment, better life-saving capabilities and new generations of ambulances. In 1997, recognising that pre-hospital emergency care required competencies and skills different from nursing, the paramedic career track was introduced.

Paramedics and Emergency Medical Technicians (EMTs) now form the bedrock of EMS in Singapore. The pursuit of excellence in EMS continues, leading to the shift from clinical audit to QM in 2023.

CLINICAL AUDIT TO ENHANCE CLINICAL COMPLIANCE AND PERFORMANCE

The concept of clinical audit in the early years was rudimentary, where a couple of auditors conducted the Ambulance Proficiency Test (APT) on paramedics twice a year to check on their clinical proficiency. To create a formal structure and devote resources for sufficient compliance, a dedicated clinical audit team was formed in the EMS Department in March 2014. Under the new Clinical Quality Framework, the audit scope was expanded to include routine documentation checks and monthly clinical performance screening.

Figure 1. The ARRA Audit Cycle extracted from "Clinical Audit Framework for EMS"

Learning from best practices in other industries, the audit team adapted the PDCA (Plan-Do-Check-Act) method to create the ARRA (Audit-Review-Recommend-Action) Audit Cycle.[1]

A key differentiating component of ARRA is developing efficient and effective ways to follow up with relevant stakeholders on recommendations. The quarterly Audit and Continuous Training (ACT) meeting was thus created to better facilitate communications and coordination.

Leveraging the EMS Build Up Plan 2018, new auditor positions were also created in each division in 2017. This provides the clinical audit team at HQ with a greater capacity to focus on EMS-wide data analytics and systemic improvements while division auditors handle case-specific audits.

THE DAWN OF QM

Whilst clinical standards had improved with the new Clinical Audit Framework, the overall system was still reactive. As the framework focuses on past incidents, the implemented "solutions" tended to be short-term. The framework also does not address root causes, as factors beyond clinical management are not considered. Thus, it was concluded that a broader and holistic approach was required to address clinical gaps.

[1] The PDCA cycle is commonly used in businesses for continuous improvement. It is based on the scientific method of proposing a change to a process, implementing the change, measuring the results, and finally taking appropriate action to improve the process further. It is also known as the Deming Cycle, named after W. Edwards Deming, who introduced the concept after World War II in Japan.

In May 2022, former Chief Medical Officer COL(Dr) Colin Tan introduced the concept of QM to the clinical audit team. In Singapore, the Public Hospital and Medical Clinics (PHMC) Act 1980[2] requires all entities under PHMC to have a quality assurance (QA) committee. The QA committee is tasked with monitoring and evaluating the quality and appropriateness of services, practices, and procedures at a specified healthcare institution, as well as identifying and resolving any related problems. Additionally, this committee is responsible for making recommendations to enhance healthcare services and practices, and ensuring that those recommendations are effectively monitored. Nevertheless, QM only became widely adopted in Singapore within the past decade, as healthcare institutions responded to the international trend and growing emphasis on implementing quality management principles.

The SCDF EMS QM Framework was proposed and approved by SCDF's senior management in October 2022. Consequently, an SCDF EMS QM committee was formed, heralding a new era of transformative pre-hospital emergency care.

THE SCDF EMS QM FRAMEWORK

The SCDF EMS QM Framework incorporates five desired outcomes, namely, patient safety, personnel safety, benchmarked clinical standards, resource/value optimisation, and quality services. These are supported by two main categories of enablers — QA and Quality Improvement (QI). Together with the QM committee, these enablers would institutionalise QM practice and shift the mindset from audit to QM. The EMS Audit Team would also be renamed as the EMS QM Branch.

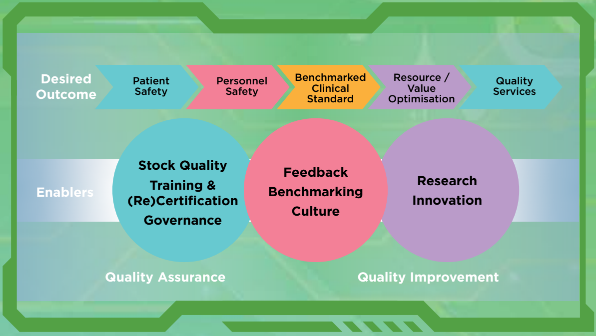

Figure 2. SCDF EMS QM Framework

ENSURING EMS STANDARDS THROUGH QA ENABLERS

Prior to the introduction of QM, EMS standards were mainly maintained by clinical or operational audits. Although efforts were made by different departments towards better stock quality, training, (re)certification and governance, a structured and evidence-based approach was needed to make well-informed decisions. With the implementation of the QM Framework, the EMS Department strives to integrate all QA enablers to improve overall standards. This is done by collecting baseline data and analysing trends with every new initiative implemented.

SHIFTING MINDSETS AND FOSTERING CONTINUOUS IMPROVEMENT

For the QM Framework to be effective, it is imperative that all EMS personnel understand the principles of QM and work together to continuously improve both clinical and operational aspects of EMS in a conducive environment. In addition, it is necessary for a shift in mindset towards viewing incidents holistically and without undue emphasis on blame. To inculcate a culture of safety that focuses on "fact-finding and not fault-finding", the EMS QM Branch promulgates the formal Root Cause Analysis (RCA) method. This method allows an in-depth investigation to identify root causes instead of mitigating "symptoms" based on assumptions or bias. The

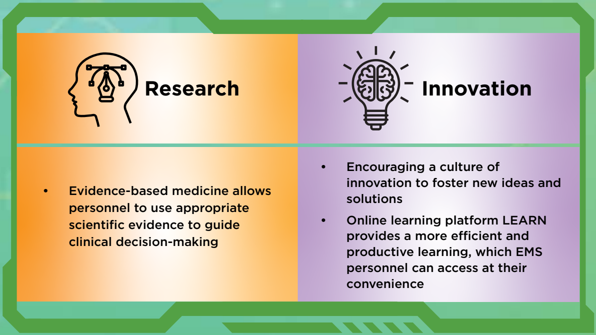

Figure 3. Factors under QI

[2] The PHMC Act 1980 provides for the control, licensing and inspection of private hospitals, medical clinics, clinical laboratories, and healthcare establishments. The Act was revised in 2020. https://sso.agc.gov.sg/Act/PHMCA1980.

QI enablers, as described in Figure 3, aim to realise the vision of continuous improvement with ground-up initiatives and professional guidance from subject matter experts in research and innovation.

DEVELOPMENT OF QM TRAINING FRAMEWORK

To introduce the concept of QM to all EMS personnel, the QM Training Framework was developed. The objective is to equip each personnel with the requisite QM skills and knowledge corresponding to their seniority level. Additionally, the training framework aims to cultivate a mindset of continuous improvement (or "changes") and instil a sense of pride in clinical excellence.

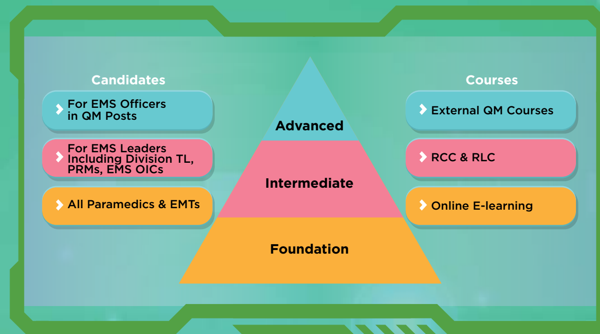

Figure 4. The QM Training Framework

CHALLENGES ON THE PATH TO TRANSFORMATION

Like any transformation, there were bound to be challenges. Taking reference from the "Diffusion of Innovations Theory — The Adoption Curve" (see Figure 5 for illustration), which outlines strategies such as gathering a small group of innovators to brainstorm an idea and reaching out to the majority of the population about a modus operandi, each challenge requires a different approach to encourage QM adoption. Hence, a multi-pronged approach was needed to achieve widespread adoption as expounded below.

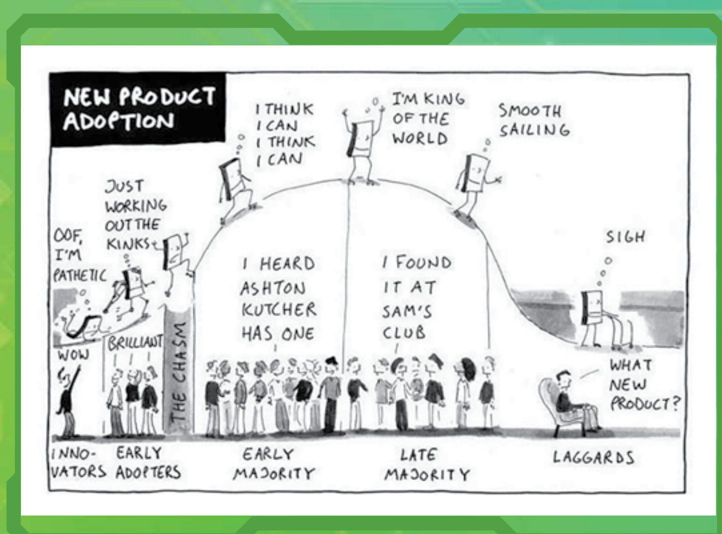

Figure 5. The Adoption Curve of the Diffusion of Innovations Theory (Fisburne, 2007)

Fundamental QM Training for Newly-Appointed QM Officers

To ensure that QM officers are well equipped with the knowledge and ability to apply the concept of QM effectively, they attended specialised courses by the SingHealth Institute for Patient Safety & Quality (IPSQ).[3] Courses included Human Factors for Process Improvement in Healthcare, Design Thinking and Introduction to Quality Improvement. Overseas conferences were also organised by

[3] IPSQ is established by SingHealth to integrate cluster-wide efforts in patient safety, quality improvement in clinical services, research, and education.

the likes of the Institute for Healthcare Improvement (IHI) so officers could learn from their global counterparts. These courses offered great knowledge and insights about QM in healthcare.

Creating QM Champions and Advocates

To institutionalise the QM Framework in SCDF and convince EMS personnel to adopt new QI initiatives on top of their heavy workload, the QM Branch developed a fun and refreshing programme. The aim was to imbue QM concepts into EMS leaders, securing them as advocates or champions of QM principles.

Within just six months, the QM Branch attended multiple QM courses and conferences, both local and overseas, and developed an in-house SCDF QM workshop to train EMS leaders.

Overcoming Resistance to Change

Resistance to change is recognised in organisational change. It could range from adverse reactions towards changes due to negative attitudes (Folger and Knonosky, 1989) to fear of changes from not understanding their benefits (Ford and Ford, 2010). One common approach is to engage and empower personnel by allowing them to share their ideas and thoughts in a safe and neutral space. This approach was adopted during the intermediate QM workshop for EMS leaders. This highly interactive half-day workshop incorporates LEGO® Serious Play® (LSP) designed to promote participation, creativity, and collaboration among personnel from diverse backgrounds.[4] This in turn helps introduce participants to basic principles of the QM Framework and QI tools, and foster a deeper understanding of underlying issues in healthcare processes.

Through these workshops and fundamental training via e-learning, the vision is for all EMS personnel to be aware of the QM Framework from the start of their career in SCDF, be proactive in making positive changes to their work processes, and take ownership of their service quality.

Figure 6. QM workshop

[4] LSP is a facilitated workshop methodology developed by The LEGO® Group, using LEGO® bricks as a communication and problem-solving tool. It is utilised in various fields, including healthcare, for RCA activities. The hands-on nature of LSP enhances engagement, creativity and collaboration.

Figure 7. Group's model

Celebrating Early Success and Embracing the Future

The EMS intermediate level QM workshop was encouraging. QI methodologies such as RCA and "Gemba walk" were used by different project teams to look into relevant issues such as improving hospital turnaround time and reducing needlestick injuries.[5] It was also impressive that the QI teams managed to identify root causes and pain points by simply applying the methodology they had learnt. In addition, these QM workshops received rave reviews from participants. Altogether, the workshop not only met its objectives but also provided the QM team with added confidence to take on future challenges.

5 The word "Gemba" originates from the Japanese word "the actual place". The term "Gemba walk" was created by Toyota Chairman Taiichi Ohno to represent going down to "see" the ground and understand the actual process.

Figure 8. Identifying root causes using RCA

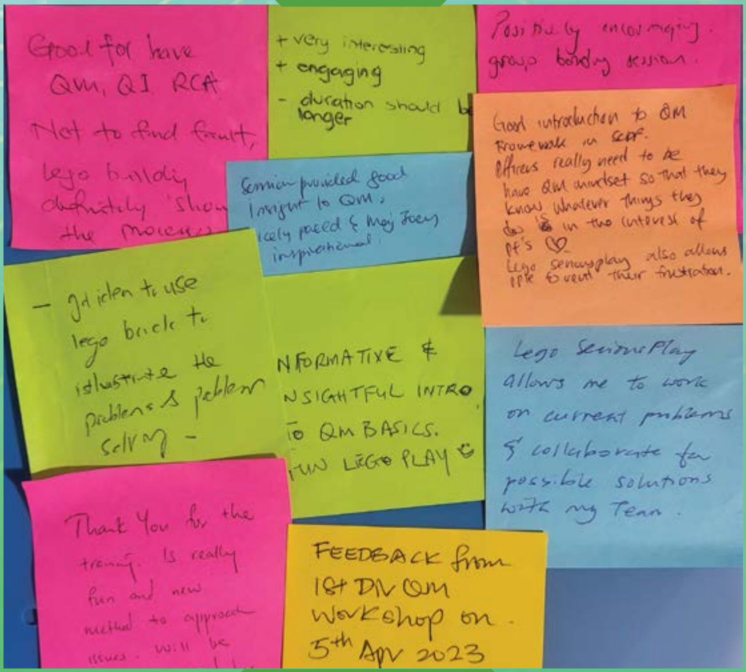

Figure 9. Post-workshop feedback

CONCLUSION

The introduction of QM in EMS is timely. It signals a new era for pre-hospital emergency care in Singapore, where driving excellence will be embedded in the DNA of EMS personnel. The EMS QM transformation journey has come a long way. With SCDF's culture of embracing change and steadfast commitment to improving patient outcomes, SCDF's EMS is poised to conquer emerging challenges and reach new heights in pre-hospital emergency care. QM aims to inspire passion, commitment and excellence among EMS leaders, paramedics and EMTs at all levels.

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LEVERAGING EXTENDED REALITY IN THE EVOLUTION OF TRAINING

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EDITORIAL PREVIEW

The Singapore Civil Defence Force (SCDF) conducts road traffic accident (RTA) extrication training through a mixture of classroom theory lessons and practical sessions at the Civil Defence Academy (CDA) to equip emergency responders with the necessary skills and knowledge for real-life operations. While the current training methodology has groomed emergency responders to meet operational demands, there are limitations when it comes to simulating different scenarios. Therefore, it is important for the training methodology to evolve to enhance training effectiveness and learning efficiency.

INTRODUCTION

In recent years, virtual reality (VR) and extended reality (XR) technologies have emerged as powerful tools with the potential to revolutionise education and training. These immersive technologies provide learners with an environment that replicates real-world scenarios, enabling them to engage in experiential learning. This essay explores the pedagogy of training using VR and XR, highlighting their benefits, applications across various fields, and their transformative impact on SCDF's RTA extrication training.

SCDF, Home Team Science and Technology Agency (HTX) & Keio-NUS CUTE (Connective Ubiquitous Technology for Embodiments) Center[1] have jointly developed a proof of concept that aims to enhance RTA extrication training through the implementation of XR technology. The technology combines both physical and virtual elements to bring about greater realism and enhance user immersion.

Physical mock-ups of equipment (e.g., hydraulic spreader cutter) will be instrumented to allow tangible interaction with the VR training environment, while the patent-pending Multi-Sensory Augmented Virtuality Suit (MAV Suit) not only provides optical, auditory and haptic feedback but also emits smell and heat.

Figure 1. Trainee performing extrication with replicated XR spreader cutter

Trainees will be in a learning environment that is safe yet mentally stimulating to allow for deeper learning, conditioned responses and increased exposure. Realistic training scenarios replicated via XR technology will enhance training effectiveness and efficiency, as these scenarios typically take significant time and effort to replicate in real life. The computer-controlled environment also facilitates better monitoring and supervision of the trainees' progress in proficiency, situational response and decision-making.

[1] Keio-NUS CUTE Center is a collaboration between the National University of Singapore (NUS) and Keio University, Japan. The centre is supported by the National Research Foundation, Prime Minister's Office, Singapore, under its International Research Centres in Singapore Funding Initiative, administrated through the Infocomm Media Development Authority (IMDA) of Singapore.

WHY EXTENDED REALITY?

The current SCDF RTA extrication training and assessment methodologies involve a mix of theory lessons and practical training sessions. RTA extrication trainings are conducted at designated wreckage sites with scrap cars. SCDF conducts one scrap car session per training day, providing effective training for up to four trainees.

While still relevant, the existing training modus operandi poses several drawbacks: manpower intensive, limitations in simulation realism and poor resource efficiency (especially during small group practical training sessions which require close instructor supervision). Scrap cars used for training are also costly and limited in availability.

Driving greater productivity and more effective training, there are significant advantages to developing an XR training system. Benefits include: (a) increased trainee participation/engagement and better training efficiency, as trainees undergo scenario-based training before they proceed with practical training; (b) increased logistical and cost efficiency resulting from a reduced reliance on scrap cars and the ability to conduct virtual training with types of vehicles that are not as easily available; and (c) increased consistency and accuracy in the skill proficiency assessment through an after action review (AAR).

Figure 2. RTA field training

Figure 3. Skill proficiency assessment

BENEFITS

With the new XR training system, trainees simply don a headset to enter an immersive VR. They are equipped with tangible equipment and an MAV Suit. A physical car frame mock-up instrumented with sensors and magnets provides realistic haptic feedback to reproduce the sensation of operating a real spreader cutter. The MAV Suit is also able to reproduce heat from a vehicle fire, which allows trainees to keep a safe distance while eliminating fire hazards.

The XR experience is further enhanced with realistic simulated RTA extrication scenarios that are specifically designed based on established curriculum materials (e.g., types of vehicles, different vehicle entrapment scenarios, extrication techniques, hazard identification, vehicle stabilisation, and vehicle anatomy).

It is envisaged that the development of the wearable XR training system will benefit RTA extrication training in three main areas:

Instructional Perspective

From the instructional perspective, the XR training system provides trainees with configurable RTA entrapment scenarios through virtual simulation, using instrumented mock equipment for a realistic experience.

Training can take place in a safe environment and not be affected by wet weather. This potentially increases the number of trainees that can be trained effectively per year. The use of XR will also instil a more positive and engaging training experience compared to theory lessons. Trainers do not have to be concerned by inconsistent exposure for trainees in a large group setting and, once deployed, training components can easily be repeated for a more detailed understanding. This reduces turnover time between trainees and facilitates self-directed learning.

The AAR feature also allows trainees to observe their actions and responses during the VR training sessions, thus significantly enhancing training effectiveness.

Logistical and Resource Efficiency

Presently, RTA practical training sessions are conducted at designated wreckage sites with scrap cars. These scrap cars must be purchased in advance and are limited both in terms of availability and type. With the XR training system, trainers are not constrained by resources and setup time can be reduced. Trainees are also able to virtually train with vehicles that are not as easily available, such as trucks and ISO tankers.

The XR training system is also a mobile solution which can be deployed to multiple locations and can be easily incorporated into training schedules for both active trainees and staff returning for refresher courses.

Performance Assessment

The XR training system provides a more objective performance assessment. With an integrated assessment module, training data can be captured to augment learning assessment and become a feedback tool for trainees, with or without a trainer. At a systems level, SCDF can analyse the efficiency and effectiveness of training. The data analytics tools unlock the possibility for newer training modalities, such as adaptive learning and video analytics, which will also be incorporated into motor skills performance assessments. This data-driven approach also allows instructors to identify strengths and weaknesses, tailor training programmes, and provide targeted feedback to enhance individual and team performance.

EVOLUTION OF TRAINING

Current

Currently, RTA extrication practical training sessions are conducted at designated wreckage sites using scrap cars. These scrap cars must be purchased in advance and are limited both in terms of availability and type. This limits the amount of training that can be carried out and the number of trainees per session.

Assessment is conducted via a manual checklist, which is administered by instructors — a manual process that is prone to subjectivity even though the checklist is designed to be as objective as possible.

Future

The XR training system will supplement the existing theory and practical training sessions. Trainees will undergo virtual training scenarios while wearing a patent-pending MAV Suit, which will provide sensory feedback such as heat, smell and touch (Figure 4). One key component of RTA extrication training featured in the training system is the door removal procedure. This will showcase the unique XR interaction of the RTA training system, where trainees can perform a specific part of the extrication process in XR space using replicated equipment, such as the hydraulic spreader cutter with haptic feedback.

Figure 4. Trainee in MAV Suit

Figure 5. Simulated XR spreader cutter

The performance assessment module of the XR training system will monitor trainees' performance based on a set of standardised criteria provided by the instructors. This will make the entire assessment process more objective, consistent, and accurate.

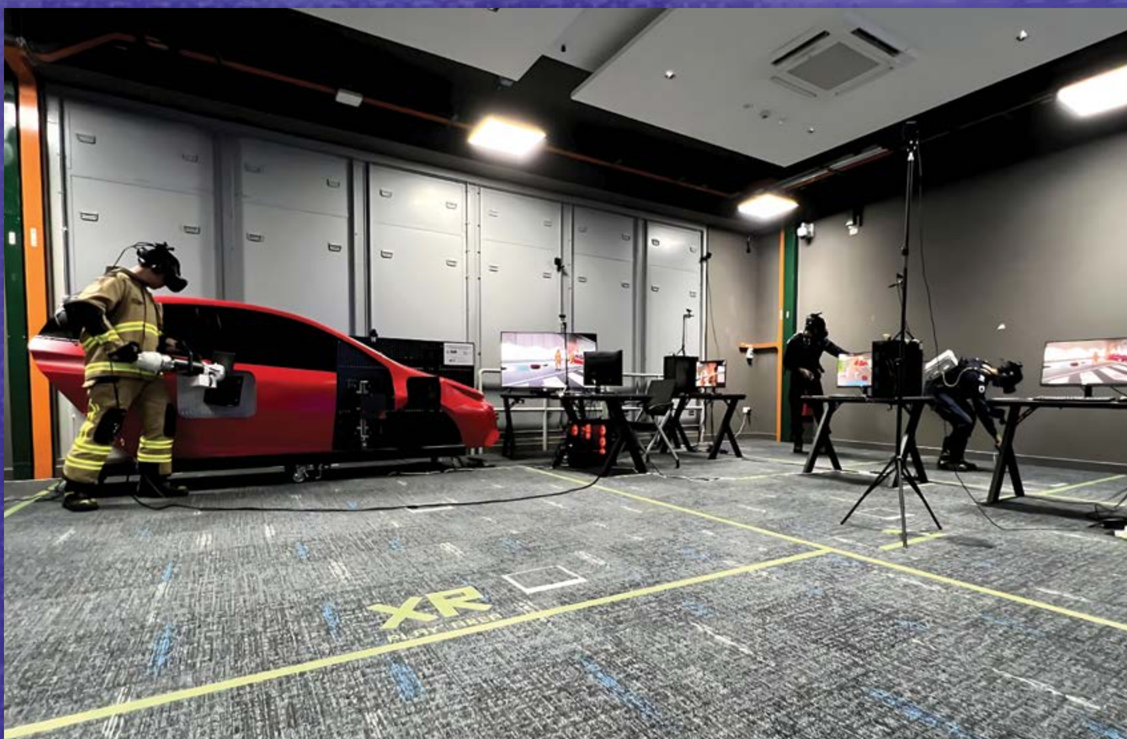

Figure 6. RTA XR training simulator

CONCLUSION

The usage of VR and XR has revolutionised the way emergency responders are trained by providing a safe, scalable, and immersive learning experience. VR and XR technologies sharpen the operational edge of emergency responders. As these technologies continue to evolve, it is crucial for fire departments and rescue organisations to embrace and integrate them into their training programmes. This will ensure that their personnel are equipped with the necessary skills to face the challenges of tomorrow.

SCDF'S SUSTAINABILITY JOURNEY — RESPONDING RESPONSIBLY, SERVING SUSTAINABLY

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EDITORIAL PREVIEW

The Singapore Civil Defence Force (SCDF) aims to be a global leader in sustainable development in the Fire, Rescue and Emergency Medical Services (EMS) fraternity. Over the years, Singapore has been actively working towards sustainability and environmental conservation. One of the key milestones is the announcement of the Singapore Green Plan 2030, which outlines a comprehensive suite of sustainability initiatives. This article provides an overview of SCDF's efforts in promoting ground-up sustainability initiatives under the GreenGov.SG framework.

PROMOTING SUSTAINABILITY EFFORTS IN SCDF

INTRODUCTION — SCDF'S SUSTAINABILITY FRAMEWORK

In recent years, SCDF has embarked on various sustainability initiatives and programmes as part of its commitment towards the GreenGov.SG framework. In support of the National Sustainability Agenda, SCDF developed its own shared sustainability vision with the aim of creating a strong sustainability culture within the organisation. The vision was built upon three key sustainability pillars — namely (i) Environment, (ii) Social, and (iii) Governance.

Figure 1. Environment (E), Social (S), Governance (G) pillars under the SCDF Sustainability Framework

To oversee and drive efforts under the framework, the SCDF Sustainability Taskforce and Framework was established. It is chaired by a chief sustainability officer (pegged at Deputy Commissioner level) and comprises representation at all levels to truly achieve its intent of embedding a culture of sustainability.

OVERVIEW OF SUSTAINABILITY INITIATIVES AND PROGRAMMES IN SCDF

SCDF's sustainability programme can be broadly summarised into a three-pronged approach, namely (i) developing a shared sustainability vision, (ii) generating awareness and understanding of the sustainability imperative, and (iii) engaging and motivating sustainable behaviour.

Developing a Shared Sustainability Vision

The Sustainability Taskforce develops the shared sustainability vision. Driven by a group of like-minded officers, the taskforce provides policy and strategic guidance and charts the roadmap to drive sustainability efforts across SCDF. The taskforce also engages the relevant stakeholders such as appointed sustainability advocates across SCDF units, and reaches out to potential sustainability partners for collaboration. As SCDF strives towards its sustainability goals, key performance indicators (KPIs) are also set and tracked to encourage ownership and maintain accountability. SCDF aims to foster a culture where sustainability is integrated into everyday practices and decision-making.

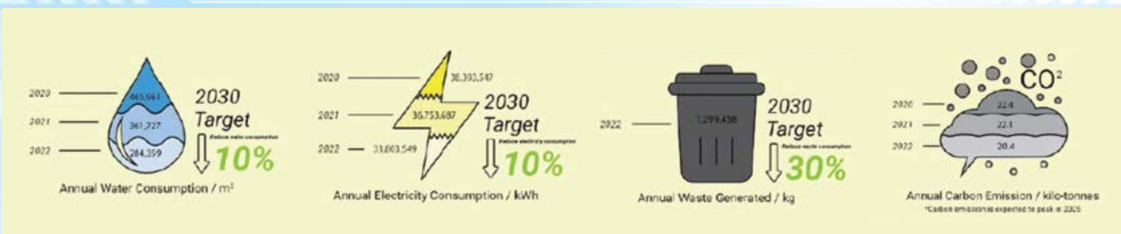

Figure 2. Examples of KPIs

Generating Awareness and Understanding of the Sustainability Imperative

SCDF believes in the importance of communication and education to onboard staff on its sustainability journey. Various initiatives have been curated to create more awareness and understanding of SCDF's sustainability efforts. These include sustainability workspaces, corporate social responsibility (CSR) programmes, and learning journeys.

Sustainability Workspaces

To promote creativity in utilising upcycled materials (e.g., condemned hoses, personal protective equipment (PPE)), sustainability workspaces have been set up within SCDF for the display and prototyping of various upcycled products. This serves as a centrepiece to showcase SCDF's sustainable efforts, and provide the tools for interested personnel to work on their sustainability ideas.

Figure 3. Sustainability workspace setup at the Civil Defence Academy

Figure 4. Sustainability corner setup at HQ SCDF

The sustainability workspace/corner will be used to conduct workshops and training for interested personnel to better understand the upcycling process and gain hands-on experience. In the long term, this is envisaged to encourage more interest groups to contribute to the upcycling drive in SCDF.

In recent years, various upcycling workshops (both internal and external) have been conducted to create awareness of upcycling. The SCDF upcycling team also creates activity packs such as DIY hand sanitiser holder to generate interest.

Figure 5. DIY hand sanitiser holder activity pack

CSR Programmes

Besides the environmental aspect of sustainability, SCDF also focuses efforts on the social pillar. Well-established CSR programmes such as the adoption of homes, Our Waters programme, beach/park clean-ups and others have been spearheaded by various frontline units to advocate social responsibility.

SCDF recognises the need for early sustainability training and learning in an individual's career development to instil the values and mindset towards a shared sustainability vision. As such, CSR programmes are weaved into SCDF's foundational courses, namely the Rota Commander Course (RCC), Section Commander Course (SCC), Firefighting Course (FFC) and Emergency Medical Technical (EMT) Course. Aligned to HQ SCDF's framework, the Civil Defence Academy (CDA) also established a framework for CSR activities as part of an officer's fundamental development.

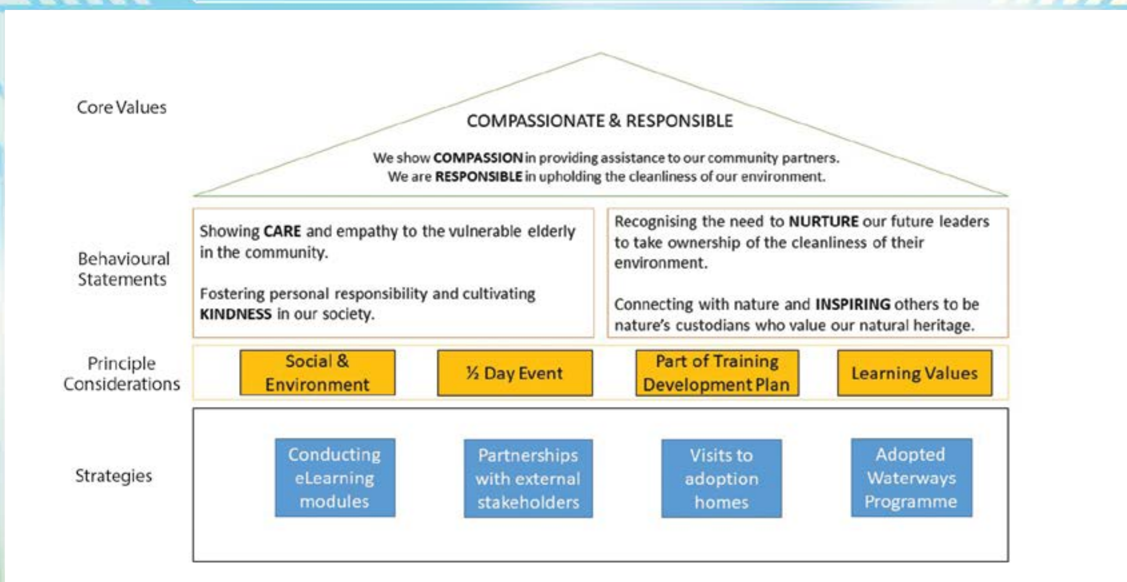

Figure 6. CDA's CSR framework

Figure 7. CDA's CSR activities

Learning Journeys

To broaden exposure to sustainability-related issues, learning journeys are also organised across SCDF units. This helps cultivate and strengthen the sustainability DNA in SCDF officers and offers networking opportunities with stakeholders towards a common goal. Such programmes also allow officers to experience a sense of satisfaction and promotes better understanding of sustainability efforts.

Engaging and Motivating Sustainable Behaviour

SCDF recognises the need to align our sustainability vision with the personal beliefs of our officers, instilling in them a deeper sense of purpose and commitment in sustainability efforts. Various initiatives have been introduced to engage our officers in contributing towards our sustainability goals, such as production of upcycled corporate gifts and donation of upcycled materials for repurposing.

Production of Upcycled Corporate Gifts

To showcase SCDF's commitment towards sustainability, there is a shift from conventional vendor-produced gifts to in-house upcycled corporate gifts. These upcycled corporate gifts feature the creative repurposing of condemned materials (i.e., beyond operational lifespan) into useful products, giving them a second life. Conscientiously designed, handcrafted and customised by SCDF's upcycling team, a full range of corporate gifts have been produced and presented to visitors to raise awareness of SCDF's sustainability efforts.

Figure 8. In-house upcycled corporate gifts

Figure 9. Upcycled corporate gifts presented during the Public Service Commission (PSC) visit to CDA in March 2022

Notable sustainability efforts were also taken in the design and production of trophies and medals for the Singapore-Global Firefighters and Paramedics Challenge (SGFPC) 2023. For instance, condemned uniforms and chemical agent (CA) training suits were reused to fabricate medal lanyards. A more sustainable approach using 3D printing and jesmonite was also taken to fabricate trophies.

Figure 10. Lanyards made from used uniforms & PPE

Figure 11. Uniform disposal bins at units & HQ SCDF

Donation of Upcycled Materials for Repurposing

In the spirit of upcycling, SCDF has implemented waste recycling bins at all units and HQ SCDF to facilitate and encourage employee involvement. Uniform disposal bins, which collect used uniforms for repurposing, were also introduced.

In addition to promoting internal upcycling efforts, SCDF also donates decommissioned firefighting hoses to external agencies such as S.E.A. Aquarium and Wildlife Reserves Singapore. They are repurposed as "furniture" to enhance the animals' living spaces.

Figure 12. Condemned firefighting hoses repurposed for use at Mandai Zoo

EXTERNAL ENGAGEMENT & SHOWCASE OF SCDF'S SUSTAINABILITY EFFORTS

Besides internal efforts, SCDF has proactively sought partnerships with external agencies to further raise awareness and promote its sustainability drive. One such example is the collaboration with the National Library Board to display SCDF's upcycled products at selected libraries. This initiative garnered much support from the community and sets the stage for more collaboration opportunities.

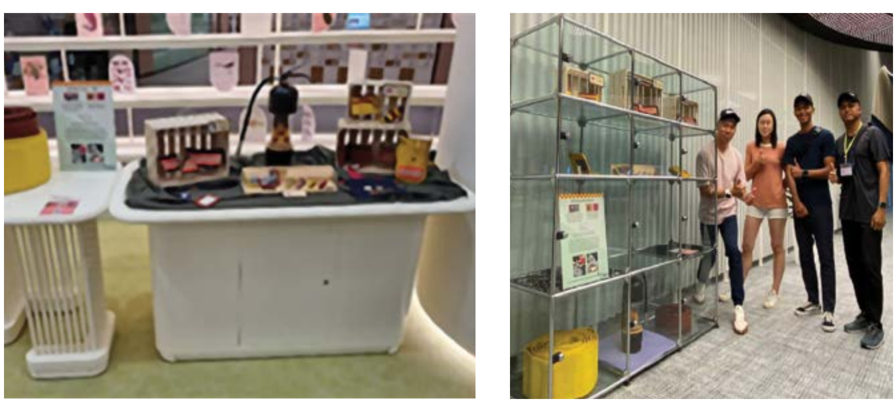

Figure 13. External displays at NLB libraries

SCDF is also currently working on collaborating with social enterprises such as Singapore Fashion Runway, SG Enable, SPD, Bizlink and others. These collaborations will help drive SCDF's sustainability efforts into the next phase.

OPTIMISING RESOURCES, MINIMISING WASTAGE

Moving forward, SCDF seeks to leverage data analytics to make informed decisions, optimise resource allocation and enhance operational effectiveness. Apart from helping SCDF in its core mission, data and technology also helps SCDF operate more sustainably by optimising the consumption of resources and streamlining workflows for enhanced efficiency. These initiatives include the food waste reduction and management framework and automated medical store.

Food Waste Reduction and Management Framework

Food waste is a major contributor to the overall waste generation in Singapore. As an academy providing a large volume of meals daily for both local and overseas residential training, CDA is recognised for its potential to play a vital role in support of the national waste reduction drive. A formal framework aimed at reducing food waste at CDA was hence established last year.

The **C.A.R.E.** (*C — Cultivate; A — Assess; R — Reduce; E — Evaluate*) model was conceptualised to comprehensively cover all aspects of food waste management. A summary of the C.A.R.E. model is illustrated in the diagram below.

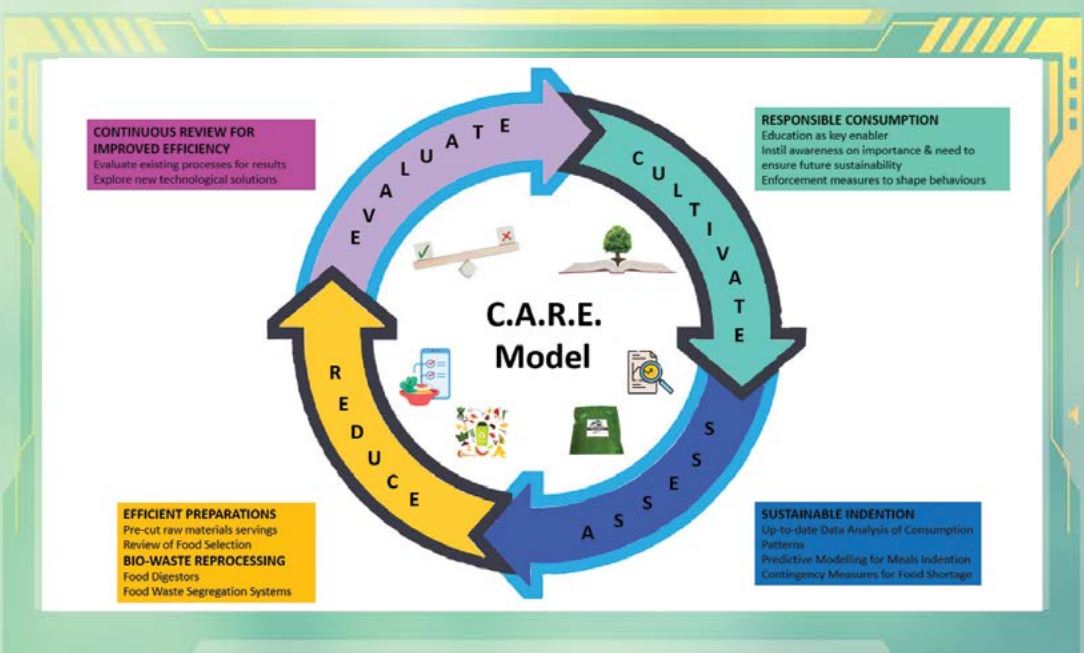

Figure 14. Illustration of C.A.R.E. model

Under this framework, KPIs are also set to evaluate the effectiveness of existing food waste reduction measures. These KPIs are also benchmarked against environmental sustainability targets set out under the GreenGov.SG initiative for continual improvements.

Automated Medical Store

The automated medical store was conceptualised and developed to improve efficiency in inventory management and workflow. With this system, trend analysis is utilised for optimal stock levels of medical supplies. This helps minimise wastage from overstocking without compromising on adequacy of supplies.

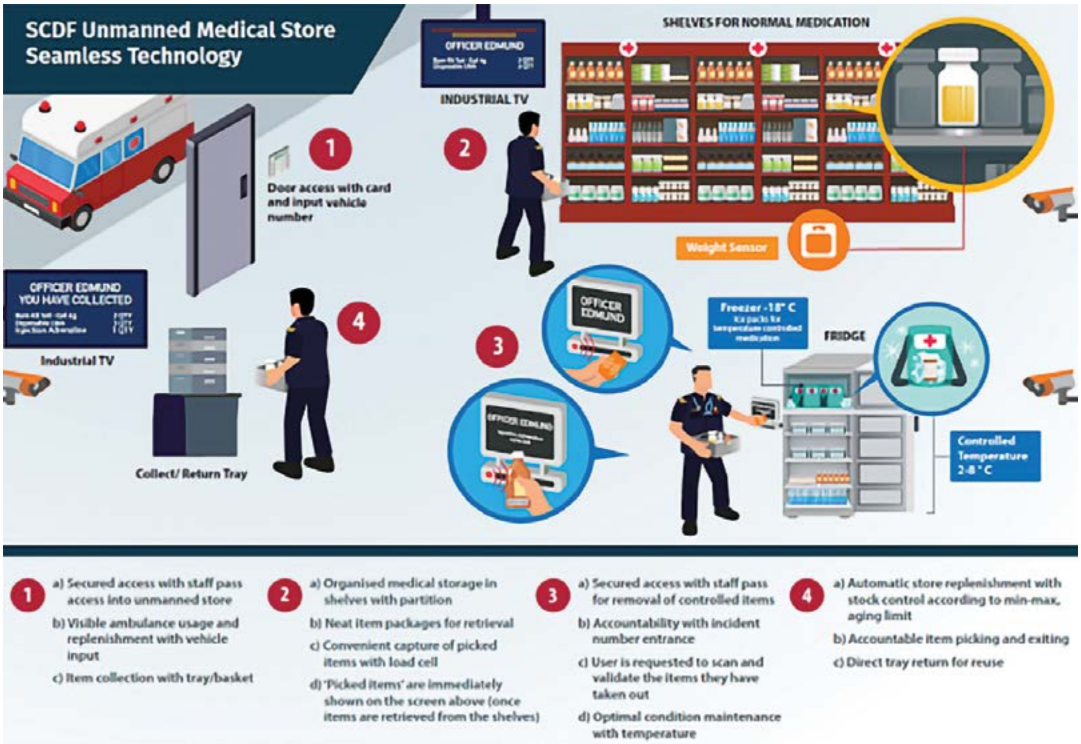

Figure 15. Automated medical store concept

CONCLUSION

SCDF is committed towards developing a strong sustainability culture within the organisation. New programmes and initiatives will continue to be rolled out to support sustainability and to encourage officers to be agents of change. Investing in sustainability is not just an act of philanthropy, but can also generate and stimulate innovation and uncover new opportunities. With this mindset change, SCDF strives to uphold a professional image as a reputable sustainable organisation, and seeks to attract like-minded employees and stakeholders.

SYSTEM REDESIGN TO IMPROVE ERGONOMIC SAFETY — THE CAF BACKPACK

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EDITORIAL PREVIEW

Ergonomics[1] plays a crucial role in the design and utilisation of systems and equipment for emergency responders. Effective ergonomic design addresses factors such as ease of use, weight distribution and adaptability, which are essential for emergency responders who often experience high-stress, time-sensitive situations. Properly designed systems and equipment reduce the risk of injuries, prevent long-term musculoskeletal disorders (MSD) and enable emergency responders to focus on their primary mission — saving lives and properties. This article explores the ergonomic assessment of retrieving Compressed Air Foam (CAF) backpacks efficiently and safely from the designated storage area of the Singapore Civil Defence Force (SCDF) Light Fire Attack Vehicle (LFAV).

[1] Ergonomics is "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system", which ensures that a worker's products, procedures, and working environment are suitable for his or her job requirements and personal capabilities. "What Is Ergonomics (HFE)?", International Ergonomics Society, 2000.

INTRODUCTION

CAF backpacks, which weigh up to 25 kg, are widely used by firefighters due to their effectiveness compared to fire extinguishers. Two CAF backpacks are stored deep within the rear cabin of the LFAV deployed to the fire site. To unload the backpack, responders are required to lean forward into the cabin, drag the backpack along an upward slope to the edge of the cabin (Figure 1A), bend down to don it (Figure 1B), and finally stand and adjust it to a comfortable position (Figure 1C). Due to awkward posture and the bag's weight, firefighters are at high risk of MSD.

Figure 1. Retrieving and donning a CAF backpack

PROPOSED SOLUTION

SCDF and the Home Team Science & Technology Agency (HTX) explored various engineering solutions to overcome this problem and decided to install a sliding tray at the rear compartment of LFAVs. CAF backpacks are stored and secured on trays at the waist level of responders with a median height of 1.70 m. Without bending down, responders can easily slide the backpack out (Figure 1D) and tighten the straps while it rests on the tray (Figure 1E). The elevated tray also eliminates the need for responders to bend or rotate their torsos when lifting the backpacks. Responders can then proceed to the incident site without further adjustments (Figure 1F).

The redesign of the storage platform has resulted in the following benefits:

- Removes the need to drag the backpack up a slope
- Reduces the extent of bending down when donning the backpack
- Simplifies the adjustment process by resting the backpack on the tray

As a result, the risk level of retrieving and donning CAF backpacks has been significantly reduced. The improvement was affirmed by various ergonomic analysis tools.

OPTIMISATION OF TRAY HEIGHT

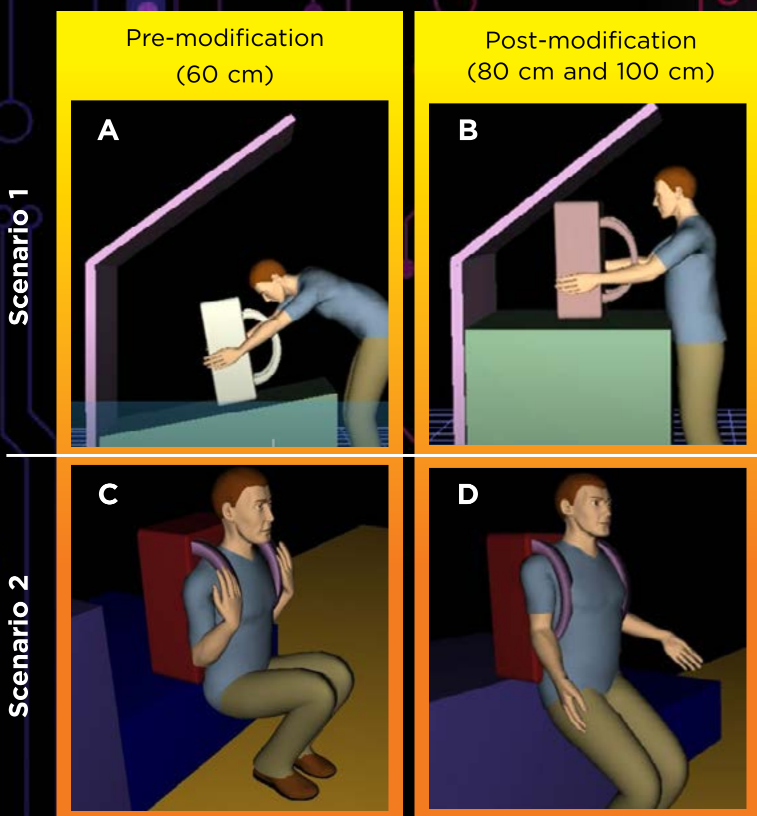

Figure 2. Two scenarios replicated in DHM simulations

One important parameter to be optimised is the height of the tray platform. If it were too low, responders may still need to bend down significantly to don the backpack; if it were too high, it may be out of reach for some. For this purpose, a digital human modelling (DHM) software, Jack, was adopted to assess ergonomic impact at different rear cabin heights.

In the DHM software, the process of backpack retrieval was reconstructed with the rear cabin and backpack represented by rectangular blocks (Figure 2). The dimensions of the blocks are the same as the rear cabin and the backpack. Two scenarios were constructed, each with pre- and post-modification of the rear cabin. The first scenario represents the dragging of the backpack along the rear cabin floor of the vehicle, while the second scenario represents the donning of the backpack off the edge of the vehicle. DHM was used to simulate the motion of a firefighter in both scenarios.

Four ergonomic analysis tools were used: Ovako Working Posture Analysis (OWAS), Rapid Upper Limb Assessment (RULA), Lower Back Compression Analysis (LBCA) and Static Strength Prediction (SSP). Parameters used in these simulations are listed in Table 1.

Table 1. Parameters used in DHM simulations

Parameter	Value
Height of edge before modification (cm)	60
Height of edge after modification (cm)	80, 100
Human height (cm)	170
Human weight (kg)	72
Weight of backpack (kg)	25

OWAS

The OWAS method identifies the frequency and time spent in certain postures during a task, then recommends corrective actions.[2] It identifies the most common work postures for the back, arms, and legs, and three categories of weight of load handled. The postures and weight categories can be arranged to form 252 combinations, each corresponding to a body posture. Each body posture is given a four-digit code and classified into one out of four action categories (Table 2). Each category indicates the extent of ergonomic change required.

Table 2. OWAS action codes[3]

Action Category	Action Required
AC1	No action required
AC2	Action required in the near future
AC3	Action required as soon as possible
AC4	Action required immediately

RULA

RULA was developed to assess the risk of upper limb disorders based on posture, muscle usage, load weight, task duration and task frequency.[4] Scores based on posture, force, and number of repetitions are derived for the following body regions: upper arm, lower arm, wrist, neck, trunk, and legs. Data collected and scored are used to compile risk factor variables, generating a single score representing the level of MSD risk (Table 3).

Table 3. Levels of MSD risk

Score	Level of MSD Risk
1 - 2	negligible risk, no action required
3 - 4	low risk, change may be needed
5 - 6	medium risk, further investigation, change soon
6+	very high risk, implement change now

LBCA

LBCA helps evaluate forces acting on the lower back and determine if workplace tasks increase the risk of lower back injuries. This method focuses on the L4-L5 portion of the spine, where back injuries are most likely to occur. It calculates compression forces (when spine vertebrae are compressed), anterior-posterior (AP) shear forces (acting on the anterior-posterior of the spine), and lateral shear forces (acting on the spine when the body moves left to right).

SSPA

SSPA predicts static strength requirements for tasks such as lifts, presses, pushes, and pulls. It also provides an approximate job simulation, including posture data, force parameters, and male/female anthropometry. The output indicates the percentage of male/female workers with a specific weight and height, and what tasks their bodies can do.[5]

The results from the above simulation tools are summarised in Table 4. A rear cabin height of 100 cm is observed to provide the least strain on the body based on the four metrics. For example, the OWAS score is reduced from 2 to 1 for scenario 2, while the RULA score is lowered from 6 to 3 for scenario 1. The LBCA score is also reduced by 25% and 39% for scenarios 1 and 2 respectively. On the other hand, SSPA results indicate that a vast majority of the population can handle the load with a 100 cm cabin height.

However, implementing a rear cabin height of 100 cm would reduce the available capacity of the rear cabin. Further, the improvement from 80 cm to 100 cm is minute; more improvement is observed when the height is increased from 60 cm to 80 cm. Therefore, considering ergonomic improvement and space availability, the rear cabin height was raised from 60 cm to 80 cm via the addition of a sliding platform.

2 Gómez-Galán M, Pérez-Alonso J, Callejón-Ferre ÁJ, López-Martínez J. Musculoskeletal disorders: OWAS review. Ind Health. 2017 Aug 8;55(4):314-337.

3 O. Karhu, K. P, and I. Kuorinka, "Correcting postures in industry: a practical method for analysis," Applied Ergonomics, vol. 8, no. 4, pp. 199-201, 1977.

4 "A Step-by-Step Guide Rapid Upper Limb Assessment (RULA)", Ergonomics Plus Inc.

5 "3D Static Strength Prediction Program™ Version 6.0.8 User's Manual", The University of Michigan Center for Ergonomics.

Table 4. Summary of results from DHM simulations

Tools	Scenario 1			Scenario 2		
	60cm	80cm	100cm	60cm	80cm	100cm
OWAS	2	2	2	2	2	1
RULA	6	4	3	5	4	4
LBCA	1973 N	1501 N	1470 N	1123 N	905 N	685 N
SSPA	< 100% population can handle the load at torso, hip, and ankle	< 100% population can handle the load at hip and ankle	< 100% population can handle the load at hip and ankle	Extremely difficult for knees to handle	~ 50% population can handle the load at knee	~ 100% population can handle the load at knee

FURTHER ERGONOMIC ASSESSMENT

After the tray height was finalised at 80 cm, we conducted further ergonomic analysis using tools such as the National Institute for Occupational Safety and Health (NIOSH) equation, Rapid Entire Body Assessment (REBA), and Manual Handling Assessment Charts (MAC) to compare risk factors in lifting CAF backpacks between the original and proposed approaches.

The International Organization for Standardization (ISO) 11228-1 specifies recommended limits for manual lifting and carrying while considering the intensity, frequency, and duration of the task.[6]

Specifically, the NIOSH equation is used to calculate the effects of lifting distance, asymmetry, vertical location, frequency, quality of gripping, etc. (Figure 3).[7] The calculated results show that the recommended lifting weight for the existing process is only 7.47 kg. As such, the lifting index for CAF backpacks is 2.67 and considered "high risk". After introducing the sliding tray, improvements in the asymmetrical, horizontal, vertical and distance factors reduced the lifting index to 1.04, corresponding to a "low-risk" level.

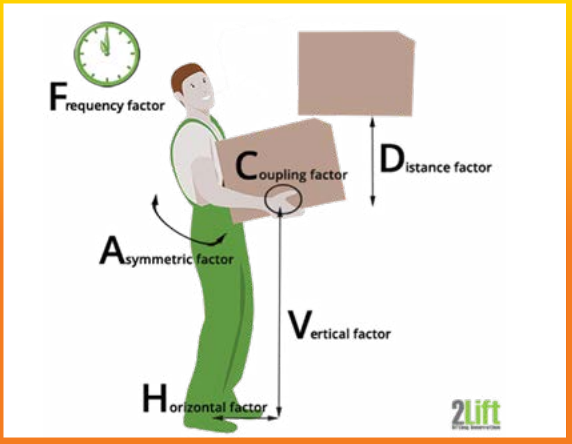

Figure 3. Multiplier factors in the NIOSH lifting equation

REBA is another ergonomic tool used to evaluate the risk of musculoskeletal disorders associated with specific tasks.[8] Based on the analysis of postures adopted in the existing work process, the team assigned appropriate ratings for various body parts. The original approach obtained a REBA score of 12, which is in the "very high-risk" range. Conversely, the proposed approach yields a much lower REBA score of 7 ("medium risk").

MAC helps assess the most common risk factors in lifting (and lowering), carrying and team handling operations. It reveals factors that require modification to control these risks.[9] For example, in the original approach, bending forward to lift the CAF backpack and twisting the body to don it was identified as high risk (red band). The sliding tray eliminates such risk factors and brings down the numerical score from 15 to 5, indicating a significantly improvement in workplace health and safety.

6 "ISO 11228-1:2021, Ergonomics — Manual handling — Part 1: Lifting, lowering and carrying", International Organization for Standardization, 2021.

7 "The NIOSH Lifting Equation for Safe Lifting", 2Lift ApS, Denmark.

8 "A Step-by-Step Guide Rapid Entire Body Assessment (REBA)", Ergonomics Plus Inc.

9 "Manual handling assessment charts (the MAC tool) — Interactive version", Institution of Occupational Safety and Health, UK.

IMPLEMENTATION

In the pilot trial, four LFAVs were retrofitted with sliding trays at the Tuas, Jurong, Alexandra, and Banyan Fire Stations. After three months of evaluation, over 95% of users were satisfied. The final design of the sliding tray was further enhanced based on feedback provided by responders. For example, strong gas springs were installed to raise the rear compartment door to a height of 2 m to prevent any head injuries. LED light strips with automatic sensors were also installed to improve visibility during night operations. Details of the final design are shown in Figure 4. After receiving overwhelmingly positive feedback from the pilot trial, SCDF moved to fully implement the solution by February 2023.

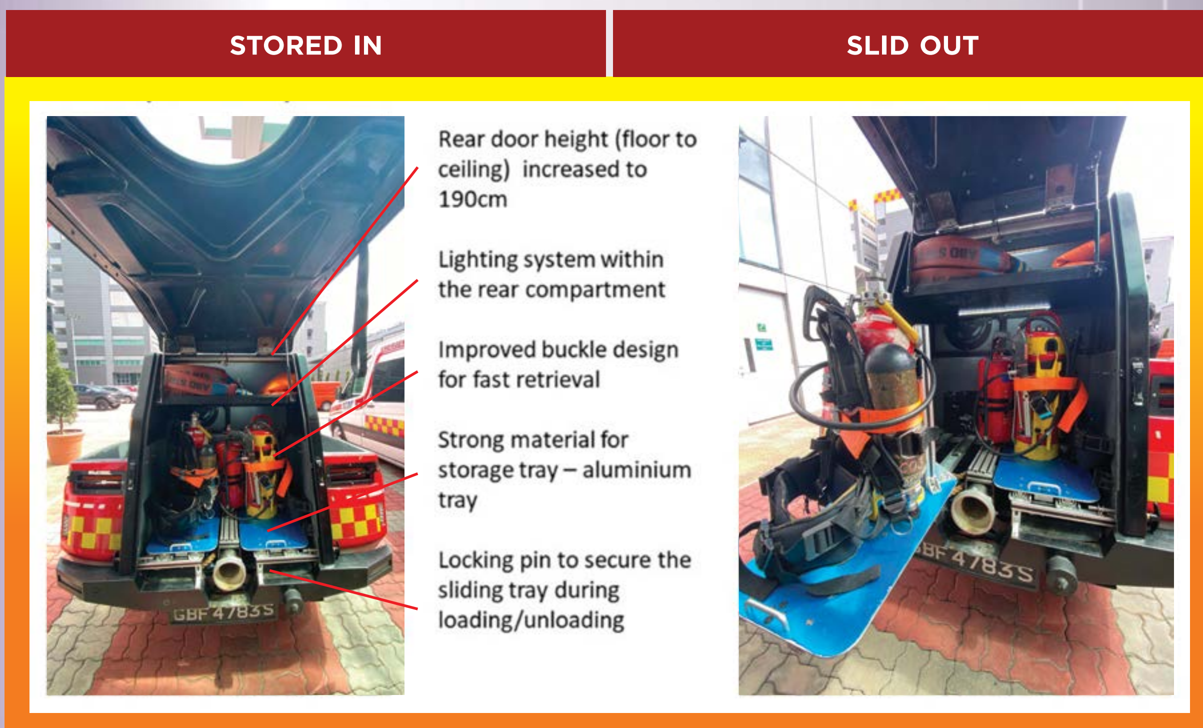

Figure 4. Redesigned LFAV with sliding tray

CONCLUSION AND FUTURE WORK

Ergonomics may seem simple and trivial but is often overlooked. It could affect our health, safety, and productivity in the long run. Ergonomic analysis tools and DHM are powerful methods that help reveal high-risk factors and assess the effectiveness of proposed solutions. We hope this encourages us to review our daily operations and assess if existing systems and processes pose ergonomic safety issues, which can be improved to ensure sustainable and optimal performance in SCDF.

THE DNA OF A SMART FIRE STATION

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EDITORIAL PREVIEW

In the age of remarkable technological advancements, the fire service industry is undergoing a profound transformation. The Singapore Civil Defence Force (SCDF) is at the forefront of exploring new technologies for firefighting, emergency medical services and training. In this article, we explore and understand what makes up the DNA of a smart fire station by drawing inspiration from Punggol Fire Station and exploring the shift from traditional to technologically empowered fire stations. We will also examine how smart infrastructure, data-driven decision-making, enhanced mobility and connectivity, and targeted training are shaping the future of fire stations.

INTRODUCTION

Before delving into the DNA of a smart fire station, it is essential to understand the workings of a traditional fire station. For decades, these fire stations have been characterised by their sturdy architecture, robust firefighting equipment, and a team of dedicated first responders ready to leap into action. This model, while effective, is now ripe for evolution, as exemplified by the groundbreaking changes introduced at Punggol Fire Station.

The smart fire station is a relatively recent development in the field of emergency services and public safety. The idea of incorporating advanced technologies into fire stations has evolved over the past couple of decades. The shift towards smart fire stations has been driven by broader trends of smart cities and the integration of technology into various aspects of urban life.

Here are some key factors and milestones that have contributed to the emergence of the smart fire station:

Advancements in Technology

The rapid advancement of technology, especially in the areas of data analytics, IoT (Internet of Things), and connectivity, has provided the foundation for the smart fire station concept. These technologies enable real-time data collection, analysis, and decision-making, which are crucial for emergency response.

Smart City Initiatives

Many cities worldwide have been pursuing smart city initiatives to improve urban infrastructure, public services, and emergency response. Fire stations have become integral parts of these efforts to enhance safety, connectivity and efficiency through technology.

Integration of Data

Fire departments started integrating data from various sources, such as weather stations, traffic management systems, and GIS (Geographic Information Systems), to optimise response times and resource allocation. This integration of data was a key precursor to the smart fire station concept.

Pilot Projects and Innovations

Various fire departments and municipalities have initiated pilot projects and collaborations with technology companies to test and implement smart technologies in fire stations. These projects demonstrated early on what smart fire stations could achieve.

Research and Development

Ongoing research and development in firefighting equipment, communication systems, and training technologies has contributed to the evolution of fire station capabilities.

Global Awareness

The need for efficient emergency response has gained global attention due to natural disasters, urbanisation, and increasing population density. This awareness has accelerated the adoption of smart technologies in fire stations worldwide.

THE SMART FIRE STATION ROADMAP

SCDF's smart fire stations followed a strategic roadmap developed by the Transformation and Future Technology Department. This roadmap is built upon four critical pillars aimed at enhancing operational efficiency, response effectiveness, and firefighter safety.

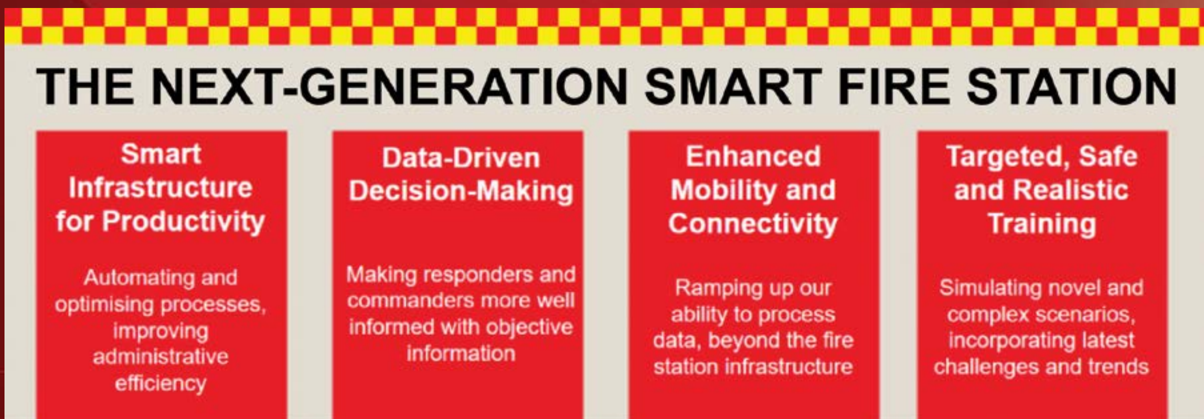

Figure 1: The four pillars of the smart fire station

Smart Infrastructure for Productivity

At the core of the smart fire station roadmap is the establishment of smart infrastructure. The objective is to optimise the station's physical environment to enhance productivity and sustainability.

Integrated Building Management Systems: These systems, exemplified by the likes of SCDF's Punggol Fire Station, ensure that the station operates at peak efficiency. Centralised control over critical functions such as HVAC (heating, ventilation, and air conditioning), lighting, and security systems not only reduces operational costs but also creates a more comfortable and productive workspace for firefighters.

Sustainability Initiatives: Smart fire stations are committed to reducing their environmental footprint. Sustainability measures, such as energy-efficient equipment and renewable energy sources, are adopted to minimise the station's environmental impact while cutting down operational costs.

Data-Driven Decision-Making

The second outcome on the roadmap emphasises data as a catalyst for more informed and efficient decision-making. Fire stations harness data to gain insights and adapt their strategies in real time. Key elements include:

Real-Time Data Monitoring: Advanced sensors continuously collect data on various parameters, such as weather conditions, traffic patterns, and station operations. This data feeds into a centralised system, allowing fire stations to monitor and analyse real-time information.

Predictive Analytics: Historical and real-time data are analysed to predict emergency patterns, enabling fire stations to pre-position resources, optimise response routes, and make informed resource allocation decisions.

Enhanced Mobility and Connectivity

Mobility and connectivity are critical for modern fire stations. The roadmap focuses on equipping firefighters with the tools and technology necessary for efficient communication and mobility:

Smart Wearables: Firefighters are provided with smart wearables such as smartwatches and smartphones. These devices keep them connected to the station and to each other, providing critical information in real time. In the field, they facilitate seamless communication, coordination, and access to data.

High-Speed Connectivity: High-speed internet and robust communication networks ensure that firefighters have access to real-time data feeds, enabling quick decision-making and resource allocation, regardless of their location.

Figure 2: Synchronisation of the smartwatch with smart tablet

Targeted, Safe, and Realistic Training

The last pillar on the roadmap revolves around training. SCDF's smart fire stations leverage technology to ensure that our responders are always prepared for any situation.

Simulation Technologies: Fire stations utilise advanced training tools, such as the road traffic accident extended reality (RTA XR) simulator. These simulators provide firefighters with realistic, immersive experiences, allowing them to practise responding to complex scenarios without exposure to real-world risks.

Customised Training Programmes: Training programmes are tailored to address specific community needs and evolving threats. This ensures that first responders are well prepared for the unique challenges they may face within their service area.

Figure 3: Training using the RTA XR simulator

By focusing on the four pillars, fire stations can not only safeguard communities more effectively but also create a safer, more efficient working environment for their firefighters. The journey towards the smart fire station of tomorrow is defined by these outcomes, reflecting a commitment to innovation and public safety.

THE SMART FIRE STATION BLUEPRINT: PUNGGOL FIRE STATION

Punggol Fire Station, SCDF's first smart fire station, located in the heartlands of Singapore, is not just a symbol of architectural innovation; it represents a paradigm shift in how SCDF envisions the future of fire stations. Punggol Fire Station will be a blueprint for smart fire stations worldwide.

Smart Infrastructure for Productivity

Punggol Fire Station showcases a remarkable integration of smart infrastructure to enhance productivity. It is home to a pioneering Smart Integrated Building Management System. This sophisticated system optimises the station's energy usage, ensures efficient operation of critical functions like HVAC and lighting, and reduces environmental impact. The result is a workplace that not only supports the well-being of firefighters but also contributes to sustainability goals.

Operational Response and Readiness

The heart of any fire station lies in its operational response and readiness. Punggol Fire Station has set a new standard with technologies such as the High-Speed Safe Shutter (HS3), an automated roller shutter designed for emergency vehicles to exit swiftly. This innovation dramatically reduces response time during critical moments, improving the station's overall operational efficiency.

Command and Control

Effective command and control is vital in emergency response scenarios. Punggol Fire Station features advanced command and control systems, including smart monitors and a commander's dashboard. These technologies provide real-time insights, facilitate decision-making, and enable commanders to coordinate operations seamlessly, ensuring that resources are deployed where they are needed most.

Figure 4: Data analytics and visualisation for operational command control

Technologies at Punggol Fire Station

The success of Punggol Fire Station as a smart fire station can be attributed to the incorporation of cutting-edge technologies.

Automated Fire Station Access Control: Punggol Fire Station employs a guest management system for personnel and vehicles, enhancing security and streamlining access.

Figure 5: Entry and exit using the automated fire station access control

Automated Medical Store: Taking a page from Amazon's smart warehouse, Punggol Fire Station's automated medical store ensures that essential medical supplies are efficiently managed and readily available during emergencies.

Figure 6: Automated logistics management in the automated medical store

CCTV Video Analytics: Advanced video analytics technology is employed for security surveillance, providing enhanced monitoring and safety within the station.

Gamification of Training: Punggol Fire Station embraces gamification through virtual reality and augmented reality training for emergency medical services, road traffic accidents, and fire investigations. This immersive training approach prepares firefighters for complex scenarios, making learning engaging and effective in a safe environment, while eliminating the need to set up extensive physical training scenarios that cost time and money.

Robotics for Enhanced Response: To reduce risks faced by responders, SCDF has incorporated robotics into various areas of its operation in recent years. Robots operationalised at Punggol Fire Station include the Unmanned Firefighting Machine (UFM) and the Pumper Firefighting Machine (PFM). These robots assist responders in navigating hazardous environments and suppressing fires in areas that may be too dangerous for human responders, hence keeping them out of harm's way.

Figure 7: PFM and UFM at Punggol Fire Station

By addressing critical areas such as smart infrastructure, operational response and readiness, and command and control, Punggol Fire Station has demonstrated how technology can elevate emergency response. The incorporation of advanced technologies, from automated access control to gamified training, showcases a commitment to innovation and public safety. As the global firefighting community embraces the smart fire station concept, Punggol Fire Station's legacy remains a testament to the limitless potential of technology in safeguarding our communities.

A GLIMPSE INTO THE FUTURE OF SMART FIRE STATIONS

As we stand on the precipice of a new era in emergency response, the smart fire station vision extends beyond innovations we see today. The future promises a realm of possibilities where technology and ingenuity converge to redefine the very essence of fire stations.

Electric Emergency Vehicles

Electric emergency vehicles will become a cornerstone of sustainable firefighting efforts. These vehicles, powered by clean and efficient electric drivetrains, will not only reduce environmental impact but also offer rapid response capabilities. They will seamlessly integrate into the station's infrastructure, embracing a green and resilient approach to emergency response.

Figure 8: Rosenbauer Concept Fire Truck — electric pump ladder

Wireless Charging of Emergency Vehicles

Charging technology will evolve to offer wireless charging solutions for emergency vehicles. Stations of the future will be equipped with wireless charging pads that automatically replenish the batteries of electric emergency vehicles while they rest in their bays. This innovation ensures that response vehicles are always at peak performance and ready for action.

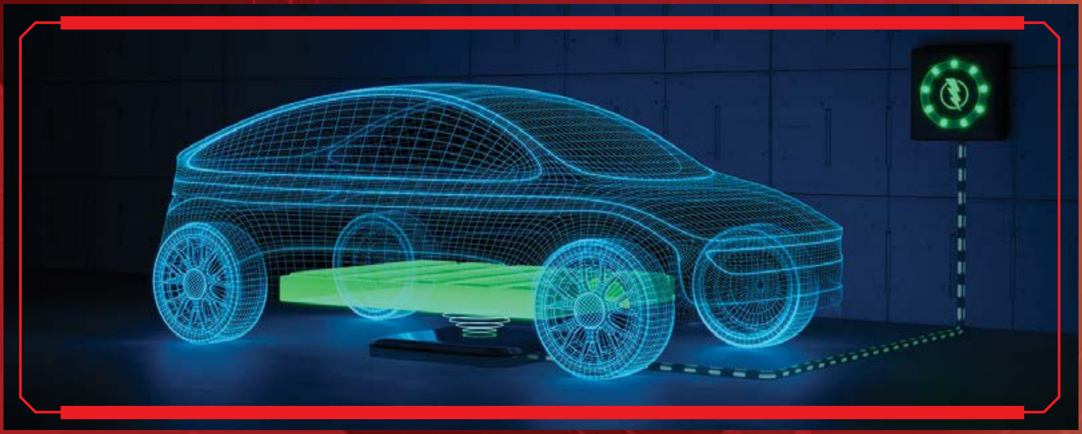

Figure 9: Illustration of wireless charging for vehicles

eHydrants for Remote Monitoring

The introduction of eHydrants will transform the way fire stations manage hydrant resources. These smart hydrants will transmit test data remotely, enabling real-time monitoring and diagnostics. Smart fire stations will have access to critical information about hydrant conditions and performance, ensuring that vital firefighting water supplies remain reliable and efficient.

eEnforcement App for Real-Time Updates

Enforcement checks and fire safety inspections will enter the digital age with the eEnforcement app. This integrated tool will empower personnel conducting checks on site with real-time updates and access to information. Inspectors will be able to efficiently record findings, generate reports, and address compliance issues on the spot. This streamlined approach to enforcement ensures that fire safety regulations are upheld promptly and comprehensively.

Smart Glasses for Medical Assessments

In a world where every second counts, smart glasses will revolutionise the medical assessment process. Doctors and healthcare professionals will remotely assess patients through the eyes of emergency responders. These smart glasses will transmit real-time audio and video, allowing medical experts to provide guidance and make critical decisions, even before arriving at the scene. This technology will significantly enhance patient care and outcomes.

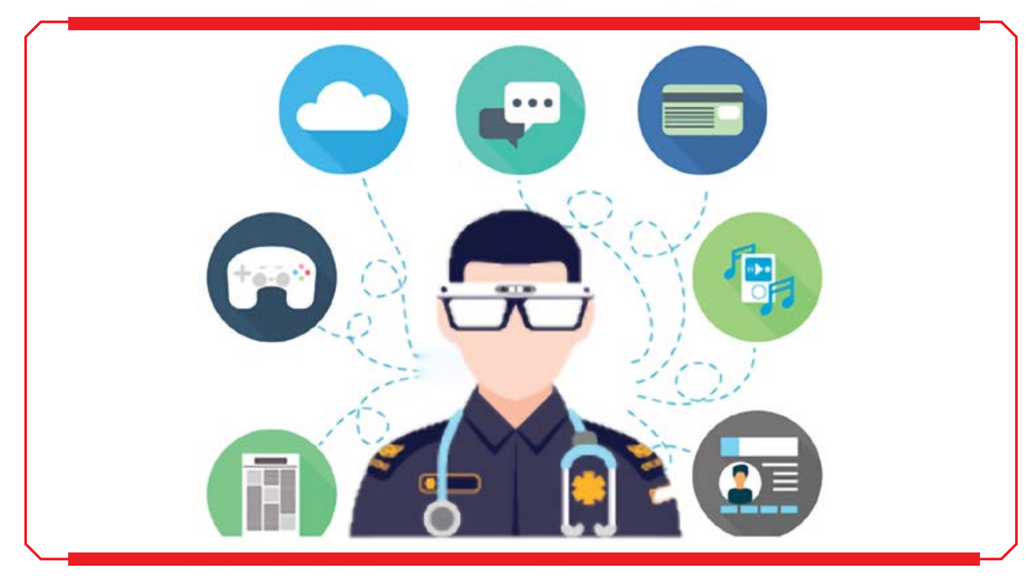

Figure 10: Illustration of smart glasses capabilities in emergency medical services

CONCLUSION

As we wrap up our exploration of the DNA of a smart fire station, it is evident that we stand on the brink of a transformative era for emergency response. Punggol Fire Station is a shining example of what is possible. The convergence of technology and tradition is reshaping the way we perceive and interact with fire stations. By embracing smart infrastructure, data-driven decision-making, enhanced mobility and connectivity, and targeted training, fire stations are becoming more efficient, safer, and better equipped to protect our communities. The future holds great promise for the smart fire station, and as technology continues to advance, so will our ability to respond to emergencies with precision and agility, as demonstrated by SCDF's first smart fire station, Punggol Fire Station.

DOES A SHORTER REST DURATION LEAD TO BETTER COGNITIVE AND PHYSIOLOGICAL PERFORMANCE AMONG SCDF HAZMAT SPECIALISTS?

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EDITORIAL PREVIEW

While work-rest cycles have been implemented based on risk assessment and illness prevention, the question remains whether existing cycles can maintain optimal cognitive and physiological performance among operationally ready officers in the Singapore Civil Defence Force (SCDF).

In this study, the rest durations of 60 hazardous materials (HazMat) specialists were systematically examined after one simulated HazMat operation and a hypothesis was made — the longer the rest duration, the better the cognitive and physiological performance. These HazMat specialists were randomly assigned to receive either 5 minutes, 15 minutes, or 25 minutes of rest after a HazMat operation. Interestingly, results suggest better vigilance with shorter rest durations and lower vigilance with longer rest durations. When looking at work-rest cycles of operations requiring physical exertion, cognitive performance should consider not only rest durations but also physiological arousal. A follow-up study exploring the relationship between physiological arousal and the cumulative fatigue of two simulated HazMat operations is ongoing.

INTRODUCTION

When SCDF HazMat specialists are deployed to handle and dispose of HazMat, they must carefully manage the depleting air levels in their breathing apparatus and the urgency of the situation. Oftentimes, these incidents are not only highly time-sensitive and dangerous, but also demand intense concentration and cognitive effort from specialists. As it is, the bulky and heavy encapsulated suits that form the necessary personal protective equipment (PPE) for HazMat operations can cause considerable heat strain, physical discomfort, and feelings of overall burden (Rubenstein, DenHartog, Deaton, Bogerd, & DeKant, 2017).

On top of that, HazMat specialists work in shifts and may be deployed to respond to incidents multiple times in a span of 24 hours. Considering that HazMat incidents can happen at any time of the day and specialists can be deployed for extended periods of time, it is vital that there is sufficient rest period between deployments. Most importantly, the rest period must be able to support HazMat specialists, such that they can still perform effectively and safely. What then, is the optimal rest duration for our HazMat specialists? Will a shorter or longer rest duration lead to better cognitive and physiological performance?

To address these questions, it is necessary to first assess exactly how fatigued HazMat specialists are after each operation and if their rest period allows them to recover well enough for their next deployment. Currently, based on existing practices, HazMat specialists are recommended to rest for 30 minutes after the first operation (i.e., 30 minutes of work). While this current work-rest cycle appears to work reasonably well for our specialists, there has not been any systematic study of cognitive and physiological states to indicate if the recommended rest period is optimal. This report marks SCDF and the Home Team Science and Technology Agency's (HTX) first attempt to scientifically understand how the current work-rest cycle of 30-minute work and 30-minute rest supports our HazMat specialists in their cognitive and physiological performance. This is achieved by administering standardised cognitive and physiological fitness assessments in regular intervals, before and after one simulated HazMat operation.

REST DURATIONS: 5 MINUTES VS 15 MINUTES VS 25 MINUTES

Based on current practices, assessments of cognitive and physiological states are administered at the 5-minute, 15-minute, or 25-minute mark into the 30-minute rest period. As HazMat specialists spend the first five minutes removing their PPE, the first measurement is taken at the 5-minute mark. And since we do not expect large differences in cognitive performance by the minute (Eddy, et al., 2015), subsequent measurements are taken at 10-minute intervals.

The Psychomotor Vigilance Task (PVT; Dinges & Powell, 1985) and Operation Span (OSPAN) task (Turner & Engle, 1989) are used to measure cognitive performance. PVT is a simple visual reaction time test that has been used to measure sustained attention and alertness in various contexts. These include studies on sleep deprivation in US Air Force pilots (Lopez, Previc, Fischer, Heitz, & Engle, 2012) and extended shift work in emergency physicians (Berastegui, Jaspar, Ghuysen, & Nyssen, 2020).

The OSPAN task is used to measure working memory (WM). WM is the ability to hold information in one's mind and mentally work with it, and is believed to be crucial in allowing us to draw connections between seemingly unrelated things (Diamond, 2013). This is particularly pertinent during HazMat operations where risks are high. It is not only necessary to keep in mind the steps and protocol to arrest the situation but also to react properly to the ever-changing environment.

Heart rate, body temperature, and oxygen saturation levels (SpO_2) are recorded to measure the physiological state. Body temperature provides a good indicator of how much heat stress the officer is under, while maximal heart rate and SpO_2 provide insights into how taxed the physical body is in that moment.

As it can be difficult to administer these cognitive and physiological assessments at the actual incident scene without being disruptive, the practical component of the HazMat Specialist Certification Test (HSCT) is used as a simulation. HSCT is a standardised test that HazMat specialists must pass to be certified operational.

With the assessments administered at regular intervals over the recommended 30-minute rest, it is hypothesised that the more rest HazMat specialists receive after the first operation, the better the cognitive and physiological performance. Specifically, it is predicted that the group of specialists receiving 25 minutes of rest would perform better in the cognitive and physiological assessments than the group receiving 5 minutes of rest.

METHODS

Participants. A total of 60 male HazMat specialists participated in this study (M_{age} = 36.63 years, SD = 4.61 years).

Materials. The cognitive measures used in this study were the PVT and OSPAN task. The PVT is a computer-based 10-minute version that runs on E-Prime 3.0 software (Psychology Software Tools, Pittsburgh, PA). In this version, a red circle would appear in the centre of the screen at random intervals. Participants were required to respond on the keyboard with their preferred hand as soon as the red circle appeared. The interstimulus intervals varied from 2000 to 10000 milliseconds. The dependent variables are the average response speed, as shown in Equation (1), and the number of lapses. Lapses are defined as reaction time that is more than 500 milliseconds. Both response speed and lapses are recommended as the most sensitive outcome measures for assessing fatigue and alertness with the PVT (Basner & Dinges, 2011).

$$\frac{1}{\text{Reaction Time}} \times 1000 \qquad (1)$$

For OSPAN, participants were required to solve a series of mathematics questions and remember a series of alphabetical letters. At the start of each trial, a mathematics question was shown to the participants. They must solve the question by answering “True” or “False”, after which an alphabetical letter was shown (see Figure 1). Different alphabetical letters were shown each time. After solving a series of mathematics questions, participants were asked to recall the alphabetical letters in the order presented. The dependent variables of OSPAN were recall duration (in milliseconds) and recall accuracy. Recall duration is defined as time taken to recall all the alphabets, while recall accuracy is the correctness of the letters recalled in order. A shorter recall duration and high recall accuracy rate would indicate better performance on the OSPAN.

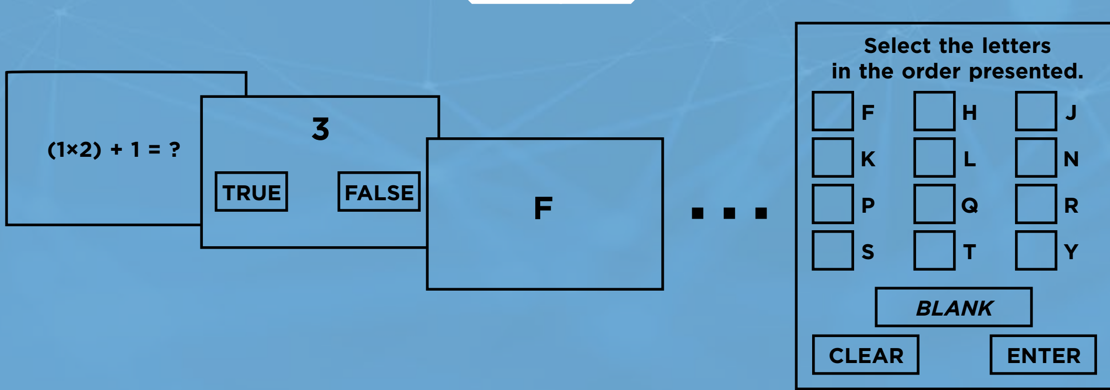

Figure 1. Example of the OSPAN task. Figure was recreated from E-Prime 3.0.

For physiological measures, participants' body temperature was measured via an ear thermometer while an oximeter was used to measure both the maximal heart rate and SpO_2. These physiological measurements were taken within one minute.

Procedure. Participants were briefed about the procedure and assured that their responses would be anonymous. The 60 HazMat specialists were randomly split into three different groups, each receiving a different amount of rest after the first HazMat operation. Group 1 received five minutes of rest after the HazMat operation, Group 2 received 15 minutes of rest, and Group 3 received 25 minutes of rest. Figure 2 outlines the study design and procedure.

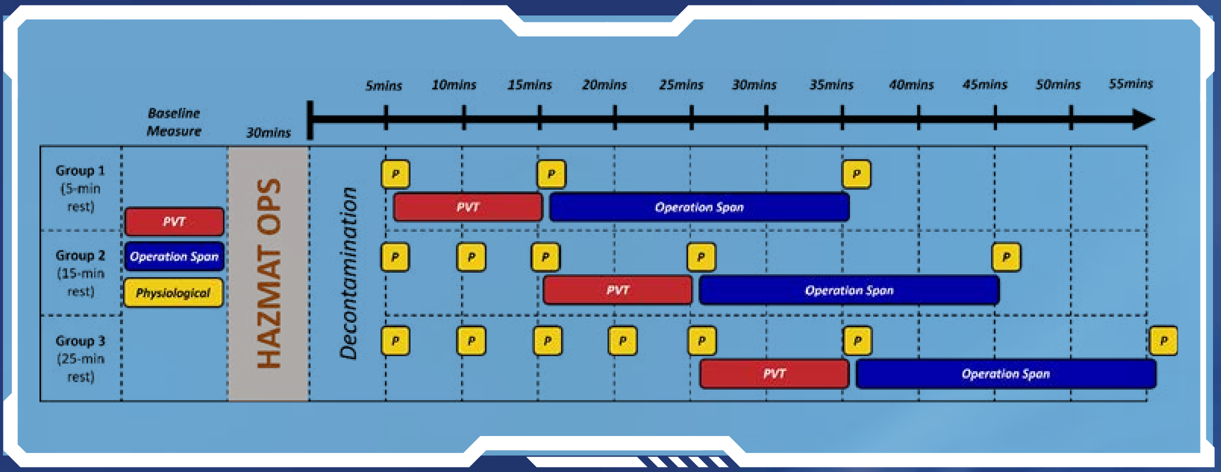

Figure 2. Study design and procedure. 'P' refers to the physiological measures of maximal heart rate, core temperature, and oxygen saturation levels. 'HAZMAT OPS' refers to HazMat Operation.

Baseline measurements of cognitive performance and physiological markers were taken prior to the HazMat operation. In this study, the HazMat operation comprised four HSCT tasks and a 500-meter brisk walk. For this study, HazMat specialists wore the Encapsulated Vapour Protective Level A PPE during the HazMat operation.

After the HazMat operation, the specialists underwent a 5-minute decontamination process where they cleaned themselves and removed their suits. This decontamination process is a necessary part of every HazMat operation, as it ensures that no hazardous material is brought outside the risk area. As it is not a strenuous activity, the 5-minute decontamination process is considered as a rest period.

Following the decontamination process, assessments of cognitive performance and physiological fitness were administered to the specialists in Group 1. For Group 2, who received 15 minutes of rest, the same assessment was administered 10 minutes after the decontamination process. For Group 3, who received 25 minutes of rest, the same assessment was administered 20 minutes after the decontamination process.

While physical exertion was not expected to be high, as part of the safety protocol, measurements of physiological fitness were also taken at 5-minute intervals whenever a cognitive assessment was not being administered. This is to minimise interruptions during completion of cognitive tasks and to ensure that body temperature, heart rate, and SpO_2 readings do not exceed established thresholds for trial discontinuation.

RESULTS AND DISCUSSION

Table 1 shows an overview of cognitive and physiological data collected from the three different groups. The mean age of Group 1, 2 and 3 is 36.90 years (*SD* = 4.05 years), 36.60 years (*SD* = 3.59 years) and 36.40 years (*SD* = 6.06 years) respectively.

Table 1. Overview of cognitive and physiological measurements

	Group 1 (5 minutes rest) *N* = 20		Group 2 (15 minutes rest) *N* = 20		Group 3 (25 minutes rest) *N* = 20	
	Pre-Ops	Post-Ops	Pre-Ops	Post-Ops	Pre-Ops	Post-Ops
PVT Response Speed	3.04 (0.79)	3.06 (0.69)	2.95 (0.79)	2.93 (0.77)	2.94 (0.74)	2.87 (0.80)
Number of PVT Lapses	9.70 (19.74)	6.10 (6.35)	9.30 (17.17)	9.30 (11.61)	9.15 (15.80)	12.10 (15.68)
OSPAN Recall Duration (ms)	5942.98 (1461.45)	5641.45 (959.55)	6612.12 (2892.86)	6140.40 (1709.20)	6125.41 (1154.53)	5752.42 (1305.82)
OSPAN Recall Accuracy	0.66 (0.29)	0.78 (0.18)	0.72 (0.29)	0.81 (0.16)	0.67 (0.24)	0.70 (0.28)
Heart Rate (bpm)	74.70 (12.07)	131.10 (20.75)	77.45 (16.42)	88.75 (14.93)	74.85 (13.14)	84.60 (9.93)
SpO_2 (%)	97.90 (0.64)	97.35 (0.67)	97.55 (1.43)	97.85 (0.49)	97.65 (0.59)	97.95 (0.39)
Body Temperature (°C)	36.76 (0.29)	37.52 (0.43)	36.55 (0.50)	36.79 (0.32)	36.32 (0.53)	36.57 (0.40)

Note: Standard deviations are indicated in parentheses.

As for cognitive measures, a significant difference was observed pre- and post-operation only for the OSPAN recall accuracy, $F(1, 57) = 11.29$, $p = .001$. The HazMat specialists appeared to be better at tapping into their WM after one operation, regardless of how long they rested after the first operation.

As for physiological measures, only the heart rate yielded enough variation for analysis. There was a significant difference between pre- and post-operation, $F(1, 57) = 164.36$, $p < .001$, and also a significant difference between groups, $F(2, 57) = 19.29$, $p < .001$. Specifically, post-operation comparisons showed significant increase in heart rate between Group 1 and Group 2 ($p < .001$), and between Group 1 and Group 3 ($p < .001$).

Plotting out the heart rates across the experiment (Figure 3), it was noted that they were very close to baseline from the 15-minute mark onwards. Interestingly, while statistically not significant, there was a difference in PVT lapse between groups that lined up with our observations of heart rates across the experiment (Figure 4). Mostly, while Group 1 experienced a decrease in PVT lapse five minutes after the operation (i.e., increased vigilance) and Group 3 experienced an increase in PVT lapse 25 minutes after the operation (i.e., decreased vigilance), Group 2 saw no changes in lapses. This suggests that 15 minutes can be an optimal rest duration, as there is little difference in heart rate and vigilance pre- and post-operation. More data will be required to see if this finding still holds.

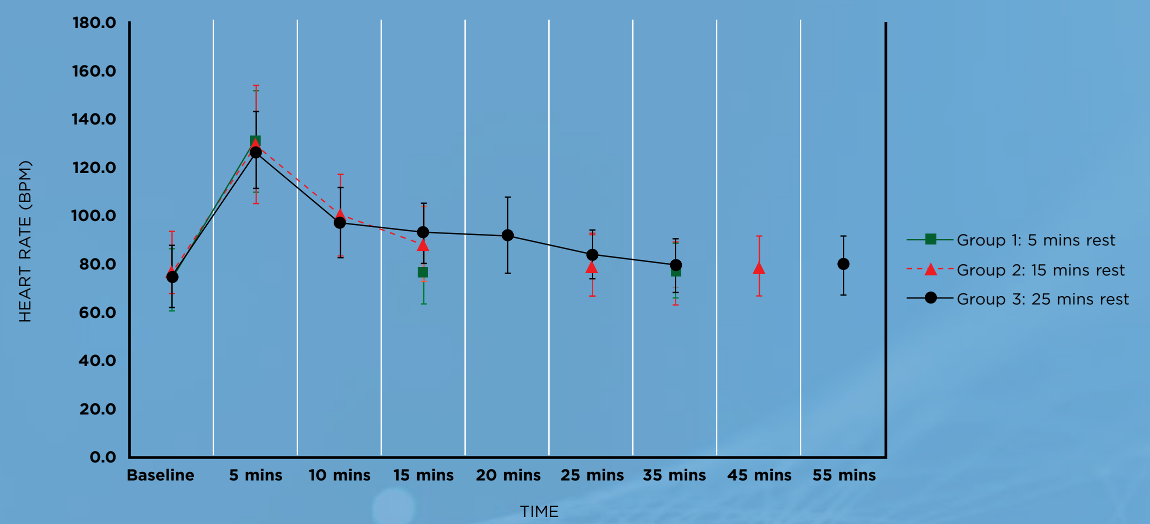

Figure 3. Participants' heart rate per minute, pre- and post-operation

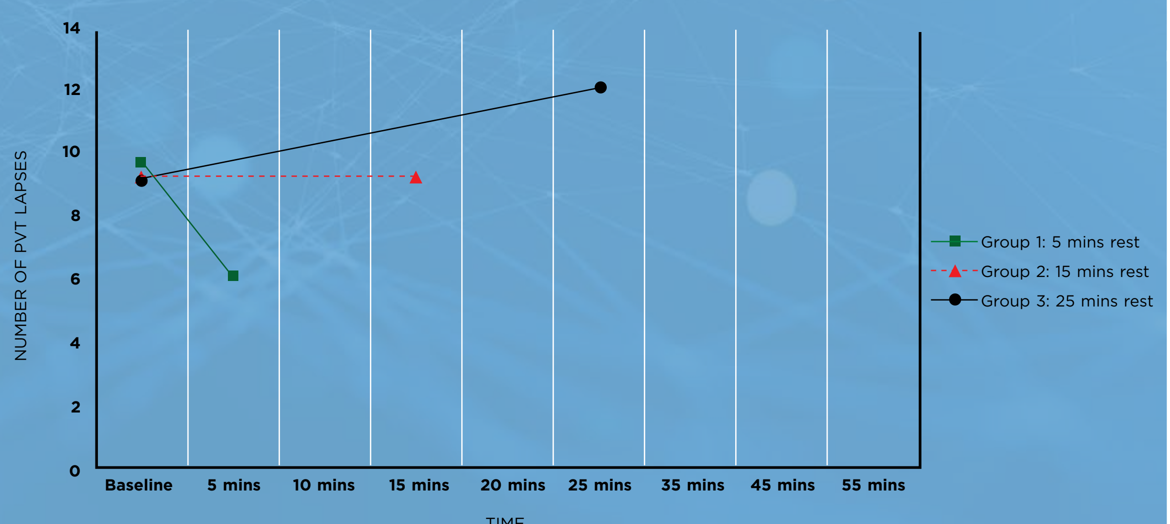

Figure 4. Number of PVT lapses pre- and post-operation

The effects of arousal induced by physical activity on cognitive performance are also likely present in this study. Group 1, with the least rest duration, was better at reducing PVT lapses post-operation than Group 2 and Group 3. This suggests that the higher the arousal, the better the cognitive performance. However, there was no difference in WM between groups. All groups were better at tapping into their WM, regardless of rest duration. If higher arousal was linked to better cognitive performance, a shorter rest duration should increase OSPAN performance (i.e., with the highest arousal levels). It is possible that arousal affects cognitive functions differently. Specifically, arousal may affect attention and vigilance in an inverted-U shape curve, where higher arousal leads to increased attention and vigilance (González-Fernández et al., 2021) but too much arousal can be detrimental (Yerkes & Dodson, 1908; McMorris et al., 2011). However, this may not be the case for executive functions like WM, where an acute bout of exercise was found to generally improve Stroop task performance (Sibley, et al., 2006).

There are a few key limitations in this study. Sample size was constrained by operational demands. Also considering the discomfort of wearing bulky PPE, physical exertion measurements were chosen where it was least uncomfortable for the officers. This meant that chest strap heart rate monitors, which could provide a more accurate reading of heart rate and heart rate variability, were not used. While heart rate readings from an oximeter provided good insight into heart rate recovery duration, heart rate variability would be valuable in understanding how the mental and physical demands of a HazMat operation affect rest and recovery rate. Moreover, findings obtained from this study is only applicable to the first HazMat operation. Cumulative fatigue may set in after completing the second HazMat operation, leading to significantly different rest durations.

A follow-up study is ongoing to examine the optimal work-rest cycle for two HazMat operations at 15 minutes, 30 minutes, and 45 minutes of rest. This study is a collaboration between HTX, SCDF, and Republic Polytechnic, and is estimated to be completed by the third quarter of 2024.

Does a shorter rest duration lead to better cognitive and physiological performance among HazMat specialists? Based on the results reported here, there is some indication that SCDF's HazMat specialists can achieve baseline cognitive and physiological performance earlier than expected. More work is required, however, before we can tell if our current set of findings is significant and if it holds when we include a second HazMat operation.

ACKNOWLEDGEMENT

This study was supported by SCDF. We thank all SCDF HazMat specialists who participated in this study and SCDF staff who assisted during the data collection phase. We also want to thank our colleagues at HTX for their helpful feedback and support.

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FATIGUE AND FIREGROUND READINESS: ENHANCING FIREFIGHTER SAFETY

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EDITORIAL PREVIEW

Fatigue induced during occupational tasks and on-duty exercise can negatively impact multiple aspects of fireground performance including work efficiency and risk of injury. This article explores these factors, describes the importance of achieving adequate levels of physical fitness, and provides evidence-based recommendations to enhance firefighter readiness and safety.

INTRODUCTION

Firefighting is composed of strenuous occupational tasks that induce fatigue, negatively impact work rate and metabolic demand, and increase risk of injury. Thus, firefighters must possess adequate levels of physical fitness to counter these deleterious effects. Although regular participation in an exercise program elicits beneficial physiological adaptations, acute fatigue induced during on-duty exercise has a negative effect on firefighter physical ability and safety. This article defines fatigue, describes the impact of occupational and exercise-induced fatigue on performance and safety, and provides practical countermeasures.

FATIGUE

On the fireground, fatigue is observed when a firefighter's work rate is reduced or maintained with a concurrent increase in physiological demand (e.g., increased heart rate or air consumption). Beyond reduced work output, fatigue is problematic as it is associated with an increased risk of musculoskeletal injuries (Kong et al., 2013). Specifically, injuries associated with overexertion/strain and slip/trip/ fall mechanisms account for nearly half of fireground injuries (Campbell & Hall, 2022) and result in significant fiscal costs and lost duty time (Butry et al., 2019).

OCCUPATIONAL PERFORMANCE — LIMITING FACTORS

There are several occupational factors that induce fatigue on the fireground, including load carriage, respiratory demands, and work cycles. Regarding load carriage, firefighters don personal protective equipment (PPE) to protect against high ambient temperatures. PPE includes boots, bunker coat and pants, gloves, hood, helmet, and self-contained breathing apparatus (SCBA), weighing approximately 23 kg. Research indicates that the mass of PPE reduces firefighter recruits' work rate by 38% (Lesniak et al., 2020). Interestingly, Taylor and colleagues (2012) noted that the mass of PPE increased the relative metabolic demand by 47% during a simple walking task (Figure 1). In addition, the SCBA utilizes a positive pressure system. This system has been shown to decrease firefighters' aerobic capacity by 13% due to a reduced ability to exhale against positive pressure (Eves et al., 2005). Thus, load carriage increases the metabolic demand of performing tasks, while the SCBA's positive pressure reduces firefighters' aerobic capacity. Collectively, these factors reduce firefighters' residual capacity to perform work (Figure 1) and demonstrate the importance of increasing the residual capacity via enhanced work capacity and fatigue tolerance.

Figure 1. Increasing firefighters' physical fitness enhances work capacity and attenuates the negative impact of load carriage and the positive-pressure SCBA. VO_2max: Maximal rate of oxygen uptake

Firefighters' work cycles are often dependent on the working duration of air cylinders (e.g., 30, 45, 60 min). When a cylinder is depleted, the firefighter may exchange it for a full cylinder and perform a second work cycle. The United States' National Fire Protection Association (1584, NFPA, 2008) recommends firefighters recover in a rehabilitation station after the second cylinder. Research has evaluated the impact of multiple work cycles on work and physiological outcomes and risk of injury. Specifically, Kesler and coworkers (2018) demonstrated that 37% of firefighters were not able to complete two work cycles during a simulated fireground exercise. On average, these firefighters possessed greater body mass and body mass index (BMI), and lower relative aerobic capacity compared to their more productive counterparts (Kesler et al., 2018), demonstrating the importance of weight management and aerobic fitness for work output. However, despite a five-minute inter-cycle recovery period, work output was significantly reduced (20%) during the second work cycle among firefighters who were able to complete two work cycles. Physiologically, firefighters' average and peak heart rates were about 80% and 95% of the age-predicted maximum, respectively, regardless of performing one or two work cycles, demonstrating high levels of physiological strain. Importantly, air consumption efficiency was reduced during the second work cycle as firefighters consumed the same amount of air yet performed less work (Kesler et al., 2018). In short, although a five-minute recovery period yielded slightly better physiological and work output outcomes compared to no inter-cycle recovery, most firefighters require longer recovery periods to restore physiological and occupational performance outcomes (Kesler et al., 2018).

OCCUPATIONAL FACTORS AND RISK OF INJURY

Occupational tasks and PPE have deleterious effects on neuromuscular function, which may be associated with risk of injury. Specifically, physical exertion-induced fatigue is associated with reduced static, dynamic, and functional balance outcomes among firefighters (Games et al., 2020; Hur et al., 2013). Furthermore, PPE has been shown to independently reduce firefighters' dynamic balance (Brown et al., 2019) and negatively impact gait parameters (Rosengren et al., 2014). Indeed, in a literature review, Kong and colleagues (2013) have concluded that fatigue and impaired balance are factors that can increase the risk of slip/trip/fall injuries.

Exercise-Induced Fatigue and Occupational Performance

Maintaining physical fitness is critical to enhance firefighter readiness. Thus, firefighters must exercise on and off duty. In fact, the National Fire Protection Association recommends that firefighters are provided with one hour of on-duty time to perform exercise (NFPA 1583, 2015). However, there is an inherent risk that on-duty exercise might be interrupted by an emergency response, requiring firefighters to perform strenuous occupational tasks in a fatigued state. Consequently, this could reduce occupational performance and increase risk of injury. The University of Kentucky's First Responder Research Laboratory has conducted a series of studies to evaluate these risks. Specifically, the goal is to identify appropriate types and intensities of on-duty exercise to maximize functional adaptations while minimizing risks.

Specifically, Dennison and coworkers (2012) observed a 9.6% decrement in occupational work rate during a simulated fireground test performed 10 minutes following a bout of circuit training exercise among firefighters who had moderate levels of resistance training experience. Despite the decreased work rate, 100% of these firefighters were able to complete the tasks. To put these findings in context, a second cohort of sedentary firefighters was asked to complete the simulated fireground test without performing prior exercise, of which 16% were unable to complete the occupational tasks. Further, the average work rate of the fit but fatigued firefighters was still greater than 70% of the sedentary (and non-fatigued) cohort (Dennison et al., 2012). Similarly, Mason and colleagues (2023) evaluated the impact of high-intensity resistance training on subsequent occupational performance. The researchers observed a dramatic decrease in firefighters' work efficiency and work rate, and an increase in air consumption (Figure 2). As a group, these metrics returned to baseline one-hour post-exercise; however, individual analysis indicated that the work rate of 43% of firefighters was still significantly reduced compared to baseline performance. These results suggest that recovery rates vary among firefighters. Collectively, these findings and long-term training interventions demonstrate that performing regular on-duty exercise is beneficial for occupational readiness (Pawlak et al., 2015), despite the risk of responding to an emergency in a fatigued state. However, firefighters should consider performing on-duty resistance training during low call volume to reduce the likelihood of emergency response and use discretion regarding appropriate on-duty training loads (i.e., intensity and volume).

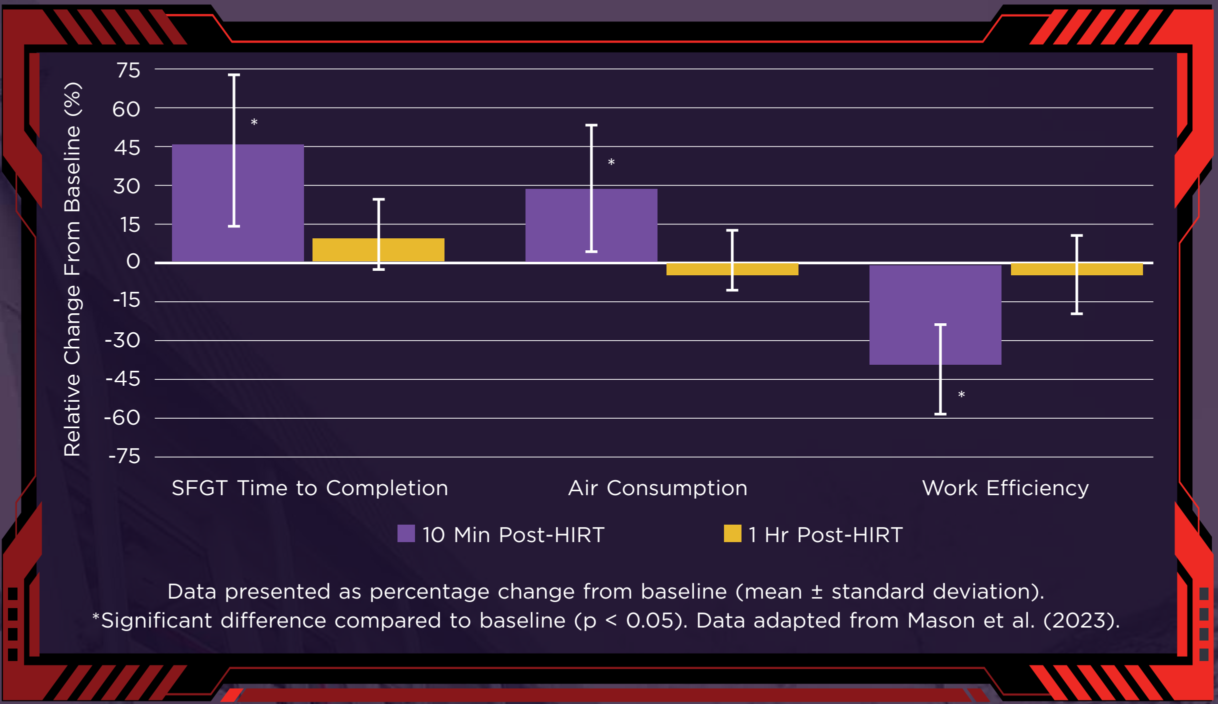

Figure 2. Relative change in simulated fireground test completion time (SFGT), air consumption, and work efficiency at 10 and 60 minutes following high-intensity resistance training (HIRT) compared to baseline in structural firefighters

Exercise Fatigue and Risk of Injury

There is limited research evaluating the impact of exercise-induced fatigue on risk of injury among firefighters. However, Games et al. (2020) found that treadmill walking in a heated room decreased firefighters' functional balance more than standing alone in a heated room or exercising at cooler ambient temperature. This indicates that there is a combined effect of ambient heat and physical activity on functional balance. Among athletic populations, research has indicated that localized muscular fatigue and prior aerobic endurance exercise negatively impact neuromuscular control (Zemková, 2022). Future research is needed to further elucidate the impact of various types of exercise on subsequent neuromuscular function to provide evidence-based recommendations regarding appropriate on-duty exercise parameters.

Fatigue Countermeasures

To optimize occupational readiness and fatigue tolerance, it is important to identify biomotor abilities that are associated with occupational demands. Research indicates that a host of biomotor abilities, spanning the fitness continuum, are necessary to perform occupational tasks safely and effectively (Figure 3; Davis et al., 1982; Langford et al., In Press; Michaelides et al., 2011; Norris et al., 2021; Rhea et al., 2004; Sheaf et al., 2010; Williams-Bell et al., 2009). For instance, strength and lean body mass are important to lift heavy equipment and rescue victims, especially while wearing 23 kg of PPE. Aerobic endurance is important to perform longer duration, lower intensity tasks such as ascending stairs and carrying equipment. Anaerobic endurance, specifically ventilatory threshold, appears to be important for air consumption and work efficiency (Langford et al., In press; Norris et al., 2022; Windisch et al., 2017). The ventilatory threshold demarcates the work rate for which ventilatory rate increases disproportionately relative to oxygen consumption (Whipp et al., 1984), thus requiring greater air consumption to maintain a given work rate. Air consumption efficiency is paramount for safety given that an air cylinder contains a finite volume of air and serves as a firefighter's lifeline in austere conditions. Thus, high-intensity interval training with 1:3 to 1:5 work-to-rest ratios (Herda & Cramer, 2015) may enhance firefighters' ventilatory threshold while performing occupational tasks. In an applied study, Norris and coworkers (2021) estimated that a 10% improvement in firefighters' relative lower body strength and aerobic endurance would yield 2.6 minutes of additional air per cylinder, demonstrating the potential impact of physical fitness on air consumption and work efficiency.

To optimize these biomotor abilities, it is important that fire departments utilize qualified tactical strength and conditioning practitioners to develop structured, periodized (e.g., linear, nonlinear, block) conditioning programs that are scaled based on firefighters' fitness. A review of exercise training programmes designed for firefighters can be found elsewhere (Abel et al., 2015). In addition to enhancing firefighters' fatigue tolerance, the physical demands of each fireground will vary and departments need to allow for adequate recovery between work cycles to enhance work output and reduce risk of injury.

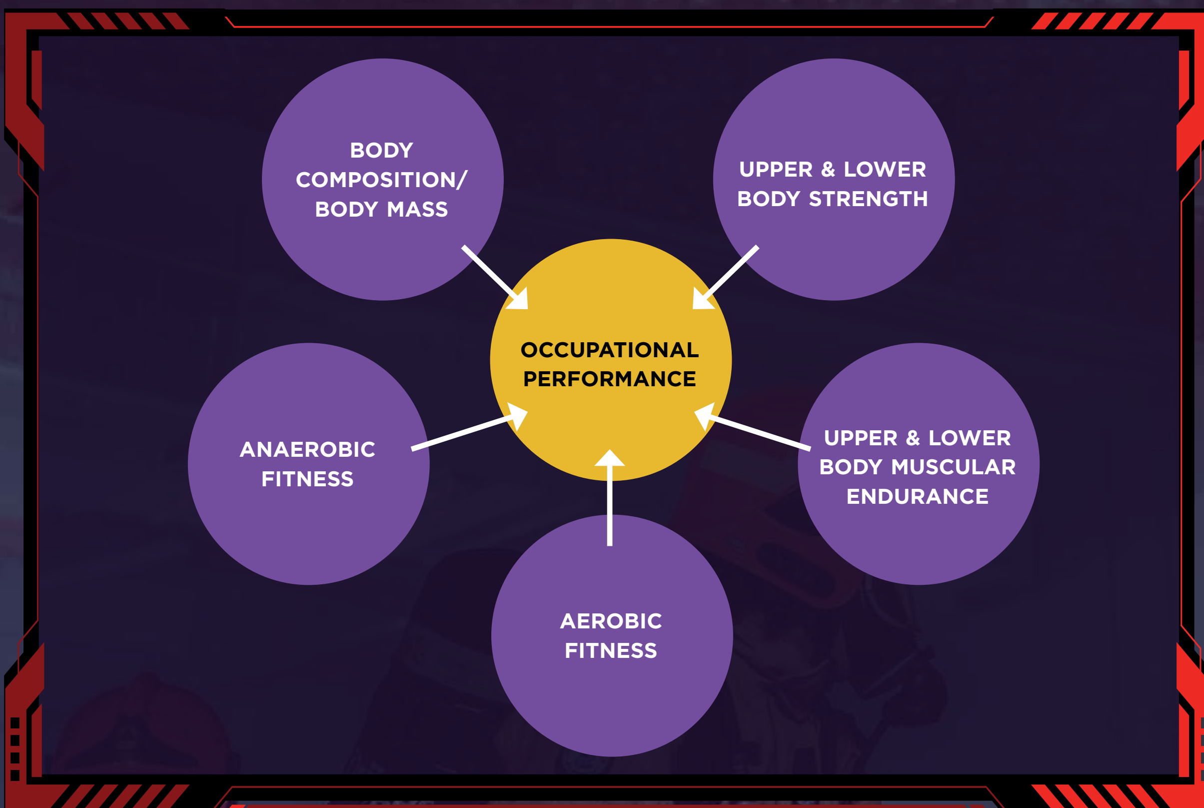

Figure 3. Biomotor abilities associated with firefighter occupational performance

CONCLUSION

Firefighting is an inherently dangerous occupation that requires adequate levels of physical fitness to optimize occupational readiness and safety. Fire departments are encouraged to promote on-duty exercise during low call volume and utilize tactical strength and conditioning practitioners to implement evidence-based practices for enhanced readiness and safety.

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PERSONAL COOLING DEVICES TO ENHANCE EMERGENCY RESPONDERS' THERMAL RESILIENCE

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The impact of climate change and the high-level humidity in Singapore will inevitably induce greater physiological strain on the general population and even more so for the local emergency responders who carry heavy loads such as firefighting and rescue equipment and don thick personal protective equipment (PPE) which exacerbate heat stress.

Thus, leveraging on technologies such as personal cooling devices during training and operations would provide early intervention to effectively attenuate rising core body temperature and delay the onset of heat stress. This article discusses ongoing evaluation and future R&D efforts by HTX and SCDF to develop a bespoke personal cooling device for SCDF emergency responders.

PERSONAL COOLING TECHNOLOGY IS IMPORTANT FOR SCDF EMERGENCY RESPONDERS

Due to their nature of work, SCDF emergency responders experience high thermal stress during training and operations. The breathing apparatus they carry and the PPE they don amount to over 22kg, not to mention being exposed to blazes with elevated temperatures of as high as 260°C.[1] On the other hand, Emergency Medical Service crews were covered head-to-toe in full protective garb

1 'Firefighter Radios may fail during high-temp fires', www.nist.gov, 2006.

during the Covid-19 pandemic response and specialists from the Hazardous Material (HazMat) team wear enclosed suits to shield them from toxic and corrosive chemical spills. Such heat stress can have negative impacts on their safety, productivity and health. They may experience painful muscle cramps, dizziness and other symptoms when the body fails to get rid of excess heat it generates and, in extreme cases, this can result in heat stroke potentially leading to death.

An effective way to alleviate the rise in body temperature is to introduce active cooling for enhanced heat removal. If the training/operations were tied to a fixed location, air-conditioning (for closed spaces) or forced ventilation (for open spaces) might provide satisfactory cooling for officers. However, this is not the case for emergency responders who may need to move around and perform duties on site. Personal cooling devices are therefore critically important in removing body heat and improving thermal comfort.

DIFFERENT TYPES OF PERSONAL COOLING DEVICE TECHNOLOGY

Personal cooling devices can be classified to the following types based on their working principles.[2,3]

- **Thermoelectric cooling:** a thermoelectric module (TEM) is a battery-powered solid-state active heat pump which transfers heat from one side of the device, in contact with the skin, to the other side.
- **Fan-based ventilation:** heat is removed via enhanced convection and sweat evaporation when air is driven by an electrically powered fan to flow across the human skin.
- **Phase-changed material (PCM):** solid material which absorbs heat from the surroundings as it melts during phase change while maintaining a constant temperature.
- **Water-vapour absorption:** solid desiccant packet, such as silicone gel or hydrogel, which facilitates heat removal via sweat evaporation by actively absorbing water vapour from the surroundings and keeping the microclimate dry.
- **Water evaporation:** a vest made of highly absorbent fabric is soaked in cool water before being worn by officers. When water evaporates from the vest, it absorbs heat from the surroundings and provides a cooling effect to the skin.
- **Circulating fluid system:** a chilled coolant is pumped to flow over the body, during which body heat is transferred to the coolant. The fluid needs to be cooled down externally by vapour compression or thermoelectric cooling before it is circulated back.

HTX and SCDF had selected and evaluated four personal cooling devices based on the first four principles mentioned above as they were deemed to be suitable for deployment in the front line among emergency responders. The other two types of cooling devices were not evaluated (i.e. water evaporation and circulating fluid system) as they posed logistical constraints to prepare and deploy them in the operational ground. The evaluation was conducted in both the controlled lab environment and field conditions with relevant scientific equipment like climatic chamber, 'Newton' thermal manikin, Nexus-16 BioTracer+ system, and iButton temperature sensors.

2 Yazdi and Sheikhzadeh. Journal of The Textile Institute (2014), 105(12): 1231-1250.

3 Sarkar and Kothari. Indian Journal of Fibre & Textile Research (2014), 39: 450-458.

Figure 1. Examples of personal cooling devices. (A) A TEM-based mini-cooling unit, (B) A fan-based cooling vest, (C) A PCM-based cooling vest, (D) A water-vapour absorption composite film, (E) A water evaporative cooling vest, (F) A water circulating cooling vest

CURRENT COOLING DEVICES — A MIXED BAG

Table 1 lists the efficiency of the different personal cooling systems that were evaluated. The evaluation results show that each cooling device has its own advantages and limitations.

Table 1. Efficiency of personal cooling systems

	Operating duration	Easy don/doff	Encapsulated suit	Working environment	Working mechanism
Criteria	>2h	Worn over PPE	Effective cooling effect	Effective at temperature >35°C	Able to remove sweat/moisture
TEM	X	√	√	√	X
PCM	√	X	√	√	X
Fan	√	X	X	X	√
Desiccant	√	X	√	√	√

√ denotes 'efficient', x denotes 'inefficient'

Thermoelectric Cooling

As shown in Figure 2A, with an ambient temperature of 35°C, the TEM-based cooling device can reduce the temperature of the contact area (body back) to as low as 17–20°C. However, the battery life is not long enough for operations lasting more than 2 hours, which poses a logistical issue for major incidents involving long-drawn-out firefighting. In addition, the TEM, when placed over the clothing renders cooling ineffective in the case of thick PPEs that pose a high resistance to heat removal.

Phase-Changed Material

The PCM-based cooling vest is capable of cooling the whole torso area, and the cooling effect is less dependent on the ambient air. Therefore, it can be used in hot and humid environments. It is also interesting to know that, in a hot environment, the cooling effect from PCM lasts longer under a uniform with higher thermal resistance (e.g. the thick bunkersuit as shown in Figure 2B). This is mainly because PCM receives slower heat transfer from the ambient due to the additional resistance brought by the thick uniform, resulting in a longer cooling duration. However, the cooling packs are usually heavy, and it cannot remove the moisture that inhibits sweat evaporation.

Fan-Based Ventilation

We can see from Figure 2C that the introduction of the fan-cooling vest can overcome thermal insulation of the bunker gear for the parts it covers, namely back, shoulder, chest and stomach. This results in easier heat removal from the body and provides better thermal comfort to officers. However, the vest relies on access to ambient air to enable cooling. Thus, heat transfer and sweat evaporation is weakened or even reversed, rendering overall cooling ineffective. when the ambient air is hot and humid or inaccessible as is the case for encapsulated suits. This is a significant limitation given the extreme conditions the firefighters operate in.

Desiccant (Water-Vapour Absorption)

Conversely, cooling packs with desiccants can effectively absorb water vapour. As shown in Figure 2D, the evaporative resistance of a medical PPE can be significantly lowered after introduction of an absorbent film. This is a desirable effect as it promotes higher amounts of sweat evaporation from the wearer's body to reduce heat strain. However, these packs fail to lower skin temperature directly. As such, cooling effects would be marginal if any, especially given the potentially heavy sweat rate experienced by firefighters.

PERSONAL COOLING DEVICES FOR THE FUTURE

The findings gathered thus far underline the need for developing a hybrid cooling strategy leveraging on two or more complementary technologies. For this purpose, potential candidates will be iteratively tested, designed and prototyped first in the lab and then in the field to ensure that both usability and cooling performance requirements are met. A key research direction will be to raise the cooling efficiency of the devices, and a hybrid cooling strategy will be central to this effort.

An approach that holds promise will be to enable cooling in hot and humid environments by integrating fan-based technology with TEM and water-vapour absorption so that air drawn in by the fan can be pre-cooled by TEM and pre-dried by desiccant before it is blown to the human skin.

Alternatively, PCM and water-vapour absorption may function synergistically where a subset of PCM packets in a cooling vest can be replaced by hydrogel packets to reduce the overall weight without compromising on the overall cooling performance.

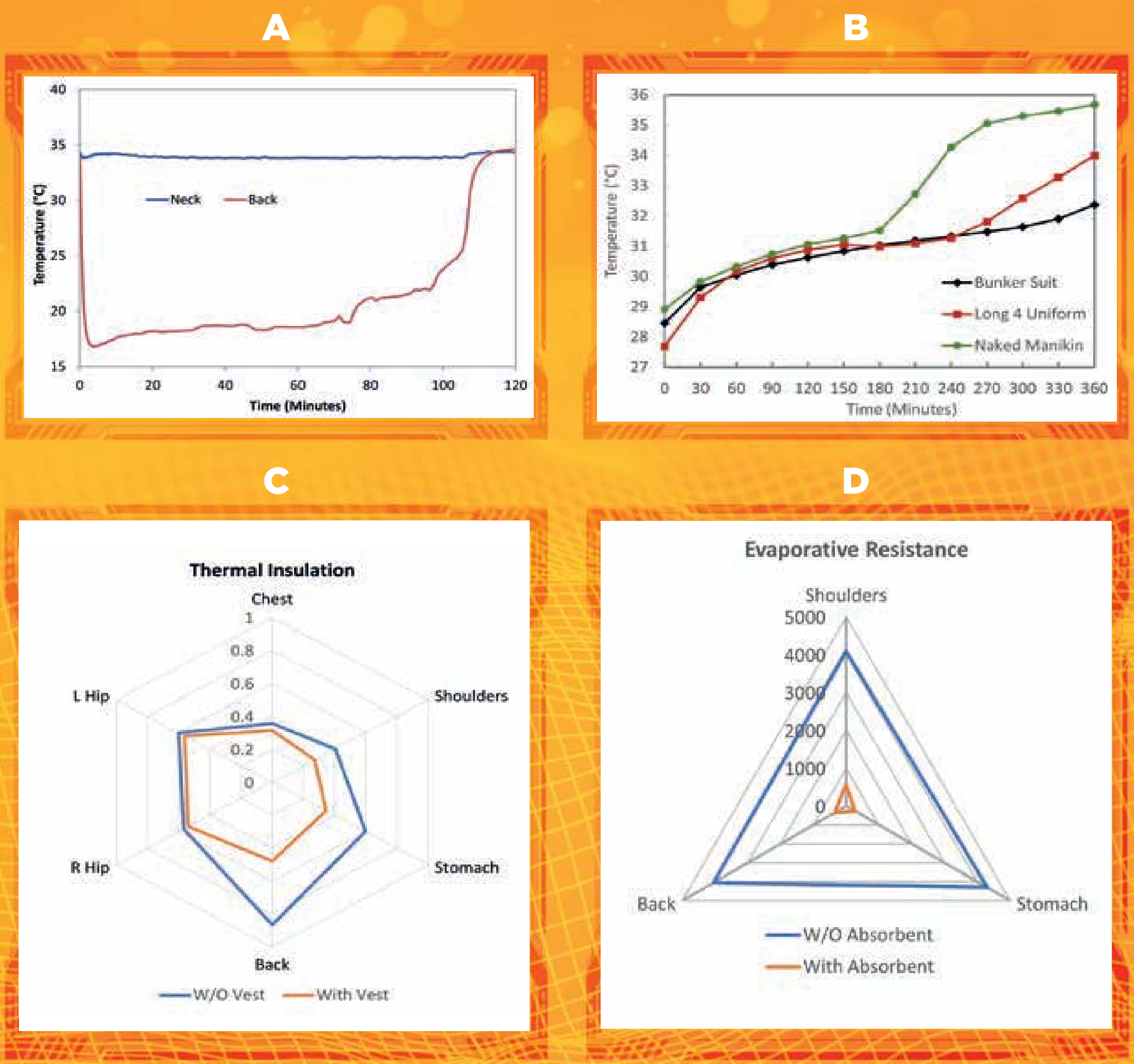

Figure 2. Cooling performance of various devices. (A) and (B) show the temperature evolution with a TEM cooling device and PCM cooling vest, respectively. (C) shows the thermal insulation the bunker gear with or without the fan-based cooling vest, while (D) shows the evaporative resistance of a medical PPE with or without the absorbent.[4] The results were measured using the Newton thermal manikin.

4 Yang et al. Small 2022, 2107636.

Rapid progress in material science may produce new phase change materials which are lighter and operate over a longer duration at lower phase-change temperatures yet demand mild air-conditioned environments for phase reversal. Additionally, more energy-efficient and greener thermoelectric modules which consume less energy may also be a reality in the future. Lastly, advancements in AI and big data offer the opportunity to develop more intelligent and customized cooling devices, for example in the areas of battery management and ergonomic design of cooling devices optimized for our local firefighters.

With the threat of climate change looming over our heads, it seems ever more urgent to develop effective and efficient heat-mitigation technologies, and personal cooling devices are critically important in enhancing the sustainment and performance of our firefighters. Our aim is to establish a library of personal cooling devices, evaluate their performances, understand their merits and limitations and develop a bespoke cooling technology for SCDF emergency responders.

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ARTICLES BY SCDF'S INTERNATIONAL PARTNERS

This section displays three articles that were authored by SCDF's international partners with the intent to share knowledge and experiences to the international emergency response fraternity.

Strength in Numbers, Power in Unity: Capacitating Community Emergency Responders from Barangays to the City

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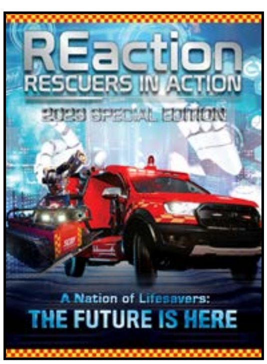

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