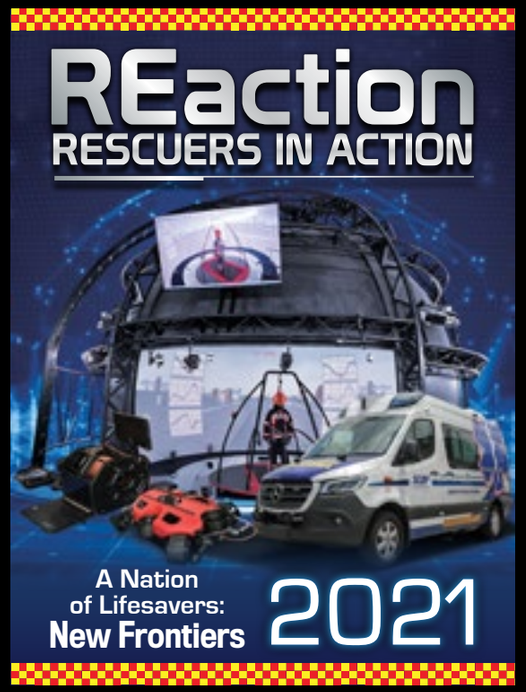
REaction

RESCUERS IN ACTION

A Nation of Lifesavers:
New Frontiers

2021



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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COMMISSIONER'S FOREWORD

2020 and 2021 were challenging years for the Singapore Civil Defence Force (SCDF), Singapore and the world due to the successive waves of COVID-19. The impact of the pandemic has been unprecedented and continues to present challenges on numerous fronts as countries find their way forward in living with COVID-19. Despite these challenges, SCDF had courageously stepped forward as One Public Service in its fight against the pandemic in various ways such as supporting temperature screening of arriving passengers at Changi Airport, conducting swab tests for persons under quarantine, and transporting COVID-19 persons to hospitals. Along the way, SCDF ensured that its safe management measures were promptly implemented to ensure that there is no disruption in the provision of its round-the-clock fire, rescue, and emergency medical services response despite surges in demand.

Notwithstanding these challenges, SCDF stayed focused on its transformation journey — believing firmly that the efforts invested will position the Force well to navigate the challenges ahead, post-COVID-19. Notably, SCDF had pivoted well on training and community engagement aspects through digital means, forging its way forward through virtual platforms.

This edition of REaction illustrates SCDF's endeavour to achieve its 2025 vision: A Nation of Lifesavers — New Frontiers. Spearheading this year's Workplan Seminar was the rollout of SCDF's next-generation command vehicles and ambulances. The new command vehicles incorporate an advanced vehicle management system that enhances situational awareness by canvassing data from multiple sources into visual dashboards for SCDF commanders to make mission-critical decisions.

The Generation-7 (Gen-7) ambulance is an SCDF in-house innovation which comes fitted with a built-in automated decontamination system, and uses solar power and intelligent charging to increase its operational readiness especially during off-site deployments. Coupled with the Gen-7 ambulance, the newly adopted digital platform called Operational Medical Networks Informatics Integrator (OMNII) allows SCDF paramedics to perform real-time sharing of patients' vital signs and incident photos with hospitals' Emergency Department staff while en route to the designated hospital. This enables the hospital to prepare their resources prior to the arrival of the SCDF ambulance, thus significantly reducing Door-to-Treatment time and preserving the 'golden hour' for better patient outcomes.

Delving further into SCDF's efforts to leverage technology, SCDF is progressively incorporating new technologies and robotics as part of our frontline response. For example, firefighting robots will progressively become a standard feature in all our frontline fire engines and Red Rhinos, complementing our emergency responders in their day-to-day response to emergencies.

Our emergency responders will also be equipped with a new enhanced PPE known as the SCDF Fire Fighting Protective Suit (FFPS) next year. With the FFPS's main outer shell made of Polybenzimidazole (PBI) material, firefighters will be better protected from intense heat. The FFPS has undergone extensive research and development to focus on providing comfort through ergonomic design. Overall, the suit will afford our personnel the best available protection when conducting firefighting operations.

On the training front, I am pleased to share that the first of three phases of the Civil Defence Academy (CDA) redevelopment project is completed. The Emergency Responders' Fitness Conditioning & Enhancement Lab (EXCEL) uses science and state-of-the-art technology to train responders' physical strength and acclimatisation, cognitive vigilance and mental resilience. It is a first in the world for a fire department to leverage science and technology in human performance analytics. This focus underlines the ethos that our people are at the front and centre of our initiatives.

CDA's full development works are scheduled to be ready by 2023. These achievements would not have been possible without the hard work put in by my SCDF colleagues and the strong support shown by our partners. I would like to take this opportunity to also express my appreciation to the authors of REaction 2021. I wish everyone an engaging and insightful read. Stay safe and keep well!

Eric Yap
Commissioner
Singapore Civil Defence Force

EMERGENCY RESPONDERS' FITNESS CONDITIONING & ENHANCEMENT LAB

A Research & Development Facility to Optimise Responder Performance

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Image 1: Façade of EXCEL

EDITORIAL PREVIEW

Emergency responders attend to cases that often require quick thinking and body strength to mitigate an incident effectively. While the demand for emergency response continues to rise, the challenge to maintain a steady count of manpower coexists in our competitive landscape. There is a need to fully optimise our responders in terms of efficient response and injury prevention. This article looks at the Emergency Responders' Fitness Conditioning and Enhancement Lab (EXCEL) at the Civil Defence Academy (CDA) of the Singapore Civil Defence Force (SCDF).

Jointly developed with Human Factors and Simulation Centre of Expertise (HTX), EXCEL is a purpose-built facility to enhance SCDF emergency responders' performance and capabilities. EXCEL seeks to optimise human performance by leveraging on research and evidence-based findings with the aim of enabling objective evaluation of training effectiveness and efficiency, thereby improving training regimes. EXCEL will serve multiple functions, namely assessment, research, conditioning and corrective training.

INTRODUCTION

Over the past year, SCDF has doubled down on investing in responder performance with an eye to health and safety in both the physical and psychological realm to build up a holistic suite of capabilities in close concert with an ecosystem of strategic partners. The key objective is to bring a steady stream of radical breakthroughs in responder performance optimisation, especially those that are relevant to SCDF's operating environment and context. A key development is EXCEL, which was operationalised at the end of 2021. This will be the centre of SCDF's research, development and education, which will provide a comprehensive and scientific approach to training and operations. EXCEL will be a focal point to drive responder performance through collaboration with research and industry partners in various areas including:

- Collecting and assessing multi-factorial longitudinal data to monitor various aspects of responder performance
- Conducting research and trials for an objective evaluation of training regimes and innovative systems to enhance responder performance
- Implementing bespoke training regimes — such as heat acclimatisation, aerobic fitness conditioning, functional fitness testing — to prepare emergency response trainees for the demands of real operations
- Designing psychological tools for the development of competent leaders in critical incidents
- Developing virtual training content focusing on specific neurocognitive functions for enhanced learning and operational preparedness

EXCEL FACILITIES

EXCEL will house five key facilities linked to a system control and data analytics room, each harnessing its own technology to enhance responder performance. These facilities offer numerous research opportunities in human factors and performance that can be pursued in the years to come.

Image 2: Key facilities of EXCEL

Strength & Conditioning and Rehabilitation in a Virtual Environment

Strength & Conditioning and Rehabilitation in a Virtual Environment (STRiVE) will be a state-of-the-art system comprising a 360-degree HD dome built around a six-degrees-of-freedom motion platform equipped with a dual-belt treadmill. It is the first of its kind in the firefighting fraternity and in Southeast Asia. STRiVE combines both physical training via the motion platform and cognitive training via the HD dome which, together, will gamify the existing training regimes to provide a highly engaging and immersive environment. STRiVE provides real-time and longitudinal monitoring of a range of human factor indices, such as gait and balance, muscle activation, endurance, reaction time, as well as psychomotor abilities for a holistic evaluation of emergency responders. It also provides immediate feedback to our first responders by comparing their human factor signature against normative data. STRiVE offers multi-modal profiling and training in the following areas:

a. Combined physical and cognitive multi-tasking-based training to prepare officers for operational tasks that require them to simultaneously think and act quickly

b. Strength and conditioning of responders in an immersive gamified environment based on weighted clothing and load carriage

c. Physical rehabilitation to address issues impacting gait and balance due to injuries sustained at incident sites

d. Situational awareness training during firefighting and search and rescue operations

e. Intervention tool for Post-Traumatic Stress Disorder (PTSD)

f. Habituation against motion sickness for emergency responders involved in maritime response

Image 3: STRiVE

Environmental Chamber

The environmental chamber allows for the simulation of desired climatic conditions. Ambient temperature, humidity and wind speed can be simulated to create a realistic yet controlled operating environment. The chambers enable a wide range of training scenarios and research studies to be conducted, from facilitating proficiency test assessment to research studies pertaining to thermal stress and personal protective gears/uniforms. These chambers can also be used to acclimatise our emergency responders in a particular environmental condition, especially those preparing for deployment to overseas missions in colder or hotter countries compared with local climatic conditions.

Image 4: BAPT static station in the environmental chamber

Breathing Apparatus Proficiency Test — Static Stations and Breathing Apparatus Maze

The Breathing Apparatus Proficiency Test (BAPT) facility is designed to assess firefighters' cardio-respiratory and thermal fitness while donning PPE gear and Self-Contained Breathing Apparatus (SCBA). A joint study was done with researchers from Republic Polytechnic to establish a new BAPT regime to simulate actual fireground actions and local ambient climatic conditions. The new BAPT regime comprises test batteries, such as the endless ladder, endless stairs, casualty drag, hose carry and Breathing Apparatus (BA) maze orientation.

The static test stations are conducted in the environmental chamber. The BA maze also enables cognitive training, as responders react to automated trigger of obstacles. Individual vital stats will be monitored throughout the BAPT to identify susceptible cardio-stressed individuals for timely medical intervention.

Cognitive Lab

The cognitive lab will house experimentation and behavioural suites to enhance cognitive and behavioural performance of responders. The experimentation suite is equipped with advanced optical imaging, sensor systems and test systems, such as the Functional Near-Infrared Spectroscopy (fNIRS), Eye Tracking System (ETS) and cognitive evaluation test panel. The behavioural suite will be equipped with audiovisual cameras to monitor and capture behavioural patterns of emergency leaders in a given scenario. The visual movement and electrical brain activity of officers can be analysed during virtual training simulations, giving insights into their cognitive and behavioural performance. Responders with innate operational qualities can then be identified for specialised vocations with high cognitive demands.

Image 5: Cognitive lab

During incidents, officers who are less experienced may be visually distracted by other stimuli and, therefore, fail to conduct a thorough appreciation of the situation. The ETS can analyse the visual focus of officers in training simulations and advise them on how to achieve a thorough assessment of the situation. Audiovisual cameras can be used during ETS to study behavioural patterns of responders. SCDF's Emergency Behavioural Sciences and Care (EBSC) unit will work with EXCEL to promote resilience of SCDF personnel, enhance supportive engagement of personnel who are faced with critical incident stress or traumatic incidents. EBSC will also train certain SCDF personnel in soft skills which would help them to support emergency responders during their daily and crisis-ridden operations.

Image 6: Fitness evaluation lab

Fitness Evaluation Lab

The lab focuses on pre- and post-analysis of individuals to evaluate training and PPE performance. Results from such analysis will be used to revise individual-specific training needs and create an avenue to optimise individual performance. Periodic screening and testing could also help identify predisposition to neuromuscular injuries. Equipment in the lab also helps quantitatively evaluate and select the best protective gear for frontline officers, providing optimal speed, agility and protection.

The lab will be equipped with a whole-body bioelectrical impedance analyser for non-invasive body composition testing, a dynamometer system to measure lower and upper extremity muscle strength as well as grip strength, an integrated metabolic measurement system for cardiopulmonary stress evaluation, and timing gates to conduct strength and reaction trials.

System Control & Data Analytics Room

The central monitoring room remotely controls all systems within EXCEL and also collates data from various facilities for a holistic analysis of responder performance monitoring by employing the Test Results and Assessment Management System (TRAMS). TRAMS will offer a data-driven and tech-enabled environment by generating individual and group test results and statistical reports. This will enable profiling and analysis of training performance at various levels and provide a predictive model of the training population. Early intervention with the introduction of relevant training tools will enhance the overall training efficacy.

FUTURE STATE

Beyond meeting SCDF's rapidly evolving training needs, the next-generation training infrastructure of the CDA is also envisioned to be a platform for collaboration and focal point of knowledge creation through scientific research and innovation. CDA keenly welcomes partnerships with other emergency response agencies, Institutes of Higher Learning (IHLs) and other like-minded entities, such as big technology companies and start-ups, in a tireless endeavour to continually improve the safety, health and performance of emergency responders. While we take time to discover the latest in firefighting technology, we should not overlook the training efficacy of our emergency responders in terms of response, performance and recovery. EXCEL's strategy can be summarised as an integrated approach to responder performance. EXCEL will be able to cater to individual-specific training needs and enhance every emergency responder to perform better, faster and longer than ever before.

APPLYING FIRE RESEARCH METHODOLOGIES IN REDUCING ROAD DIVIDER VEGETATION FIRES

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EDITORIAL PREVIEW

Road divider vegetation fires are not an uncommon sight, especially along expressways where there is heavy flow of traffic throughout the day. Although these vegetation fires are of low impact, with little risk of escalation and danger to public safety, the consequences can be grave for they consume emergency resources, which may lead to delayed responses to more acute, life-threatening incidents.

This project in March 2019 was sparked by an unusual spike of fires along particular stretches of expressways.

This article elaborates on the research and trials done to determine the root causes of this unusual occurrence as well as measures needed to reduce the frequency of such fires. Findings from this two-year project have led to stricter requirements on the kind of mulch used, and the maintenance of vegetation along expressway road dividers. These initiatives, together with added deterrence from the latest Penal Code amendments, have effectively reduced the number of road divider vegetation fires from 213 cases in 2019 to 20 cases in 2021 up till end-May.

INTRODUCTION

In 2019, road divider vegetation fires along expressways accounted for a significant 7.4% of total fire calls. Fifty-one per cent of these fires broke out on a specific stretch along the Pan-Island Expressway (PIE) between the Eng Neo Avenue and Central Expressway (CTE) exits. The Singapore Civil Defence Force (SCDF) was able to meet the response time Key Performance Indicator (KPI) of eight (8) minutes in only 76.5% of such fires.[1] While such cases pose low risks to public safety, emergency resources that may otherwise be used to attend to more critical cases are consumed.

To tackle this unusual phenomenon, a study group was formed comprising the Operations Department (Ops), the First Civil Defence Division (1st Div) and the Fire Investigation Unit (FIU). Its objectives were to determine the root causes of these fires and to work together with the National Parks Board (NParks) and the National Environment Agency (NEA) to develop and implement measures to minimise the occurrence of such fires.

Through ground observations and fire investigation findings, SCDF learnt that the mulch layer used on the vegetation stretch along the road dividers was the primary fire load in most of these cases. Although NParks had drawn up a list of criteria for the technical specifications of the mulch used, combustibility limit was not part of the requirement.[2] Hence, mulches used on stretches with higher frequency of vegetation fires could be more combustible than those used elsewhere.

To address the issues posed by road divider vegetation fires, SCDF undertook a three-pronged approach comprising (a) laboratory tests conducted by the Home Team Science and Technology Agency (HTX) and the Health Sciences Authority (HSA); (b) a trial using different types of mulches along the PIE; and (c) burn tests by the Fire Investigation and Research Laboratory (FIRL).

This paper reports on the study done in the project. Details of the root cause analysis of vegetation fires, burn tests of mulches and the firefighting risk assessment are presented. The follow-up actions and measures implemented will also be discussed.

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1 This affected SCDF's overall KPI target of reaching 90% of all fire calls within eight minutes.

2 Specifications on mulch layer included limits on pH range, soluble salts, toxic materials, and resistance to rapid decay but did not cover requirements on volatility, presence of flammable chemicals and biological activity.

OBJECTIVES AND METHODOLOGY

The objectives of the study were to understand and identify potential fire hazards associated with fires involving mulches, as well as to minimise its occurrence thereafter.

The following methodology was used to meet these objectives:

a. Review the potential causes of vegetation fires and examine the material properties of mulches, with a view to reducing these fire causes;

b. Determine the factors influencing ignitability[3] of the mulches with a view to minimising the risk of ignition of mulches; and

c. Understand the burn behaviour of the mulches to establish the potential fire risk posed to emergency responders in a mulch fire.

Identifying Causes of Vegetation Fires

Mulch is a layer of material applied above the soil to conserve moisture and improve soil conditions. Mulching materials vary in size, shape, texture, and can be organic or inorganic in nature. Organic mulches include wood chips, compost, shredded barks, sawdust, chopped leaves, straw and grass clippings. Inorganic mulches include plastic sheeting and volcanic rocks.

There are two main causes of vegetation fires, namely human activity and natural phenomena.

Human Activities

Lighted materials (such as cigarettes), refractive materials (such as transparent plastic bottles) and reflective materials (such as aluminium drink cans) are some of the common items discarded along road dividers. Under the right conditions, these items can start a fire. Unextinguished cigarettes can smoulder to start a fire, while a clear plastic bottle with water and the polished bottom of an aluminium drink can focus their respective refracted and reflected rays from direct sunlight (DeHaan & Icove, 2012) onto dry vegetation to cause a fire.

Organic mulches when collected in huge quantities, such as a pile of dried leaves and tree limbs left after cleaning, can generate sufficient heat from internal decomposition to spontaneously combust[4] (Morris, 2015).

DID YOU KNOW?

NParks uses mulching to maintain hydration, reduce weed growth, mitigate soil erosion and improve soil conditions for healthy plant growth. The mulch materials used by NParks along expressway centre medians are usually organic as they are more cost-effective and environmentally friendly.

Figure 1: Mulches used by NParks

[3] Ignitability in this study is defined as how easily a tested mulch ignites by direct flame contact.

[4] The spontaneous combustion process can be divided into two phases. Initially, the fuel (mulches, dried leaves, tree limbs, etc.) needs to provide optimal conditions for the survival of thermophilic bacteria, as well as sufficient depth to ensure thermal insulation of the centre of the pile. Thermophilic bacteria are responsible for the initial heating and drying of the pile centre, simultaneously increasing temperature and reducing humidity. At this point if sufficient heat is produced by bacterial activity, a reaction will be initiated, resulting in a continuous rise in temperature until ignition is achieved (Armstrong, 1973).

Natural Phenomena

Lightning is also a known cause of vegetation fires (Ahrens, 2013).

Examining the Material Property of Mulches

SCDF engaged HSA and HTX to conduct laboratory tests to compare the chemical composition of mulch at fire-prone (hotspot) stretches with that found along non-hotspot stretches of the affected expressway. Differences in properties between the two types of mulches could provide insights as to why fires occur more often on certain stretches of the expressway.

The findings from HTX indicated that only mulches from the hotspot stretch contained flammable compounds and elemental aluminium, which could act as a catalyst for combustion. This was consistent with the results from HSA, which indicated that fresh mulch from the hotspot stretch could release flammable vapours such as alcohols, acetone, toluene and alkanes in trace amounts even at room temperature. Separately, the ease of ignition of these mulches was evaluated by FIRL and tests revealed that mulch from the hotspot stretch ignited more readily than that used on non-hotspot stretches.

It was hence concluded that mulch from the hotspot stretch was more combustible than that used elsewhere.

Organising the Trial

A five-month trial was conducted to evaluate the correlation between type of mulch used and frequency of fires on hotspot stretches of the PIE.

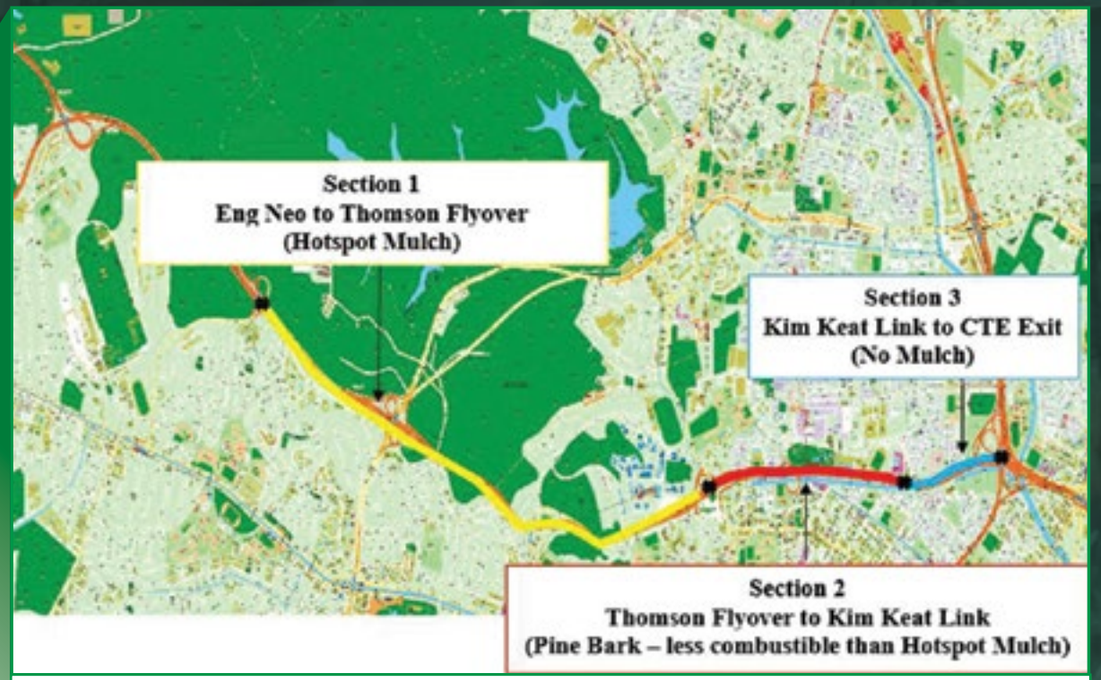


Figure 2: Mulch deployment at three sections of the PIE

Findings

As weather conditions improved during the trial period compared to the earlier months, the number of road divider fires at all three sections decreased. Findings indicated that mulch deployment could have an impact on the frequency of fires, even for a short period of time like five months (See Chart 1). There were relatively fewer fires along stretches of road laid with less combustible mulches.

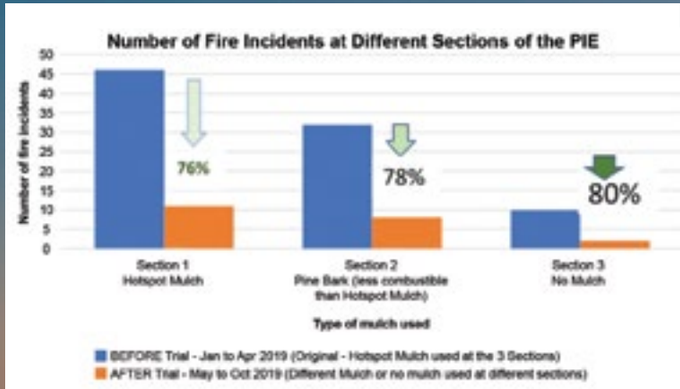


Chart 1: Results of trial

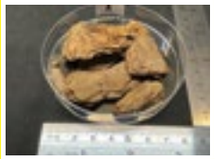
Burn Tests Conducted

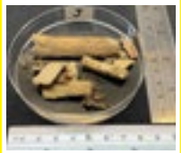
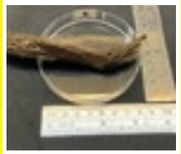
After having verified that mulches laid on stretches of expressway were combustible in nature and could be responsible for the fires there, burn tests were conducted on the mulches. By understanding the burn behaviour of these mulches, appropriate measures can be devised to minimise fire outbreaks.

Samples

Eleven mulch samples[5] (see Table 1) were collected from NParks and used for this study.

Table 1: Samples used in this study

Sample A Pine Bark	Sample B Mulch (PIE Jalan Bahar to Toh Tuck Exit)	Sample C Coarse Wood Chips Mixture	Sample D Eugenia Coarse Wood Chips	Sample E Xantho Coarse Wood Chips
				

Sample F Filiciam Coarse Woods Chips	Sample G Swietenia Coarse Wood Chips	Sample H Yellow Flame Coarse Wood Chips	Sample I Rain Tree Coarse Wood Chips	Sample J Hopea Coarse Wood Chips	Sample K Tree Wood Chips Mixture
					

[5] Pine bark is generally used in planters along pedestrian overhead bridges. It is not used at expressway dividers as it costs about 50 times more than regular mulches.

Preparation

Fifteen replicates[6] were prepared from each of the 11 samples. Each replicate, weighing about 300 grammes, was placed in an acrylic container. Seven (7) replicates were labelled as 'Indoor', another seven (7) as 'Outdoor', and the one (1) remaining as 'Reference'. A total of 165 replicates (samples) were prepared for the entire test.

The prepared samples were placed in different simulated conditions. The indoor samples were protected in a controlled environment (average air temperature of 25°C and average relative humidity of 80%), away from sunlight and rain, while the outdoor samples were subjected to environmental weathering conditions to mimic the conditions of mulches along the expressway centre medians.

Upon ignition of mulches, smouldering and flaming fires are commonly observed.

Figure 3: Ignition test

Method

At the start of the experiment (Month 0), the reference samples were subjected to a propane torch ignition test. The flame of the propane torch was in contact with the surface of mulch samples for two (2) minutes. The torch flame was then removed. The burn behaviour of the mulches, such as sustained burning or smouldering, over a period of 60 minutes, was recorded. Residual flames or embers were mechanically extinguished after 60 minutes.

Subsequently, at the end of every month, each set of outdoor and indoor samples was subjected to the identical ignition test — the impingement of a direct propane flame on the samples for two (2) minutes to observe for sustained burning or smouldering over 60 minutes. The test was repeated over a period of seven (7) months (from July 2020 to January 2021). The weather conditions on the days of the burn test were noted, with temperatures recorded between 23˚C and 42˚C and relative humidity between 36% and 72%.

[6] A replicate refers to a sample that is taken from its original bulk sample.

RESULTS AND DISCUSSION

All Samples

None of the samples self-ignited over the period of this study. To get these mulches ignited, a sustained flaming fire was required.

Reference Samples

The ignitability of mulches labelled 'Reference' varied among the samples.

Samples A, B, C, E, F and K did not ignite.

Samples D, G, H, I and J ignited. The initial heating of these replicates led to charring, some samples turning into ashes, and the evolution of gases. Flaming fire with smouldering also occurred. Once the heat source was removed, the fire self-extinguished while smouldering continued for some time before self-extinguishment.

Outdoor Samples

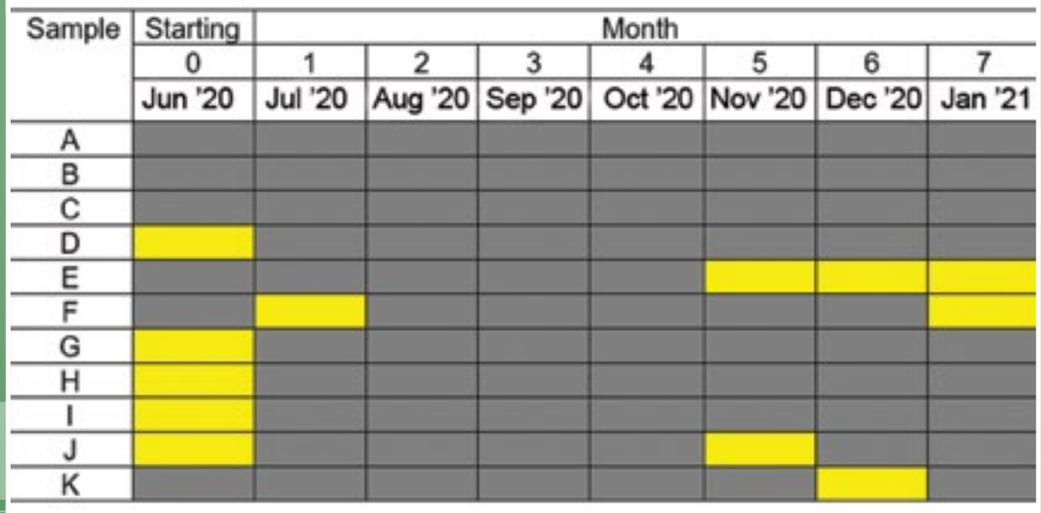
During the first four (4) months, most of the mulches did not ignite, although some burn marks and charring were observed on some of these samples.

This was expected as this period had coincided with the 'unseasonal' wet weather during the Southwest Monsoon.[7] Through absorption of moisture from the frequent intense heavy rains, the water-soaked mulches were not ignited under the test conditions.

From the fifth (5th) month onwards, Sample E started to ignite when tested. Smouldering was observed in all the ignited instances of Sample E before self-extinguishment.

Although not statistically significant, some replicates, namely Samples J and K, ignited once during the test months. Sample F ignited twice but these ignitions did not occur in consecutive months.

Table 2: Observations of burn tests for reference and outdoor samples



Legend:
- No fire observed when heat source was removed (no ignition)
- Smouldering fire did not develop into flaming fire
- Smouldering fire developed into flaming fire

[7] The Meteorological Service Singapore Annual Climate Assessment Report 2020 shows that the total rainfall islandwide from June to September 2020 was 30% above the long-term average for the same period.

Indoor Samples

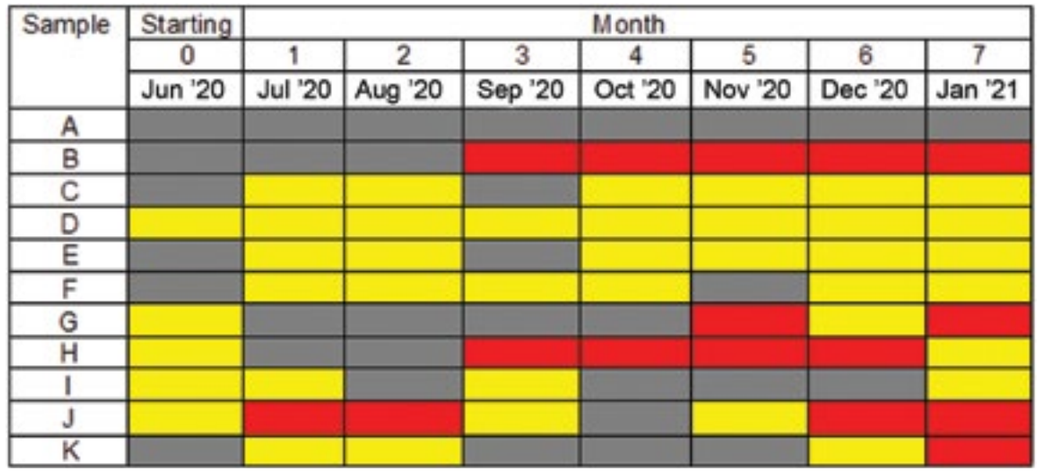
Weathering increased the ignitability of the samples. Discolouration of samples was also observed. Both the increase in susceptibility to ignition and discolouration were signs that these organic mulches were decomposing. The rate of decomposition, however, varied among the mulches. The increased ignitability of samples in the later months could be due to decreased moisture content in these samples. This was also responsible for the increased propensity of samples undergoing smouldering to flaming (StF) transition (Manzello et al., 2006a; Wang et al., 2017). Another factor influencing StF transition of smouldering mulches could be permeability[8] of samples.

For instance, structural features of the mulch (such as the loose, fine structure of Sample B in Figure 4) and structural changes to it over time (due to decomposition) may result in greater permeability. This allows higher oxygen penetration into the mulch (fuel), increases smouldering reaction rate and heat production in the 'void space' of the smouldering mulch, which may facilitate StF transition.

Loose, fine structure of Sample B

Figure 4: Sample B

Table 3: Observations of burn tests for reference and indoor samples



Legend:
- No fire observed when heat source was removed (no ignition)
- Smouldering fire did not develop into flaming fire
- Smouldering fire developed into flaming fire

[8] Permeability is a property of a material that represents the ability of gases or liquids to flow through it.

The burn behaviour of the samples varied among mulches. The mulch samples were categorised according to risk types (low risk, middle risk and high risk) based on the stage when the fire on the respective sample was totally extinguished. The details are summarised in Table 4.

Table 4: Burning behaviour of indoor samples

Type		Sample
Low Risk	Initial heating of the sample resulted in burn marks and charring. Flaming fire with no smouldering occurred. Upon removal of heat source, fire self-extinguished. **No further burning observed once the propane torch burner (heat source) was removed.** 	A Pine Bark
Middle Risk	Initial heating of the sample resulted in charring, ashes and evolution of gases. Fire with smouldering occurred. Upon removal of heat source, flaming fire self-extinguished. Smouldering continued for a while before self-extinguishment. **Smouldering fire tended to travel and spread below the surface the mulch. This caused burn holes in the pot of some mulch samples.** 	C Coarse Wood Chips Mixture D Eugenia Coarse Wood Chips E Xantho Coarse Wood Chips F Filiciam Coarse Wood Chips I Rain Tree Coarse Wood Chips
High Risk	Initial heating of the sample resulted in charring, ashes and evolution of gases. Fire with smouldering occurred. Upon removal of heat source, fire self-extinguished. **Smouldering continued for a period of time before it 'suddenly' developed into a flaming fire.** 	B Mulch (PIE Jalan Bahar to Toh Tuck Exit) G Swietenia Coarse Wood Chips H Yellow Flame Coarse Wood Chips J Hopea Coarse Wood Chips K Tree Wood Chips Mixture

Factors Affecting Ignitability of Mulches

The ignitability of these mulches varied considerably. It was influenced by a combination of type, structure and moisture content of the mulches.

Type

Different types of mulches burn at different temperatures. Mulches with lower ignition temperature will be easily ignited.

Structure

Smaller pieces of mulch get ignited more easily as they take less time to absorb heat energy to reach its ignition temperature. In addition, the burning process is faster due to efficient combustion as more oxygen molecules are involved over a wider surface area.

Table 5: Size and surface area

	
Specimen 1 Large pieces with small surface area (small ratio of surface area to volume)	**Specimen 2** Small, fine pieces with large surface area (large ratio of surface area to volume)

Both specimens were from Sample C. It was more difficult to ignite and sustain burning for Specimen 1 than for Specimen 2.

Moisture Content

Moisture content is the most important factor in governing the ignitability of mulches (fuel). Higher moisture content leads to higher heat capacity of the mulches. As a result, more heat must be absorbed by the mulches for ignition and to sustain combustion (Dimitrakopoulos & Papaioannou, 2001; White & Zipperer, 2010).

It is difficult to ignite a water-soaked mulch as a long preheating time is required to remove moisture to reach its ignition temperature. Conversely, a weathered, dried, continually decomposing batch of mulch can be easily ignited.

Weather elements such as temperature, wind and precipitation (rain) have a direct impact on the moisture content of mulches. (1) Hot weather dries out the moisture content, so less preheating is required to reach ignition temperature. (2) Wind dries the mulch by increasing evaporation, making ignition much easier. (3) Rain, however, is the only weather element that can completely prevent ignition. A prolonged wet season keeps the mulch damp and eliminates the risk of ignition.

Flaming and Smouldering Fires

Flaming and smouldering fires were observed during the burning process of mulches. In some cases, an already extinguished flaming fire was seen being rekindled.

A flaming fire is a fast, high-temperature, high heat releasing, visible flame burning process. It produces a large quantity of flames with a smaller amount of smoke.

In contrast, smouldering combustion is a slow, low-temperature, low heat releasing, flameless form of burning (Rein, 2016). It emits a large amount of thick smoked gases (such as toxic, flammable carbon monoxide). The flammable gases could ignite later and trigger the transition to flaming combustion (Ohlemiller, 2002). Smouldering has the propensity to travel and spread below the surface (Rein, 2016).

Pyrolysis:	Equation 1
Fuel (solid) + Heat → Pyrolyzate (gas) + Char (solid) + Ash (solid)	
Gas-phase oxidation (flaming):	Equation 2a
Pyrolyzate (gas) + O_2 (gas) → Heat + CO_2 + H_2O + other gases	
Solid-gas phase oxidation (smouldering):	Equation 2b
Char (solid) + O_2 (gas) → Heat + CO_2 + H_2O + other gases + Ash (solid)	

In general, the combustion of a solid fuel is dictated by two (2) chemical pathways: pyrolysis (Equation 1) followed by oxidation (Equation 2a or 2b).

Both flaming and smouldering fires come from the same process — pyrolysis (Equation 1). Due to this commonality, transition between them is possible (Santoso et al., 2019). Both flaming and smouldering can occur, and one can lead to the other (Rein, 2016). A flaming fire can be extinguished then 'rekindled' through the StF transition of an undetected smouldering fire.

The current understanding of the mechanism leading to StF transition in vegetation fires, however, is limited, as most studies focused on synthetic polymers. These studies, however, have identified oxygen concentration and heat flux as the primary variables governing StF transition (Santoso et al., 2019). Further research is required to investigate StF transition in vegetation fuels.

StF transition is considered a threat because of the following sudden increase in fire spread rate, power and hazard (Table 6). A creeping, low-heat and low-temperature smouldering fire can suddenly transform into a flaming fire that quickly spreads over the surface, consuming all fuels along its way and releasing intense heat. This behaviour can be hazardous to responders who may suddenly find themselves trapped by high-intensity burning flames in an unexpected location and at an unexpected time (e.g. long after the burnout of the initial fire).

Table 6: Characteristics of flaming and smouldering combustion (Rein, 2016)

Characteristics	Flaming	Smouldering
Peak temperature (°C)	1,500 – 1,800	450 – 700
Typical spread rate (mm/min)	100	1
Effective heat of combustion (kJ/kg)	16 – 30	6 – 12
Ignition source (kW/m²)	30	8

STUDY APPLICATIONS

Eliminating Potential Fire Causes

FIU's investigation shows that roadside and road divider vegetation fires are mostly caused by lighted materials. To address this issue comprehensively, a two-pronged fire prevention strategy focusing on removing combustible materials on road dividers and preventing disposal of such items on roadsides needed to be considered.

It is recommended that roadside rubbish and trash be cleared more often from expressways, especially during dry periods. Furthermore, to reduce potential spontaneous combustion, piles of rubbish, dried leaves and tree limbs lopped off during maintenance activities should also be removed as soon as is practicable.

To prevent pedestrians and motorists from disposing of items on roadsides, public education and legislative measures can be considered.

Hazard Awareness

The burn tests of mulches in the study revealed that there are serious hazards associated with smouldering. In vegetation fires, smouldering is dangerous to firefighters for the following reasons:

a. Difficulties in detection (Rein, 2016), *due to its low temperature, tendency to travel below surface level, and flameless characteristics;*

b. Emission of more toxic, flammable gases than flaming fires (Rein, 2016);

c. Difficulties in extinguishment, *as the fire may travel below surface level, so detection is difficult and great quantities of water may be needed to extinguish it (Rein, 2016).*

Awareness of the possible hazards posed by smouldering fires will help the responding team adopt appropriate firefighting strategy, thereby leading to a safe and successful operation.

Fire Prevention Measures

This study shows that there are fire threats associated with mulches. The following factors have to be taken into account to prevent mulches from catching fire:

a. Selection of the type (and size) of mulch materials: *It is necessary to avoid materials that exhibit the burning behaviour of high-risk type of mulches and to consider selecting bigger-sized mulch chips;*

b. Duration for mulch replacement: *A shorter replacement cycle is recommended to ensure 'freshness' and a high moisture content in mulches;*

c. Frequency of site maintenance: *Debris/Trash/Rubbish needs to be removed regularly from the roadside, as heat released from these items, if ignited, may ignite mulches; and*

d. Frequency of watering mulch layer: *Regular watering helps keep mulches consistently moist and helps prevent ignition.*

FOLLOW-UP ACTIONS

Maintenance Programme

The results from the studies led to a review of mulch specifications and maintenance regimes. Subsequently, NParks and NEA:

a. Accept only mulches that meet revised specifications covering limits on flammable compounds (e.g. alcohols, alkanes) and size of the mulch chips;

b. Ensure the replacement of mulches along expressways every two to three months as fresh mulch has more moisture and is relatively less combustible;

c. Enforce regular clearing of rubbish and leaf litter along road dividers on expressways once every two weeks during dry periods; and

d. Conduct preventive watering (full soak) at hotspots (identified stretches of expressways with high frequency of vegetation fires) during dry periods.

Stronger Deterrence through Legislative Measures

Tackling human behaviour is equally critical in reducing road divider fires as these are mostly caused by lighted materials disposed of indiscriminately by pedestrians and motorists.

The Singapore Police Force (SPF) worked with SCDF to revise the Penal Code[9] to introduce a new offence — causing or contributing to the risk of a dangerous fire — and a presumption clause. This took effect from January 2020 and addressed the evidentiary difficulty previously faced in proving a direct causal relationship between a fire and a preceding rash or negligent act likely to cause a fire. In the context of vegetation fires, the SPF can now take firm action against people who casually dispose of lighted materials (e.g. cigarette butts) onto vegetation that catches fire subsequently. Furthermore, penalties under the amendments are appropriately apportioned based on the damage caused by the fire.[10]

In addition, SCDF is working with NEA and SPF on enforcement actions to deter people from throwing cigarette butts out of vehicles.[11]

Increasing Hazard Awareness

An edition of the Fire Investigation Bulletin, an in-house SCDF publication, covering the subject of vegetation fires was issued in July 2021. Information on potential hazards posed by smouldering fires was conveyed to members of the SCDF.

Improvements in Outcome

After implementing the various initiatives, the number of road divider vegetation fires dropped significantly from 213 cases in 2019 to 20 cases in 2021 up till end-May. However, it is plausible that other external factors, such as a wetter 2020 and lower vehicle throughput due to COVID-19, could have contributed to this decrease.

Therefore, SCDF monitored the proportion of expressway divider fires to the total of vegetation fires, as it is believed that all these fires ought to be similarly affected by the abovementioned external factors. The proportion hovered around the 40-50% range prior to implementing the recommendations covered in this paper but dropped to below 20% after the measures were progressively introduced.

[9] Under the amended Penal Code S285 and S286, if a fire occurs within 60 mins at the place or in the vicinity of that place where a material likely to cause fire was deposited or placed, it will be presumed that the person who deposited or placed this material had contributed to the risk of causing that fire and can be found liable.

[10] Causing fires that bring damage to or diminishes the value of any property will carry a maximum jail term of 18 months or a fine, or both. Causing fires that result in death will carry a maximum jail term of seven years or a fine, or both.

[11] SCDF shares information on roadside vegetation fires due to dropped lights with NEA monthly and this is cross-referenced with NEA's database of littering offences. If there are positive hits, details of the fire and particulars of the littering offender will be routed to the police for further investigation.

CONCLUSION

Road divider fires are low-impact incidents with little risk of escalation, but they have a disproportionate impact by consuming emergency resources and affecting our response KPIs. The study had discovered that a change in mulch layer could reduce road divider fires along expressways. As a result, measures such as the revision of mulch specifications, maintenance of mulch, preventive watering and stricter enforcement on clearing leaf litter were implemented. These initiatives, together with added deterrence from the latest Penal Code amendments, have effectively reduced the number of road divider vegetation fires in Singapore since 2021.

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DATA-DRIVEN EMERGENCY RESPONSE – UNLOCKING HIGHER PERFORMANCE WITH DATA ANALYTICS IN THE SINGAPORE CIVIL DEFENCE FORCE

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EDITORIAL PREVIEW

The Singapore Civil Defence Force (SCDF) has seen an increasing demand for Emergency Medical Services (EMS) due to an ageing population. However, it is not possible to increase the ambulance fleet and human resources indefinitely to match the rising demand, as this is not sustainable. Hence, SCDF developed the Dynamic Resource Optimisation (DRO) system, based on data analytics and optimisation methods, as a force multiplier to augment our operations planning. A critical function of DRO is recommending the best placement configuration of resources to achieve a minimum overall response time. Compared to using traditional statistical methods, DRO improves the EMS response time in the 11-minute zone by a simulated average of 3.7%. Since December 2017, SCDF has utilised DRO to recommend resource placements in the planning for its ambulance fleet expansion, suggest locations for supporting dynamic deployment, and compare performances between multiple deployment configurations. Correspondingly, SCDF's key performance indicator (KPI) in EMS operational response has improved from 88.9% in 2017 to 91.8% in 2019.

INTRODUCTION

Over the years, SCDF has experienced a growing demand for EMS. The rise is due to an ageing population, a common phenomenon encountered by developed countries such as Japan, Italy and Germany [1, 2]. In conjunction, the United Nations projected the percentage of old-age dependants (65 years old and above) to increase across all regions [3]. However, it is not possible to increase ambulances and staffing indefinitely to meet the rising demand. Hence, SCDF explores advanced data analytics and optimisation methodologies to serve as a force multiplier to enhance operational efficiency.

CONVENTIONAL APPROACH

The conventional approach to the placement of ambulances is by comparing KPIs based on aggregated statistics, i.e. statistical configuration (SC). Table 1 shows some examples of KPIs with hypothetical data. The top five regions (highlighted) in each category would receive additional resources to aid them in their operations — these are the regions with the highest number of incidents or relatively poorer operational response.

Table 1: Examples of KPI performance with hypothetical data. The five underperforming regions for each category are highlighted.

Incident Boundary Code	Total Number of Incidents	Number of Incidents Responded to by Other Regions	Number of Late Incidents Responded to by Other Regions	Percentage of Timely Response	Number of Incidents per Ambulance
3C	10,440	2,030	720	87.5%	2,640
1A	9,540	2,080	500	85.5%	2,810
4C	5,850	1,560	490	86.0%	2,260
4D	7,480	1,450	470	89.5%	2,810
2B	7,350	1,980	480	91.5%	2,740
2A	6,530	750	220	83.0%	2,460
1E	5,300	1,380	560	87.5%	2,800
1B	5,510	1,490	440	91.0%	2,870
3B	4,940	1,390	490	88.5%	2,660
3A	5,630	1,070	370	92.5%	2,830
2C	5,170	1,620	340	88.0%	2,620
4A	6,630	1,060	220	91.5%	3,160
1C	3,550	590	190	86.0%	2,290
1G	3,230	1,550	250	90.0%	2,240
4B	3,060	360	190	85.0%	2,500

However, this approach in developing SC is inferior as it does not consider the temporal nature of the incidents. It solely utilises traditional statistics to aggregate characteristics such as demand and performance. Thus, the need to assign more resources to a station with many overlapping incidents is overlooked.

Additionally, the conventional method assumes each base station can and would only serve the area within its administrative boundary (B_{admin}). The B_{admin} is a static boundary where the station exercises administrative control such as carrying out hydrant checks and surveys. However, the furthest geographical reach of an ambulance within 11 minutes (B_{11min}) for a timely response is more vital during operations. Figure 1 shows the conceptual difference between the two boundaries and the inadequacies of the conventional approach.

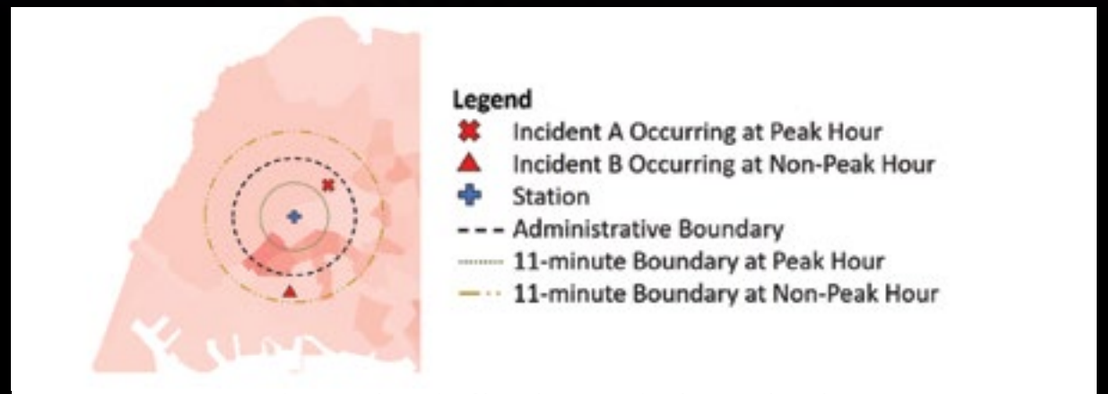

Figure 1: Schematic of how the conventional approach works

The B_{11min} of a station varies with changes in environmental factors such as traffic conditions. Based on SC, the station will deploy its ambulance when Incident A occurs within its B_{admin} during peak hours. However, it will not reach within 11 minutes since the incident location falls outside its B_{11min} at peak hours. Conversely, B_{11min} would widen during the non-peak period due to less traffic. The increase in coverage would allow the station to respond promptly to Incident B despite it being located outside of its B_{admin}. The SC would not have considered the changes in B_{11min}, and other stations could be activated instead. These issues reflect the inadaptability of the conventional approach to address the variables.

Overall, the traditional configurations focus on static allocation without addressing the interaction of time and space. Consequently, resources were not optimised for operational efficiency.

DYNAMIC RESOURCE OPTIMISATION

Hence, SCDF leveraged on advanced data analytics and optimisation techniques to assist in deploying scarce resources. Specifically, SCDF has collaborated with Singapore Management University and Home Team Science and Technology Agency to develop a DRO system. With this platform, the overall response time across different timings and locations is minimised from a systemic perspective. This enhancement has also increased the resource availability for subsequent incidents, leading to a virtuous cycle that improves operational effectiveness.

METHODOLOGY

The development of DRO involved advanced and complex machine learning techniques. Figure 2 illustrates the schematic of the DRO system. It presents the various steps involved and the eventual output in the form of a deployment plan.

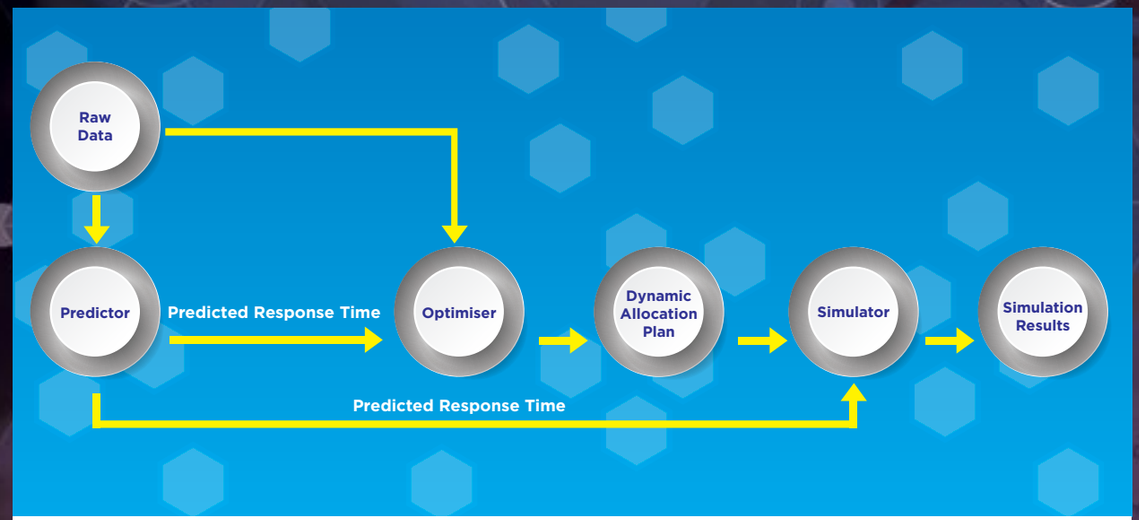

Figure 2: Schematic of DRO system workflow. Adapted from [4].

The objective of DRO is to generate an ideal allocation plan by maximising the performance metrics via the Optimiser tool [4]. Equation (1) shows an overview of its inputs and output [4, 5]. The inputs were fed into a mixed-integer linear program and solved by the Optimiser via the minimisation of response time. These inputs include the number of ambulances and stations. The locations of the stations and incidents were needed as well to predict the response time as a prerequisite for the optimisation process. Various constraints such as the dispatch policy (deployment of nearest idle ambulance) were introduced to produce a more holistic outcome [5]. The final output of the Optimiser is an optimised configuration (OC). It consists of the deployment of the entire ambulance fleet and the predicted performance [5].

$$\text{Allocation plan} = \frac{d}{d(\text{time})} \quad \text{(fleet size of appliances, set of stations, set of nearby stations for each incident and their corresponding predicted response time, round trip time)} \qquad (1)$$

In addition, DRO offers simulation capabilities [4]. On some occasions, SCDF is not able to adopt OC thoroughly due to practical limitations. The simulation algorithm allows the testing of various scenarios that deviated from the OC. The user could use the results to decide and implement the configuration that best meets the constraints and has the most negligible adverse impact on the performance. The simulation works by taking a set of incident requests from the data set and feeding it to both SC and OC [6]. The Simulator handles all incoming calls on a first-come-first-serve basis. Under the conventional approach, the nearest (distance) available ambulance will be dispatched to the incident site when a call is received. Whereas in the OC, the Predictor will first estimate the travel time between the incident site and stations. The algorithm then deploys the ambulance with the shortest response time. The simulated results generated from both plans are compared and discussed in the next section.

Before implementing the platform, it was trained using SCDF's historical data over a one-year period to reduce potential seasonality effects. Subsequently, the system is updated yearly by providing the most recent data for training. This measure ensures that the platform would continue to deliver good results in the future.

RESULTS AND DISCUSSIONS

The DRO performance is evaluated by assessing it against the conventional approach. SCDF has traditionally relied on human judgment based on statistics to decide on ambulance placement. To compare the performance, both SC and OC were subjected to simulation to ascertain the configuration that creates a better overall response time. Each configuration describes how many ambulances are deployed to each station. The two performance metrics studied are 1) the response time of the 80th percentile and 2) the percentage of timely response [4, 5]. Table 2 presents the simulation results of the difference between the two metrics between SC and OC. Equations (2) and (3) indicate the derivation of the difference between the 80th percentile response time and the percentage of timely response, respectively. *R* refers to the response time, while *T* denotes the timely response percentage. The subscript *SC* signifies the statistical configuration, and subscript *OC* represents the optimised configuration.

Table 2: Simulated differences between SC and OC. Adapted from [4].

	Difference in Response Time of 80th Percentile (min)	Difference in Percentage of Timely Response (%)
Monday	0.9	3.8
Tuesday	0.9	4.6
Wednesday	0.8	3.8
Thursday	0.8	4.6
Friday	0.8	3.9
Saturday	0.7	3.7
Sunday	0.8	2.5
Overall	**0.8**	**3.7**

$$\text{Difference in 80th percentile response time} = R_{SC} - R_{OC} \qquad (2)$$

$$\text{Difference in percentage of timely response} = T_{OC} - T_{SC} \qquad (3)$$

SCDF has seen an improvement in response time and operational efficiency with the implementation of DRO. According to Table 2, an ambulance in the 80th percentile would experience an average reduction in response time by 0.8 min, or 48 s (minimum reduction 42 s, maximum reduction 55 s). Correspondingly, the timely response percentage increases. The operational efficiency is estimated to rise by an average of 3.7% (minimum improvement 2.5%, maximum improvement 4.6%). Due to these enhancements, SCDF can react timely to approximately 7,000 more calls per year.

Nonetheless, the comparison cannot be evaluated under real-world conditions. Many factors influence the performance, and real-time incident patterns are not duplicable to have an unbiased test. Simulation provides an experimentation environment with the deployment configuration as the only variable. The simulation results would reflect more accurately the impact of the tested variable on the operational efficiency. The above simulation concludes that given identical operating conditions, DRO can better optimise ambulance deployment than the conventional method.

CURRENT APPLICATIONS

DRO functions as a simulation and optimisation platform, proposing the optimal placement of ambulances to minimise response time for emergency incidents. The optimised configuration allows SCDF to provide more timely interventions, especially for high-priority incidents such as cardiac arrest. Currently, DRO supports SCDF's operations in three ways:

a. Recommending the placement of new ambulances. SCDF has implemented DRO since December 2017 to support the expansion of the ambulance fleet. The system proposes to SCDF the locations to place additional ambulances to maintain a strong performance in response time. Over the last few years, SCDF's performance for EMS incidents has improved from 88.9% in 2017 to 91.8% in 2019 (before COVID-19).

b. Recommending new locations to support dynamic deployment. DRO has been used to assess suitable public locations as new bases to close current performance gaps. Dynamic deployment was implemented in 2018 by the EMS department to support potential demand hotspots during peak hours. A trial conducted from October to December 2018 showed that these new locations had improved EMS performance by 5.6%.

c. Allowing simulation of performance for comparing alternative deployment configurations. Occasionally, SCDF is not able to follow the optimal allocation due to operational constraints. DRO permits the users to test and simulate multiple 'what if' scenarios. The users can then analyse the results and execute an alternative deployment configuration with the most negligible impact on performance.

Having such capabilities allows SCDF to be more data-driven when making operational decisions for forward planning. The planners would be able to ascertain when and how many ambulances to acquire and where to place them to achieve the KPIs desired by SCDF. Such information could also assist SCDF to develop the infrastructure and logistics required to support its fleet expansion plan.

CONCLUSION AND FUTURE WORK

SCDF has made significant progress in employing data analytics and optimisation techniques to enhance its operational efficiency and effectiveness. Specifically, DRO recommends the optimal placement of ambulances through the minimisation of response time. The performance of the platform is evaluated via the simulation of incident demand and supply data. The simulation results have demonstrated a reduction in average response time and an increase in the average percentage of timely response.

The initial DRO system was built in 2017 with EMS in mind. With the success of the original platform, SCDF sought further support from Singapore Management University to revamp the DRO by including data from both fire and rescue incidents. The enhancements were completed in early 2021, and the DRO now supports SCDF in optimising deployment for EMS, fire and rescue calls.

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OPERATIONAL MEDICAL NETWORKS INFORMATICS INTEGRATOR

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EDITORIAL PREVIEW

An Integrated EMS Augmented by Ops-Tech

Ops-Tech plays an important role in the transformation of Emergency Medical Services (EMS) in SCDF. SCDF has been continuously adopting some of the most reliable and advanced technologies to improve the quality of service delivery and overall outcomes of Pre-hospital Emergency Care (PEC) in Singapore. Global best practices show there is a need for an integrated set of technologies to deliver a comprehensive PEC system.

With the implementation of Operational Medical Networks Informatics Integrator (OMNII) since 26 August 2021, SCDF and Emergency Departments (EDs) have received a critical speed boost to save lives and improve patient outcomes. OMNII is Singapore's first nationwide PEC digital project between SCDF and the Ministry of Health (MOH). The advent of OMNII will transform the PEC information flow as we go digital and help develop a world-class digitally connected national PEC system. OMNII is envisioned to create a paradigm shift in the way pre-hospital care is delivered and transform the PEC landscape in Singapore.

The OMNII system is a common collaborative platform linking all PEC stakeholders, including Ops Centre, SCDF EMS and hospitals' EDs across PEC services, so that they will be able to view, share and document relevant patient data seamlessly to improve patient care management throughout the continuum of care.

OMNII enables every PEC stakeholder access to the right information at the right time. Across all stakeholders and business processes, OMNII converges data from all relevant systems [Advanced C3 Emergency System (ACES), National Electronic Health Records (NEHR), Critical Medical Information System (CMIS), hospitals' ED System] and acts as a convergent point to make such critical information available to the paramedic through a mobile application. OMNII enables sharing of this data which can then be accessed by the stakeholders through various channels. It supports a common representation of data, avoiding duplication and redundancy.

ENABLED STRATEGIC OBJECTIVES	
Enhanced Situational Awareness	OMNII will provide the ability to enable all stakeholders across the PEC landscape to be aware of what is happening or about to happen (future phases) at any given point in time through the provision of real-time information dissemination and analysis.
Empowered Field Operations	OMNII will allow paramedics to access critical information they need such as the patient's health record and possible underlying medical conditions. For future phases of OMNII's development, there might be plans to provide real-time information on hospital bed and resource capacity.
Seamless Operations Integrator	OMNII will enable situational awareness and empowered field operations, with the capability to have access to relevant data and system integration of the different operational systems in SCDF, hospitals' EDs and other key stakeholders.
Improved Quality	OMNII will provide the ability to improve triage diagnosis, provide better treatment to patients by having timely information, system integration and guidelines-based decision support availability when required.
Evidence-enabled Planning, Policymaking and Performance Improvement	As OMNII develops its capability to gather and analyse data, it can provide evidence-based planning and analysis using historical or near-time data. Having the right tools and processes in place will empower SCDF to better govern, analyse and plan; to transform the PEC landscape into a world-class system that is readily accessible to all, resulting in excellent patient outcomes.

KEY FEATURES OF OMNII

1. Enhanced Clinical Information

   ✓ Access to selected patient medical records in NEHR
   ✓ Real-time sharing of patient's vital signs

2. Enhanced Operational Efficiency

   ✓ Pre-registration
   ✓ Electronic Patient Case Record

3. Improving Patient Outcomes

   ✓ Telemedicine (text and video)

OMNII WORKFLOW — THE RACE AGAINST TIME

Every day, SCDF and hospitals are in a race against time. With OMNII, SCDF and hospitals receive a critical speed boost to save lives and improve patient outcomes.

995 Operations Centre

Upon receiving a 995 call, the call taker creates the incident case and dispatches an SCDF ambulance. The call taker will proceed to ask for the patient's NRIC number as part of the phone triaging framework.

Proceeding to the Location

A ruggedised mobile tablet with the OMNII app installed is issued to every SCDF paramedic. Paramedics will have enhanced situational awareness as they draw information on the case location, contact and patient's medical history from the OMNII tablet. Paramedics will have access to selected patient medical records from NEHR if the patient's NRIC is known. OMNII will also allow for the retrieval of past SCDF Patient Case Records through the OMNII-SCDF database.

At Incident Site

Paramedics will have empowered field operations as the information from OMNII guides crews' clinical management of the patient. Paramedics will also verify the patient's identification at the incident site. Once the patient has been assessed and stabilised, the Emergency Medical Technician (EMT) will use the OMNII tablet to capture photos and/or short video clips to transmit to the receiving ED.

En route to Hospital

Should the paramedic triage the patient as critical, a 'STANDBY' alert will be triggered via the OMNII tablet and this will sound the audio and visual alert to the ED's Display Terminal. While the emergency physician and nurse acknowledge the 'STANDBY' alert, they will be able to view real-time information about the case, including the ambulance's estimated time of arrival, vital signs updates and interventions carried out.

Through OMNII's seamless operations integrator, the paramedic will pre-register the patient into the hospital's system and this will kickstart the ED's preparation process to receive the patient. Pre-registration of the patient allows the preparation of controlled drugs and pre-ordering of procedures (CT scan/X-ray). The ED's Display Terminal will also stream the live incident/injury photos and/or videos taken by the SCDF ambulance crew. Should the condition be deemed critical, additional resources such as trauma surgeons will be activated to the ED to assist in the resuscitation room. This will allow a significant reduction in Door-to-Treatment time which will result in higher chances of survival for the patient.

In the event of a complex incident, OMNII's telemedicine module will bring the physician virtually into the ambulance. The paramedic will contact the EMS support physician via video conferencing or texting. Advanced clinical procedures can then be implemented with the guidance of the EMS support physician to improve patient outcomes. This will also improve the triage diagnosis of the patient.

While the patient is hooked up to the patient monitoring equipment in the ambulance, their vital signs are wirelessly transmitted from the patient monitoring equipment to OMNII and the ED's Display Terminal. This will allow enhanced clinical information and updates to be provided in real time to the receiving ED.

Countdown to SCDF's Arrival at the ED

While waiting for the SCDF ambulance to arrive with the patient, critical decisions can be made. The emergency physician and trauma surgeon will discuss the resuscitation plan in order to reduce Door-to-Treatment time.

By the time the patient arrives at the ED, the resuscitation team is gathered. Resuscitation equipment and imaging procedures will be prepared in advance. The resuscitation team will receive real-time updates on the patient's vital signs, medical history and treatment performed by the paramedic. Should the patient's condition deteriorate, the paramedic will immediately update the ED via OMNII.

Arrival at the ED

Upon arrival at the ED, the patient will be swiftly taken charge of by the resuscitation team. The patient will be taken to the resuscitation room immediately. Event history and vital signs will be made available to the ED prior to the ambulance's arrival. Patient care will transit seamlessly to the ED without delay. With medications and imaging procedures ready for immediate deployment, the 'golden hour' of the patient will be preserved which will result in better patient outcomes and survivability.

OMNII's photo gallery will also allow for improved accuracy during the clinical handing over process. The paramedic will document patient data on an electronic Patient Care Record (ePCR), doing away with the hard copy PCR. Minimal data entry by the crew is required to accurately document and timestamp every aspect of the incident, from the first dispatch timing to handover at the ED.

This allows for an Incremental Build-up of Incident Case Records (IBCR) that brings all stakeholders across the PEC landscape on one platform — giving an overall view of the live patient case record to all participants at any given point of time. At the heart of IBCR is the ability to allow real-time collaborative capabilities between SCDF and the EDs.

After the paramedic hands over the patient and closes the case in the OMNII app, the ePCR will flow back to NEHR for clinicians at the EDs to ensure continuity of care. The uploading of clinical records into the national system allows for the seamless integration of clinical records which is accessible throughout the patient's continuum of care. This IBCR will enable integration of common data and information across the PEC lifecycle, at both SCDF and EDs. This will allow for situational awareness, field empowerment, clinical quality improvement and, most importantly, seamless integration of information.

CONCLUSION

Future plans of OMNII may include the enablement of a feedback loop of patient care outcome/ diagnosis by the ED back to SCDF. As the IBCR is integrated with NEHR and the ED system, the ePCR can be reconciled with the ED notes or diagnosis reports. This may be made available through OMNII for continuous education and feedback to the SCDF paramedic.

As SCDF EMS progresses towards a new era of digital transformation, we aim to leverage technology to minimise gaps in the current PEC landscape. Through a holistic framework covering technology, process, and governance, the EMS will advance PEC's vision for Singapore to possess a world-class PEC system, readily accessible to all, and achieving excellent patient outcomes.

SUMMARY OF OMNII

OMNII is a common collaborative platform linking all stakeholders, including SCDF Operations Centre, SCDF paramedics, and hospitals' EDs, to PEC services, so that they would be able to view, share, and document relevant patient data to improve patient care management throughout the continuum of care.

Enhances Operational Awareness

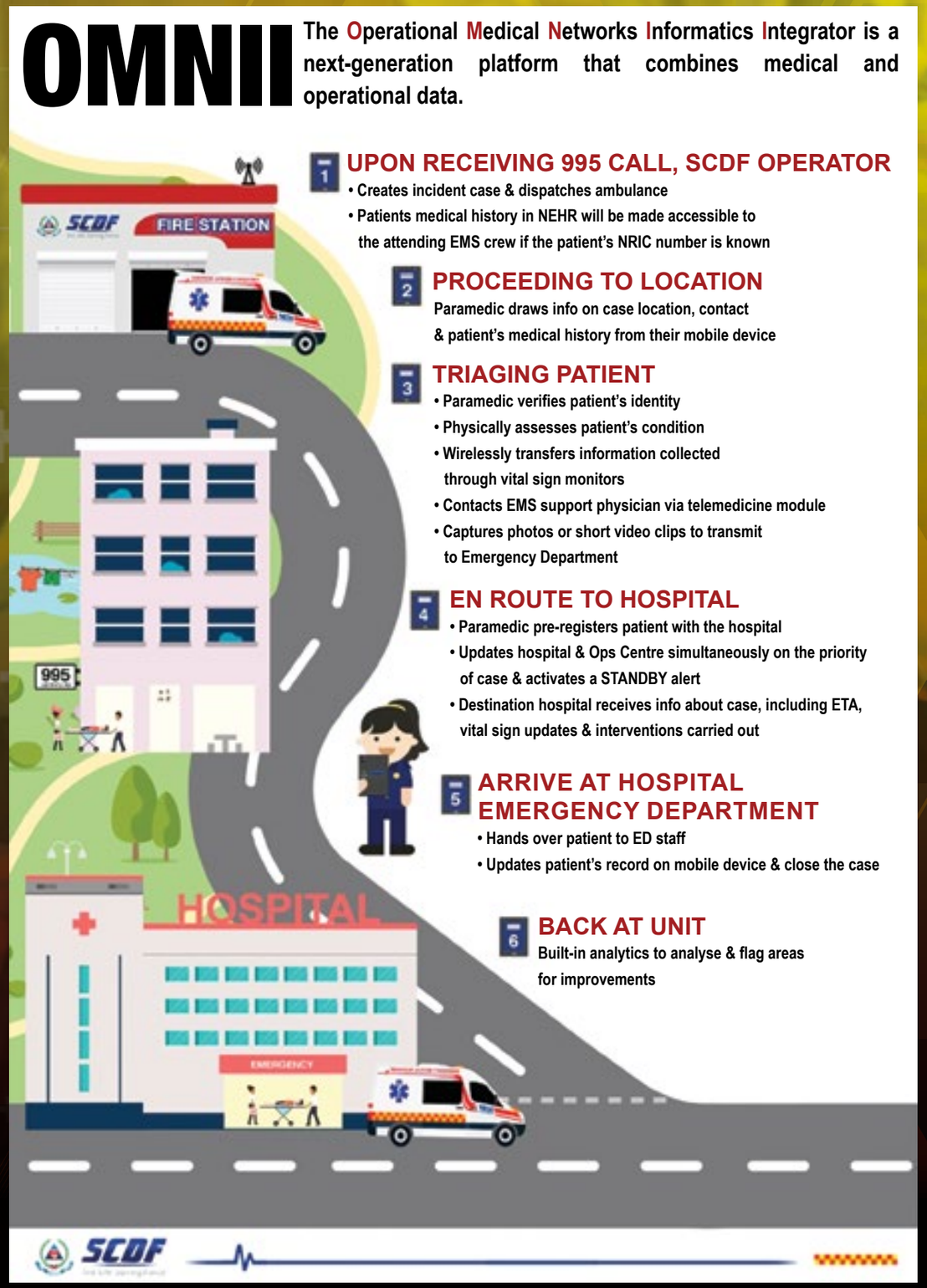
- SCDF paramedics can access their patients' NEHR via the OMNII app to view relevant medical data of the patient to guide their clinical management.
- Vital signs data measured by the various medical equipment on the ambulance would be transmitted wirelessly to the electronic Patient Care Record (ePCR) on OMNII.

Enhances Operational Efficiency

- Paramedics enter patient data, their clinical assessment, interventions carried out, and other information from the scene, such as photographs, onto the ePCR, all of which can be transmitted to the hospitals prior to the ambulance's arrival.
- Save time spent on patient registration and enable EDs to anticipate resources needed for incoming cases.

Improving Patient Outcomes

- For complicated cases, paramedics can seek medical advice from EMS support physicians using the telemedicine module within the OMNII app.
- Guidance on clinical protocols and operating procedures can also be better communicated using the telemedicine module.
- Reduces Door-to-Treatment time and preserves the 'golden hour' for better patient outcomes.



FIRE MODELLING ANALYSIS OF VERTICAL FIRE SPREAD IN HIGH-RISE RESIDENTIAL BUILDINGS

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EDITORIAL PREVIEW

In the early hours of 12 March 2020, 25 people were evacuated from their homes as a fire destroyed three flats in Block 845 Woodlands St 82. The fire, which started in a bedroom on the eighth floor, spread to the ninth and tenth floors. Vertical fire spread (VFS) is relatively rare in local fires involving high-rise residential premises — accounting for about 0.12% of all known residential fires in the past five years — but high-profile overseas cases such as the Grenfell Tower (2017, 72 deaths) and Ulsan Samhwan Art Nouveau (2020, 93 injured) fires illustrate the dangers of VFS.

Could safer building design have minimised VFS in the Woodlands fire? SCDF carried out fire modelling studies to gain some insight into how the fire behaved after it started on the eighth floor. The studies sought to understand how varying the building geometry could reduce VFS. Specifically, they were an attempt to evaluate the effectiveness of structures such as a 1.6 m-high fire-rated spandrel or a 0.6 m-wide horizontal projection in containing VFS in a high-rise (i.e. at least 24 m high) residential fire.[1] Notably, such buildings are exempted from sprinkler provision, which would otherwise help minimise the spread of a fire.

Q: What is a spandrel?

The external part of the building façade which vertically separates openings (e.g. windows) from each other.

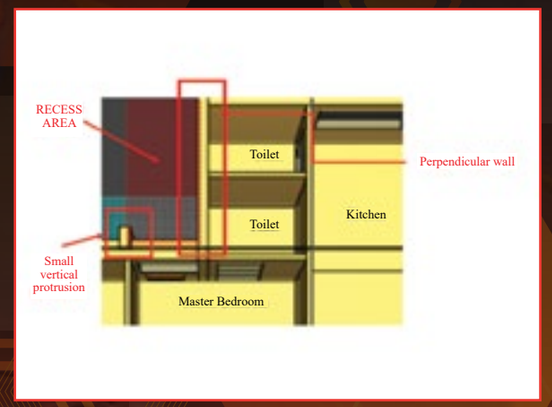
[1] As of Fire Code 2018, SCDF requires high-rise residential buildings to be designed with either a minimum 1.5 m-high spandrel or 600 mm-wide horizontal projection.

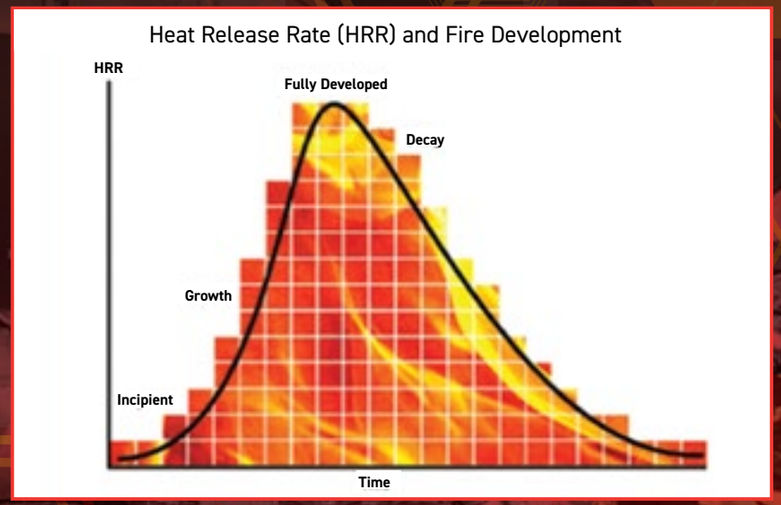
THE FIRE MODEL

Using the Fire Dynamics Simulator 6 modelling software tool, developed by the American National Institute of Standards and Technology, SCDF ran a simulation based on the design layout of the four-room flat involved in the Woodlands fire. The fire size was estimated to be 7.3 MW based on the contents of the bedroom (e.g. bed with spring mattress, wardrobe, bookshelf, etc.) where the fire originated.

In a typical blaze, fire undergoes several stages of development: incipient, growth, fully developed, and decay. At each stage, the heat release rate (HRR) increases except during decay when it decreases as the fuel for combustion (household contents) is reduced.[2] However, the fire model adopted a conservative approach by using a fire that was fully developed throughout the simulation study, i.e. until a steady state was reached.[3] Each simulation modelled 300 s of the fire burning in the bedroom. The study tested for radiant heat flux as well as factors which could contribute to fire spreading to the unit(s) above, e.g. through radiant heat scorching the walls or direct flame impingement through openings.

Six fire models were simulated by varying four factors, namely, (1) length of horizontal projection; (2) presence of spandrel; (3) presence of wall perpendicular to the building façade; and (4) presence of small vertical protrusion.





[2] Photo taken from journeytofirefighter.com.

[3] In future, with the completion of SCDF's fire research centre, the project team will be able to conduct actual fire tests to validate the computer modelling.

Model		Horizontal projection (mm)	1.6 m fire-rated spandrel	Layout with perpendicular wall	Small vertical protrusion
Base Case	1	200 (Actual)	No	Yes	Yes
Sensitivity Analysis	2	600	No	Yes	Yes
	3	200	Yes	Yes	Yes
	4	600	Yes	Yes	Yes
	5	200	No	Yes	No
	6	200	No	No	No


Model 1 (Base case)


Model 2


Model 3


Model 4

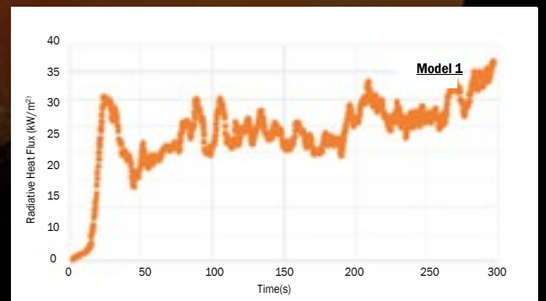

Model 5


Model 6

Model 1 (base case) was the actual design layout of the flat involved in the Woodlands fire. The building had a 200 mm horizontal projection and the spandrel was interrupted by air-con access openings covered up with plywood. In Model 2, the horizontal projection was increased from 200 mm to 600 mm to assess its effectiveness. In Model 3, the 1.6 m spandrel without the 600 mm horizontal projection was modelled. Model 4 included both the spandrel and 600 mm horizontal projection. For Model 5, the vertical protrusion was removed from Model 1. Finally, in Model 6, a flat layout was used, removing the wall perpendicular to the building façade.

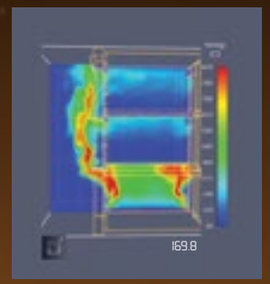
RESULTS AND KEY FINDINGS

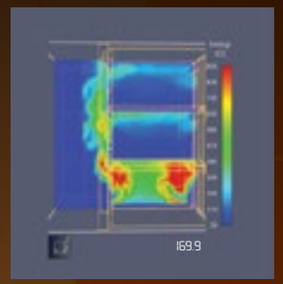
In Model 1, the radiative heat flux readings exceeded 12.6 kW/m².[4] At this value, cellulosic materials (fibres, paper, wood) can generally be expected to combust. VFS is thus expected, as most wooden combustible items within the units above would have ignited as seen in the graph on the right. The results also showed that the plywood gave way at 15.6 s and 22.5 s one and two floors above respectively. This mirrored fire investigation findings, which found that the plywood had burned through in the actual fire.

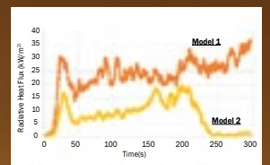


Model 1 (+1 Floor)

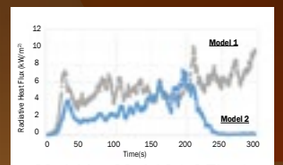
[4] The heat flux readings were taken by detectors positioned on the inside of the window, at one and two floors above.







Model 1 vs Model 2 (+1 Floor)



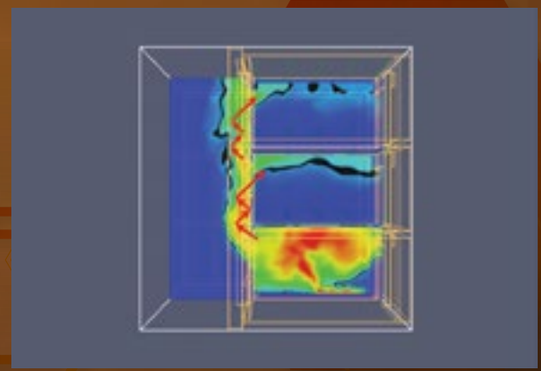
Model 1 vs Model 2 (+2 Floor)

Model 1 vs Model 2: Increasing the horizontal projection from 200 to 600 mm

In Model 2 (left), it was observed that the longer horizontal projection 'pushed' the hot gases away from the building façade. See Model 1 (far left) for comparison. This resulted in lower radiative heat flux on the upper two floors as shown in the graphs on the left. The plywood one floor above gave way at 167.4 s, while it did not give way two floors above, by the end of the 300 s simulation. It was, however, observed that, after a period, the flames would eventually cling to the building façade[5], especially the lower regions. This underscores the importance of having a spandrel above the horizontal projection to reduce the flames penetrating the floors above.

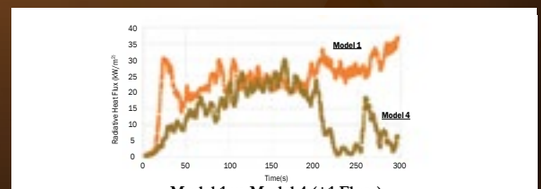
Model 1 vs Model 3: Having a 1.6 m-high solid spandrel without an opening in the spandrel

In Model 3, it was shown that the 1.6 m-high spandrel provided protection along the height of the spandrel. It is postulated that the fire-rated spandrel provided a surface against which to reflect and concentrate heat to the windows, thus resulting in higher heat flux at window level. However, given the possible presence of low-lying combustibles, a minimum height of spandrel is still needed to delay ignition of these combustibles.

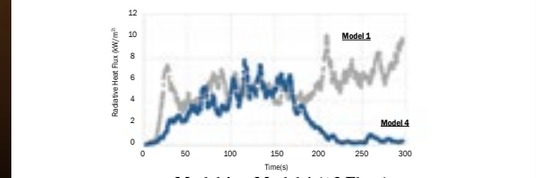


Model 1 vs Model 4: Having both the 600 mm horizontal projection and 1.6 m-high spandrel

The graphs on the right showed the effectiveness of the combination of horizontal projection and spandrel. The heat flux measured on the upper floors was reduced. For both one and two floors above, it was found that the two measures helped dissipate the heat after the 150 to 200 s mark.



Model 1 vs Model 4 (+1 Floor)

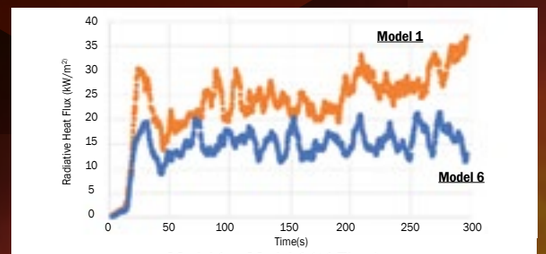


Model 1 vs Model 4 (+2 Floor)

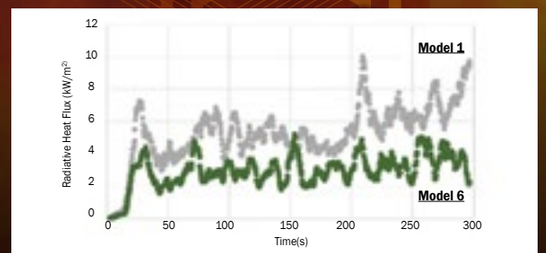
[5] Yokoi (1960) also observed from small-scale experiments a similar finding. It was observed in their experiment that the fire plume, as it rises, will converge to the trajectory similar to before it was affected by the horizontal projection. *Yokoi, S. (1960). Study on the Prevention of Fire-Spread Caused by Hot Upward Current. Building Tokyo: Building Research Institute, Ministry of Construction, Japanese Government, Report No. 34.*

Model 1 vs Model 5: Impact of the small vertical protrusion

There was little noticeable impact made by the small vertical protrusion on VFS. From the simulations, the outward 'throw' of the flame far exceeded the length of the small vertical protrusion. As a result, there appeared to be no significant effect on the heat flux readings. This was, however, not the case for the perpendicular wall, discussed in the next paragraph.



Model 1 vs Model 6 (+1 Floor)

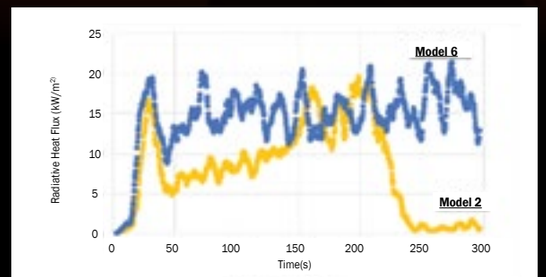


Model 1 vs Model 6 (+2 Floor)

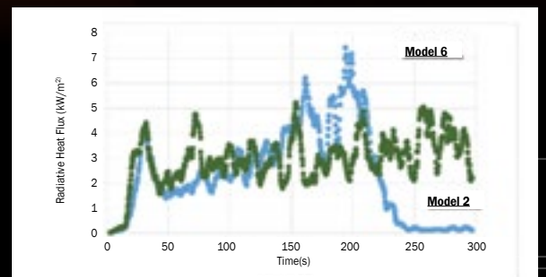
Model 1 vs Model 6: Impact of the perpendicular wall

In Model 1 vs Model 6, the readings showed that a flat layout (Model 6) generated lower heat flux readings, compared with the actual scenario (Model 1) that had a wall perpendicular to the façade. This was not unexpected as fire science literature shows that fires in corners tend to develop faster. This could be due to heat not being able to dissipate as well when enclosed on two sides. While this observation may be of limited architectural use in land-scarce Singapore, architects may consider this fact when designing their building layout.

Model 2 vs Model 6: Comparing benefits of a 600 mm horizontal projection vs flat layout



Model 2 vs Model 6 (+1 Floor)



Model 2 vs Model 6 (+2 Floor)

Moreover, when Model 2 (horizontal projection only, but with perpendicular wall) was compared with Model 6 (no horizontal projection, perpendicular wall removed), the benefits of the horizontal projection surpassed that of a flat layout — heat began to dissipate at about the 200 s mark in Model 2, whereas readings remained high in Model 6.

DISCUSSION

The results clearly show the benefits of having a horizontal projection to 'push' rising hot gases and flames away from the building façade in delaying the progress of VFS. While the spandrel did not have much effect on minimising flame propagation on its own, it did contribute to higher heat flux at the window openings on floors above the fire as the fire rose. A spandrel of a minimum height was, however, still needed to delay ignition of low-lying combustibles on the floor above the fire. The use of the spandrel must thus be complemented with a horizontal projection to push flames away from the wall.

Studies overseas corroborate the findings in this study. For instance, Igor Oleszkiewicz (1991), through fire tests, found that horizontal projections were effective, whereas for spandrels to be effective they would need to be impractically high.[6] Similarly, while Hong Kong requires either a 900 mm-high spandrel or 500 mm-wide horizontal projection, a 2001 review by Laou et al. found the horizontal projection to perform better than the spandrel.[7] In the case of New Zealand, various combinations of horizontal projection and spandrel are allowed, perhaps to give the building industry some flexibility (refer to table 5.4).

Spandrels and apron projections

Spandrels may be omitted where an apron, projecting no less than 0.6 m is constructed. Table 5.4 provides acceptable combinations of apron projection and spandrel height.

Table 5.4 Combinations of aprons and spandrels

Apron projection (m)	Spandrel height (m)
0.0	1.5
0.3	1.0
0.45	0.5
0.6	0.0

This study suggests that horizontal projections are needed to minimise VFS. To complement the horizontal projection, a spandrel of optimal height is needed to prevent ignition of low-lying combustibles. Further studies are underway to determine the optimal dimensions of horizontal projections and spandrels. While New Zealand's Fire Code stipulates this information, studies can be done to understand whether the data is applicable to Singapore, considering, for instance, the climate difference. With this knowledge, relevant fire safety provisions can be designed to further enhance fire safety in high-rise residential buildings.

LIMITATIONS OF STUDY

This study was designed specifically to focus on the layout of the Woodlands building affected by the fire on 12 March 2020. The findings may not be applicable to newer building layouts and larger or smaller flats with rooms of other sizes. For instance, fires in rooms with smaller windows may have a longer outwards 'throw', thus possibly needing longer horizontal projections to push the fire away from the façade. Future studies on VFS may be supported with actual fire tests to corroborate the findings generated by computer simulations.

CONCLUSION

With most of the population living in high-rise residential buildings in Singapore, containing VFS in such premises is of paramount importance, as it can lead to high casualties. SCDF will continue to explore ways to refine its Fire Code requirements and looks forward to working with relevant stakeholders.[8] Further studies can be jointly conducted to identify and implement the most effective ways to reduce VFS risks, whether to include horizontal projections, spandrels, or even fire safety measures, e.g. sprinkler systems.

6 "Vertical Separation of Windows Using Spandrel Walls and Horizontal Projections", published in Fire Technology Technical Notes.

7 "Performance-based Fire Engineering Design: Application of a CFD Model for the Prevention of External Fire Spread", M. Laou, L. Zhao, et al., Hong Kong, China.

8 Stakeholders such as the Housing and Development Board, the building industry, and the academia, etc.

EVOLUTION OF SCDF'S HAZMAT PREDICTION MODELLING CAPABILITIES

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EDITORIAL PREVIEW

Hazardous materials (HazMat) such as toxic industrial chemicals, when released, could have dire consequences, for example, affecting the health of the population and damaging property and infrastructure. There is, therefore, an impetus to be able to predict how far they can spread. Hazard prediction modelling provides an estimate of areas likely to be affected and ambient air concentrations. This would allow emergency response agencies such as SCDF to take appropriate action — evacuate the people, if necessary, or ensure in-place protection (IPP). With the advent of modern technology, the Hazard Prediction Modelling Software (HPMS) was developed to provide advanced plume dispersion modelling capabilities for the Whole of Government (WoG) to provide decision support during HazMat incidents.

INTRODUCTION

Hazardous materials range from toxic industrial chemicals to radiological agents and have widespread application in various industries (e.g. medical applications and chemical processing). In spite of regulatory measures to ensure that these hazardous materials are used safely, there are risks of HazMat incidents. Inadvertently or deliberately with malicious intent, hazardous materials may be released into the environment. There could be accidental liquid spills or direct airborne release. When the discharged hazardous material becomes airborne and is further propagated by wind beyond the incident location, there could be adverse effects on public health and widespread damage to the environment, critical installations and property.

Such HazMat incidents are a matter of concern to the public and authorities. Airborne hazardous materials could travel far and affect a large area. Therefore, there is an impetus to understand the nature of the hazardous material and ascertain how far it has spread in a HazMat incident to enable timely countermeasures, so as to safeguard public health and protect property. For example, the public would be advised to either evacuate to safety or perform in-place protection (IPP), so as to avoid exposure to hazardous substances and minimise the risk of health effects.

As part of incident response management, emergency response forces will go on site with various HazMat sensors to determine the severity of the incident. However, HazMat sensor readings would not have sufficient spatial resolution for hazard zone mapping and would not be able to project the plume trajectory. There is, therefore, a need to perform dispersion modelling, and have on-site information for plume projection to enhance situational awareness during an incident and to enable appropriate downstream response actions to be taken.

HAZARD PREDICTION MODELLING

Hazard prediction modelling by emergency response forces involves estimating the amount of hazardous material released and propagated downwind via dispersion modelling and ascertaining if the dispersed hazardous material would pose a human health hazard via health effects modelling. This may be done as part of:

- pre-incident planning operations, using historical information to determine countermeasure resource allocation;
- ongoing real-time response, using real-time sensors to guide emergency response deployment;
- predictive operations, to determine how the incident will evolve, based on predictive weather information; or
- post-incident operations, to determine the extent of post-incident cleanup required.

Dispersion modelling software predicts and analyses the propagation of hazardous materials into the atmosphere. Such models require environmental information on the affected premises (e.g. weather conditions and type of terrain) and on-site observations by frontline responders, who have to ascertain the incident release location and mechanism as well as the properties of the hazardous material, typically known as the 'source term'. These inputs are needed for the dispersion model to ascertain the atmospheric transport of hazardous materials.

Atmospheric dispersion models vary in complexity, from the simple Gaussian Plume Dispersion Model, which is expedient in computation but unable to account for the spatial and temporal heterogeneity of wind information, to the sophisticated Computational Fluid Dynamics (CFD) Dispersion Model, which is able to account for complex wind patterns within urban environments. Sophisticated models are more computationally intensive and suited for pre-incident planning operations. For real-time response, the Gaussian Puff Dispersion Model, which is able to account for spatial and temporal heterogeneity of wind patterns at a reasonable computation expense, is widely used.

The estimation of the 'source term', a key input for dispersion models, involves figuring out how much of the hazardous material has been initially discharged in the atmosphere. The extent to which the airborne material is propagated is dependent not only on the amount released but also on the hazardous materials' physico-chemical properties (e.g. boiling point) and storage conditions. Thus, a deep understanding of chemical industrial processes and knowledge of the properties of the hazardous material are required.

Weather conditions (e.g. wind) are another important input for atmospheric dispersion models, which determine how airborne materials are propagated. While historical weather information is useful for pre-incident planning, real-time and prognostic weather data are needed to enable timely incident response and prognostic plume estimation.

The dispersion area and the effect on public health could be estimated by human effects modelling to assess the risks to the surrounding population and property in the affected zone. The extent of health effects is dependent on the duration of exposure and concentration level of the hazardous material. Incident management agencies would refer to these hazard zone estimations to ascertain the impact of release, allocate resources and devise operational responses to manage the incident.

Hazard prediction modelling (hazard zoning) is, thus, critical to the development of prompt and effective location-specific alerts and warnings, which should be communicated via public broadcast systems to avoid unnecessary exposure to hazardous materials, should an incident occur.

USE OF HAZARD PREDICTION MODELLING BY SCDF

In Singapore, SCDF has been leveraging hazard plume dispersion models to support its contingency planning and emergency response actions. The first iteration used for dispersion modelling was based on a commercial-off-the-shelf (COTS) standalone software for chemical incidents. Though useful for planning operations for contingency standby events, the software as a standalone COTS model was not easily customisable and not integrated with the systems of other WoG stakeholders for nationwide emergency response operations. There were other advanced algorithms which could not be included in the software. In addition, the capabilities of hazard prediction modelling in the COTS software were limited to scenarios based on the release of chemicals and did not include modelling for other types of hazardous materials, such as radiological agents.

Hazard Prediction Modelling Software

As there is a need for hazard prediction capability customised for Singapore's environment and designed to evolve with ongoing algorithm advancements, the Hazard Prediction Modelling Software (HPMS) was conceived by DSO National Laboratories (DSO) to enable decision support for WoG during chemical and radiological incident response operations in Singapore and designed to evolve according to the increasingly complex needs of emergency responders.

SCDF acquired the first-generation HPMS in 2020 when the system also came into possession of the Singapore Armed Forces (SAF) and the National Environment Agency (NEA), which utilises validated algorithms coupled with local historical weather and local terrain information to facilitate radiological incident emergency response planning operations. This version of HPMS is able to model dispersion over kilometres (i.e. mesoscale) in various scenarios, accounting for the different modes of radiological agent release.

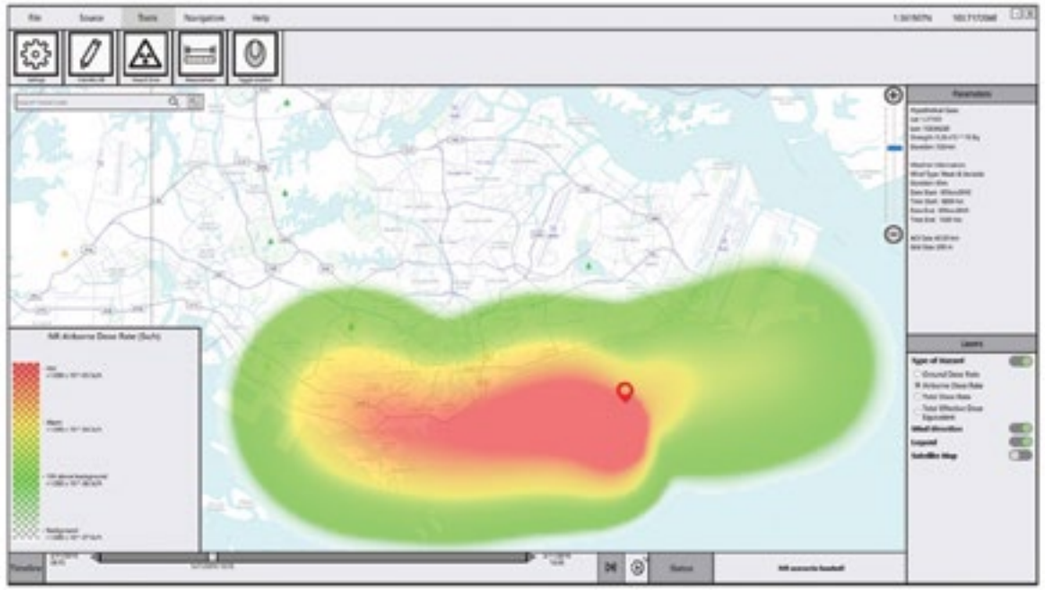

Figure 1: Illustration of hazard prediction output from the 1st generation HPMS

The HPMS is now being evolved to support WoG real-time operations for improved situational awareness, enabled by the following sensor-driven algorithms:

- Chemical Sensor Information Harmonisation: In the early phase of an incident, the identity of the incident chemical is likely to be unknown and emergency responders would have to make sense of potentially conflicting information from a suite of chemical sensors of different characteristics (e.g. detection sensitivity, detection thresholds). This implies that the responder might not be able to identify the chemical with certainty should he or she encounter sensor readings of various chemical identities. An algorithm is thus incorporated to automatically harmonise multiple sensor information, considering the different sensor technologies and chemical characteristics, to enable chemical identification with a higher certainty, so that appropriate downstream measures can be taken to address and mitigate hazards associated with the identified chemical.

- Incident Localisation: If the identification of the incident chemical takes place at locations far away from chemical storage locations (e.g. residential areas), the next question would be what is the source of the chemical release. To that end, a real-time localisation algorithm will be incorporated to advise on probable release source locations, using real-time wind field information generated by wind sensors across the island.

- Plume Dispersion Modelling/Hazard Zoning: To enable real-time hazard zoning once the source of the incident is confirmed, the current algorithm used in the first generation of HPMS will be enhanced to enable real-time mesoscale dispersion of hazardous materials, informed by wind field information generated by wind sensors across the island. To complement the mesoscale dispersion capability and to better characterise small-scale building-influenced dispersion patterns near the incident release site, plans are underway to incorporate an urban 3-D Plume Dispersion Model to enable 3-D visualisation of the plume, to better facilitate planning operations.

The capabilities of the HPMS will continue to evolve in tandem with the advance of technology to better meet user requirements. Additional modules (e.g. plume projection using predicted weather information) would be incorporated in the future to estimate how hazards will evolve over time to better enable pre-emptive countermeasure decisions. This way, the incident manager would be able to know when the plume would reach a particular location of concern, so that timely protective measures can be taken.

The HPMS' development requires multidisciplinary capabilities, involving chemical/nuclear engineering, atmospheric sciences, chemistry, software engineering and human factor engineering to deliver a useful capability for emergency management. This has been possible with the collaboration and cooperation of various stakeholders. With increasingly complex user requirements and a constantly changing security landscape, the HPMS' evolution needs to be accelerated. This would require even closer interaction with various governmental bodies, the industry and academia.

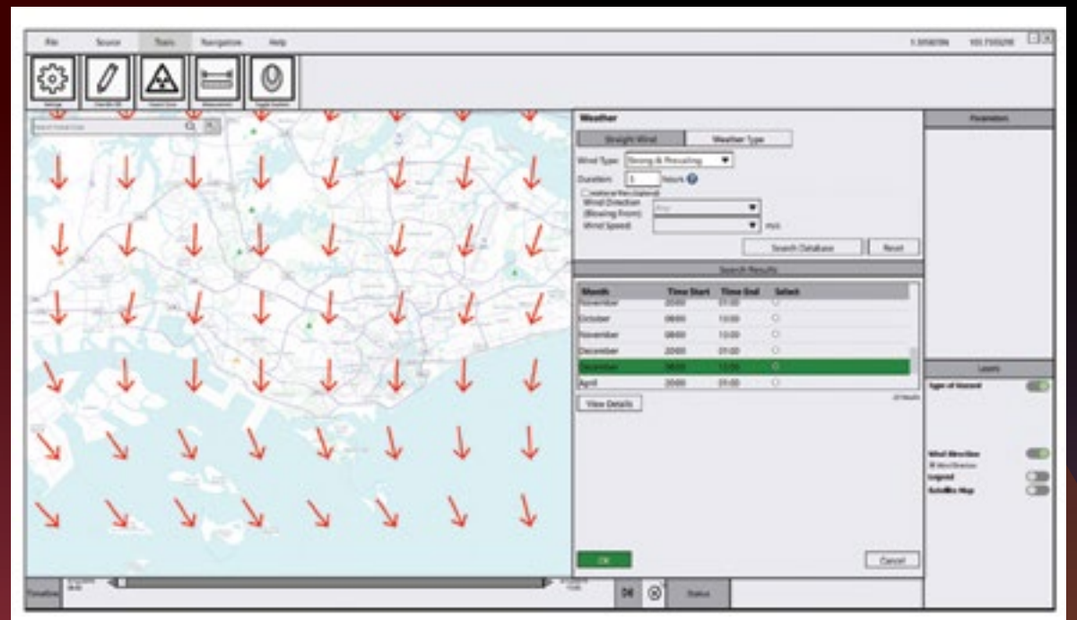

Figure 2: The HPMS user interface facilitates selection of historical local weather information to support planning operations

CONCLUSION

Plume dispersion modelling is essential for the protection of the population from harmful effects of hazardous materials as well as for devising appropriate emergency response action plans in the event of accidental or malicious releases. In spite of the ever-changing security landscape and needs of the industry, the HPMS team remains steadfast in its commitment to enhancing its capabilities to keep Singapore safe.

SCDF acknowledges the technical contribution and collaboration of the team from DSO in the development of HPMS.

APPLICATION OF ROBOTICS FOR SCDF OPERATIONS

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EDITORIAL PREVIEW

SCDF began its robotics exploration with the Unmanned Firefighting Machine (UFM) in 2014. The UFM is a ruggedised robot that has been deployed for many SCDF operations, mostly industrial fires that require large-scale manpower and coordination. The UFM has been able to provide us with sustained firefighting power especially for prolonged operations (some of these operations can last for six hours or more). SCDF has also been exploring various other platforms to enhance operational response and to alleviate manpower crunch.

Unmanned Ground Vehicles (UGVs) are robotic systems that operate on land without an onboard human operator. At its current state, SCDF has a fleet of UGVs serving various functions, ranging from firefighting to HazMat monitoring and rescue. SCDF has also embarked on various platforms such as wheels, tracks and even quadruped robots. The amalgamation of robotic platforms and responders will provide leverage for enhancements in operations and training.

Robotics platforms would also provide new tactical options. SCDF responders are better equipped to deal with emergencies from the inside out. Robots can penetrate straight into the heart of a hazard and perform surgical procedures, such as cutting off the source of fuel. SCDF would be able to mitigate emergencies in the shortest time possible. Essentially, the advent of robotics in SCDF has enhanced the safety of our responders and allows our responders to focus on other critical aspects of operations. SCDF has also embarked on platforms that will traverse the sea, such as Unmanned Surface Vessels (USVs) and platforms that will provide aerial superiority such as Unmanned Aerial Vehicles (UAVs).

EMERGING TRENDS

Technological developments are transforming the work processes and operational capacity of many organisations around the world. As technology develops, the extent of human-machine interaction increases in tandem with the complexity of the interactions. SCDF will be leveraging on emerging technologies to advance the existing robotics platforms. For example, video analytics coupled with edge computing will increase the speed of detection of anomalies and hazards. Advancements in scanning technology will allow robots to map the environment and track local position, enabling commanders to make prompt decisions during tactical operations.

Robotic manipulation, teleconferencing, augmented reality, and low-latency communication networks such as 5G are increasingly maturing. With the incorporation of such technologies, we will be able to alleviate gaps in frontline emergency responses. The envisaged robotics platforms of SCDF will constantly provide critical information to responders, while carrying out tasks pertaining to the operations. Feedback will be provided by the robots to responders to monitor the status of incidents. This process flow for UGVs in SCDF operations has been mapped out, as shown below.

Figure 1: Process flow for SCDF UGV Ops

UGV CAPABILITIES ROADMAP

In consultation with the Home Team Science and Technology Agency (HTX), SCDF has projected the technological capabilities for SCDF ground robotics over a span of five to ten years. Robots will undergo iterative upgrades as the technology reaches maturity in the industry.

UNMANNED GROUND VEHICLES (UGV) CAPABILITIES ROADMAP

Areas of Focus	Before 2020	2021	Towards 2025	2025 - 2030
Environment Sensing (Perception)	Basic Waypoint Navigation	Navigation in Challenging Terrains	Autonomous Exploration	Swarm Technology for Multiple Purposes
Planning and Decision Making (Analysis)	Basic Monitoring - Location, Camera, Battery/Fuel, Sensors	Able to monitor and track all robots at incident	UGV to make sense of sensor information; Machine learning for UGV to recommend actions	
Operations and Control (Action)	Single user controls a single robot to carry out a single function	Modular & Multipurpose Robots	Single user controls multiple robots with BVLOS and autonomous features	

Figure 2: Unmanned Ground Vehicles (UGV) capabilities roadmap

Rapidly Evolving Environment

Technology is transforming work processes and operational capacities of organisations globally. COVID-19 has led to a surge in demand for robots to assist with tasks such as monitoring people, sanitising environments and making deliveries. SCDF is working towards an autonomous, self-diagnostic, remotely operable, seamless ecosystem of multi-modular UGVs by 2030. It envisages a future where robots will interact with each other and provide remote diagnosis and analysis to users. The UGVs should also operate autonomously with little human intervention. The envisaged UGV capabilities, especially lessons from SCDF's experience in operating firefighting UGVs, will advance its overall application of UGVs, significantly alleviate manpower needs and improve responder safety in operations.

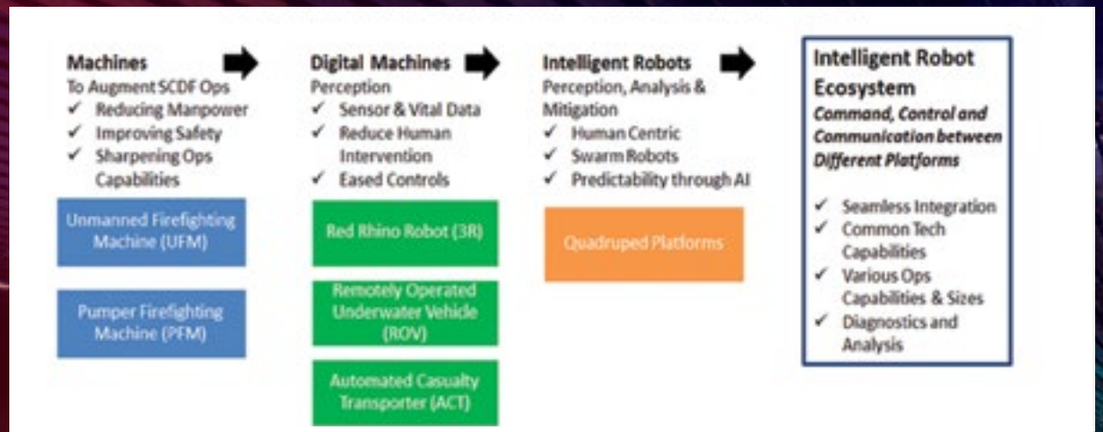

Figure 3: Envisioned robotics evolution in SCDF

Further Advancement in Concept of Operations

Swarm robotics will provide an agile way to gather large amounts of data and coordinate operations of multiple robots. Swarming capabilities will allow for a multi-pronged response from various robots for a range of tasks, e.g. situational awareness, firefighting and mitigation, casualty conveyance and back-end logistics transportation.

The boundaries of remote control will also be pushed with the integration of a low-latency 5G network. Robots could be controlled beyond the line of sight and monitored centrally in real time. When deployed for operations, robots could be automatically despatched, ready to carry out required tasks. On site, multiple robots will be operated by a single operator, through an integrated console that will connect to all robots at the incident site. Data, images, and videos collected from the robots will be used for better sense making. Together with cameras and sensors from UAVs, the commanders will have a comprehensive and holistic situational picture.

Improving Management of Robots

Operational readiness of robots would be centrally monitored through remote diagnostics, with a central server monitoring the status of robots providing alerts of possible hardware or software issues and intelligently scheduling the servicing of robots. IOT sensors on board robotic platforms will seamlessly provide data on vital statistics of the robots and their surroundings. This data will then be centrally available to sustainment personnel, responders and commanders through smart devices such as tablets and smartphones for immediate rectification should a robot malfunction.

CONCEPT OF OPERATIONS FOR FIREFIGHTING UGVs

Two-Tier Firefighting UGV Deployment Approach

SCDF's use of firefighting UGVs represents its most developed concept of operations (CONOPS), the fruit of its experience since it began deploying UFMs in 2014. In 2020, SCDF laid out its firefighting UGV CONOPS as a two-tiered deployment approach.

Tier 1 comprises high-availability firefighting UGVs — namely the Pumper Firefighting Machine (PFM) and Red Rhino Robot (3R) — that are available on Pump Ladders (PLs) and Light Fire Attack Vehicles (LFAVs) at all fire stations. These UGVs are generally quicker to deploy and are equipped with smaller water monitors for tackling small to medium fires. They can perform simple tasks such as carrying light equipment and pulling short lengths of water hose.

Image 1: Pumper Firefighting Machine (PFM)

Tier 2 UGVs are strategically placed at selected stations based on risk assessment. These UGVs have higher monitor outputs and longer throwing ranges and would augment Tier 1 UGVs to tackle large fires. Currently, SCDF's Tier 2 UGV arsenal comprises the UFM1.0s and UFM2.0s. These are transported to the incident site using dedicated lorries. While useful and well-proven in many operations, the existing UFMs have constraints due to monitor output, size and limited mobility. SCDF is currently developing UFM3.0, which comes with an articulated arm and a higher monitor output. These are significant enhancements compared to earlier UFMs.

However, a highly mobile platform would be needed for UFM3.0 to deliver firefighting streams deep into the heart of a fire. This class of UGVs, conceptualised as the High Mobility Modular Machine (H3M), is envisaged to operate as a pair with the UFM to meet the full spectrum of capabilities required in Tier 2 UGVs. These UGVs will be transported in purpose-built vehicles, known as the Robot Tenders.

Unmanned Firefighting Machine Version 3.0 (UFM3.0)

An upgrade from the current generations of UFMs, the UFM3.0 will provide a higher output of firefighting medium, almost twice that of the UFM1.0, and better ventilation capabilities. The UFMs will enable large water streams to be adjusted and redeployed to meet operational demands. Furthermore, the UFM3.0 will also be equipped with an articulated arm, extending its reach around and/or over obstacles for more effective firefighting. Furthermore, the ventilation system could be positioned strategically above ground to enhance visibility and ventilation. The swifter commencement of offensive firefighting will translate into an earlier mitigation of the incident and possibly quicker recovery.

Image 2: Unmanned Firefighting Machine 2.0 (UFM2.0)

High Mobility Modular Machine (H3M)

Currently, for firefighters at the forefront to carry the nozzle to manoeuvre the water stream to desired locations, other firefighters have to be deployed some distance behind to help 'feed' the hoses and allow the team to push in. The H3M will have traction capacity of up to a tonne and a payload capacity of up to 500 kg. This will enable it to clear heavy obstacles and pull an equivalent of two lines with three lengths each of charged water hose deep into the seat of a fire. This will reduce the need for firefighters to perform the task manually.

Having the ability to switch between modules will enable the H3M to perform a wide range of functions required during a firefighting operation. For instance, the water monitor on the H3M can be changed to an equipment basket to help responders transport heavy equipment over a long distance, thus reducing physical fatigue among our crew. It can also be replaced with a stretcher to convey casualties from risk areas to control points where first aid can be administered. This will be particularly beneficial when there are many casualties involved in the incident.

Apart from firefighting and carrying equipment, there are other modules which can be fitted onto the H3M to provide a wide range of supporting capabilities. The motorised bull-bar module allows the H3M to clear heavy obstacles easily and facilitate brute-force entry without additional equipment.

In addition, the H3M will be able to transmit sensor images and information, such as thermal images, night vision and detector readings, to command elements for sense-making, without first committing personnel into risky areas for ground assessment.

ROBOTIC CAPABILITIES FOR MARITIME OPERATIONS

SCDF is also expanding its fleet capacity for Full Operational Capability (FOC) through acquisition of buffer fleets such as new-generation Heavy Fire Vessels (HFVs) and Rapid Response Fire Vessels (RFVs). It is working closely with HTX Robotics, Autonomous and Unmanned System (RAUS) Centre of Expertise (CoE), HTX Marine System CoE and Defence Science and Technology Agency (DSTA) to acquire such vessels. By exploring unmanned marine technologies and extending them to seaward applications, SCDF is enhancing incident management and sense-making for both land and marine domains while optimising manpower resources.

With no prior knowledge and experience in unmanned technologies in marine domains, SCDF is collaborating with HTX RAUS CoE to develop radically new USV and UAV technology for responders to handle maritime incidents in a more aggressive, safe and efficient manner. It also validates the feasibility of autonomous operations with UAV and USV through Proof-of-Concept (POC) trials. The outcome of the POC trials will help formulate technical specifications of unmanned systems for both UAVs and USVs.

New-Generation HFV with Unmanned Technologies

The new HFV is primarily deployed for firefighting (FiFi) operations and can double up as the command vessel (i.e. tactical HQ) to manage a second major incident such as HazMat and search and rescue (SAR) at sea. The new-generation fleet will operate with three robotic capabilities, namely Marine UAV, organic USV and Remote Operating Vehicle (ROV). They are able to transmit data such as thermal images and detector readings to incident command for sense-making, without committing manpower into a risky operating environment first for assessment.

The Marine UAV will be housed in a drone box prior to deployment. Upon incident activation, the operator deploys it to the casualty vessel or incident location for an Appreciation of Situation (AOS), which is often affected by factors such as weather and the size of the affected vessel. By providing incident command with a clear perspective from a bird's-eye view, the UAV helps decision makers by determining the location of fire/rescue and assessing the hazardous area, if necessary, via a built-in camera. In addition, the use of interchangeable payloads enables marine personnel to tackle the incident remotely, which translates into operational effectiveness and personnel protection.

A 6-metre organic USV will be located at the back of the HFV. It can be launched and recovered from the mother platform, that is, the HFV itself. As it is smaller and nimbler, it can manoeuvre in non-navigable, shallow and confined waters that are not reachable by bigger vessels. Since the primary function of the USV is to gain access to non-accessible areas, it can carry out autonomous surveillance (i.e. monitoring and AOS) and aid in decision-making, as well as facilitate SAR operations.

The ROV takes the role of a 'first diver' to search in unfavourable underwater conditions. During rescue operations in poor visibility where a human diver's vision is limited, the ROV can help the operator investigate and locate survivors and victims with a video feed providing more situational awareness underwater. Sending the ROV to search at a deeper operating depth also eliminates the risk of deploying personnel beyond safe depths and expands underwater search capabilities.

New-Generation RFV

The new RFV, which can operate both manned and unmanned, will be able to tackle a wider range of operations. A manned RFV requires a crew of four to operate, which can be manpower-straining if the fleet has to be expanded. The new-generation RFV will require minimal manpower to operate. This will reduce the need for personnel to perform tasks manually and optimise manpower.

When responding to an incident, the new RFV can either be manned by an operator or travel unmanned, aided by collision-detection and collision-avoidance technologies. Upon arrival, the RFV will be controlled by an operator to conduct the initial AOS. During high-risk FiFi or HazMat monitoring operations, the RFV moves either autonomously or under remote operator guidance with its built-in platform for station-keeping and water trajectory compensation technologies. While performing a high-risk task, the RFV can provide the Maritime Situational Picture by transmitting the video feed via VSAT/LTE from its all-round perception camera and seaborne Electro-Optic/Infra-Red sensor.

CONCLUSION

Given the hazardous and complex environments that responders are exposed to, there is a growing need for robotics in SCDF's daily operations. Robotics will provide an avenue for enhanced safety and capabilities while improving the response to emergencies. With the industry's move towards seamless integration of robotics and automation in work processes, SCDF will continue to explore new possibilities in robotics to enhance its capabilities and be a global leader in autonomous fire safety and emergency response.

REMOTELY OPERATED VEHICLE – ENHANCING WATER RESCUE CAPABILITIES

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EDITORIAL PREVIEW

Under SCDF's concept of operations (CONOPS), when there is a water mishap, divers from the Disaster Assistance and Rescue Team (DART) are deployed to search for drowned victims with the aim of rescue or retrieval. Operating with an eight-man crew, the deployment of DART divers for underwater search and rescue is both dangerous and time-consuming.

With improvements in technology, SCDF began using a remotely operated vehicle (ROV) with sonar to search more efficiently and ensure greater safety of DART divers during water rescue operations. The introduction of ROV ultimately reduces search time and risks to divers. At the same time, it helps to conserve divers and dive cylinders for the actual extrication and retrieval operation. The use of ROV for inland water search and rescue has been found to improve the operational effectiveness of SCDF and DART.

INLAND WATER SEARCH AND RESCUE

SCDF responds to water rescue incidents, which account for around 1.3% of incidents annually. SCDF's current operating terrain in water rescue incidents includes 4 nature reserves, 22 active water projects, marine industrial areas, and Singapore's coastline of 193 km. This makes it imperative to review and improve the response capabilities to ensure that SCDF is adequately prepared to respond to any water-related incident.

Geographical Landscape of Singapore

Singapore is a very small island city-state located at the south end of the Malayan Peninsula. It is a highly urbanised city with a dense population of about six million people occupying a total of 724.2 square kilometres of land area.

Historically, Singapore has been a trading port, with ships coming through and plying their trade along the Singapore River. These days, while Singapore is still dependent on trade as a port, traders no longer conduct business on inland water bodies such as the Singapore River. However, the inland water bodies still play an important role for essential services and recreation.

As Singapore lacks natural freshwater rivers and lakes, efforts have been made to retain as much rainwater as possible for recycling and domestic water use. This has resulted in the creation of numerous water bodies to help direct and house the collection of rainwater. To achieve this, Singapore has constructed a total of 17 reservoirs with a network of 38 rivers and canals to help channel our inland waters. This has resulted in water catchment areas making up two-thirds of Singapore's total land surface area.

Image 1: Overview of inland water bodies in Singapore

Types of Underwater Rescue

With limited land space being a challenge in Singapore, some of these water bodies have dual purposes. Besides meeting the water demands of the country, some of these inland water bodies also serve as venues for activities such as water sports and tourism. The following examples are the possible types of scenario that may require underwater search and rescue:

a. Water sports incident. With the growing affluence of Singaporeans, new water sports will find their way to the island state. Existing water sports and their possible venues include wakeboarding at Punggol Marina, windsurfing along the shoreline of Changi Beach, canoeing at MacRitchie Reservoir, sculling at Pandan Reservoir and multi-discipline sports along East Coast Park. Incidents may arise from accidents or participants' failure to observe safety procedures.

b. Suicide incident. SCDF has responded to several suicide incidents occurring at inland water bodies. Victims of such incidents are normally non-swimmers or weak swimmers who have decided to take their own lives by drowning.

c. Mass casualty incident. There could be mass casualties if a ferry or a bumboat sinks. With the rapid development of water rides like the Singapore River Water Taxi and Duck Tour to boost the tourism industry, we cannot rule out the possibility of a mass casualty situation resulting from an accident involving such vessels.

d. Industrial and vehicular incident. Such incidents will range from waterfront industrial or construction site collapsing to motor vehicles plunging into water bodies due to an accident.

e. Other water rescue incidents. Patrons of waterfront amenities like pubs and eateries may also become victims of water incidents. Possible scenarios include victims under the influence of alcohol falling into water near these amenities.

When someone drowns in an inland water body, he or she sinks immediately. This results in the victim reaching the bottom close to the point where he or she was last seen on the surface. Almost without exception, a dead body lying on the bottom of a river or lake will rise to the surface eventually.[1] This is due to gases formed in the body tissues as decay occurs. When enough gas has formed to inflate the tissues and distend the skin, the body becomes lighter than water and rises to the surface. However, this process takes up to a few days in warm waters, and even longer in cold water bodies. Hence, there is a need to deploy divers or rescuers underwater to retrieve the drowned victim.

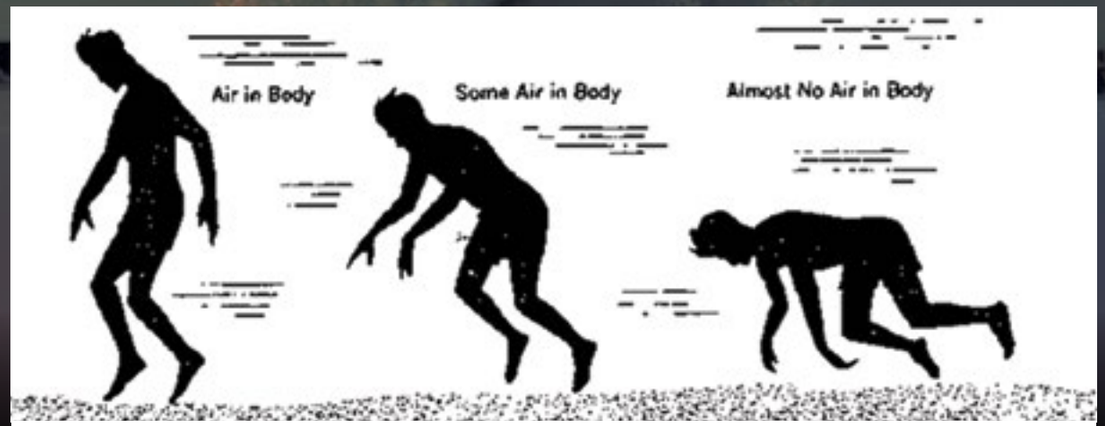


Image 2: Position of the human body in the water after sinking (extracted from Flood Rescue Boat Operation — Australian Emergency Manual)

[1] National Disaster Organisation, 'Flood Rescue Boat Operation — Australian Emergency Manual'.

CONOPS

The CONOPS for a water mishap incident entails the deployment of divers to search for the victim with the aim of rescue or retrieval. DART is the only unit in SCDF which can perform such underwater search operations. Operating with an eight-man crew, the deployment of divers for underwater search and rescue is both dangerous and time-consuming. Divers are deployed in pairs in water bodies with poor visibility and they perform a manual search using their hands, moving in an arc to locate the victim.

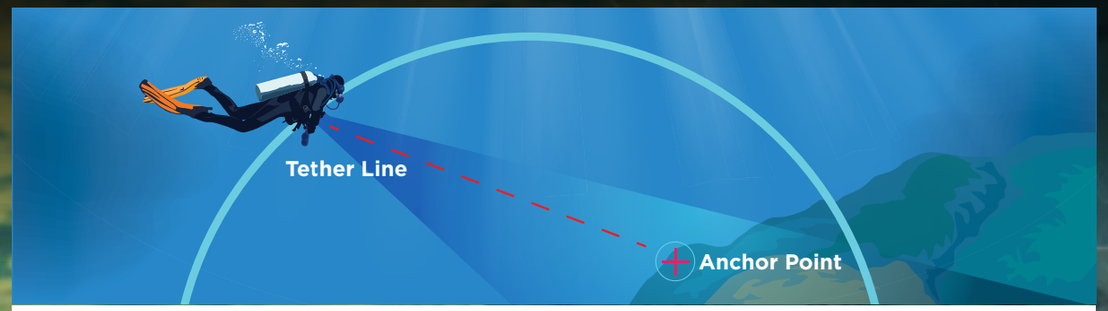


Image 3: Example of the arc search pattern

With improvements in technology, SCDF began using ROVs with sonar[2] to search more efficiently and ensure greater safety of DART divers during water rescue operations. The current operating terrains present a variety of challenges: low visibility, uncharted underwater environment, and sunken objects such as broken bottles and metal bars underwater pose risks for divers.

The introduction of ROVs ultimately reduces search time and risks to divers. At the same time, it helps to conserve divers and dive cylinders for the actual extrication and retrieval operation. The ROV incorporates the following technologies:

a. It uses multi-beam sonar imaging (Dual Frequency 750 kHz/1.2 MHz) to quickly and accurately scan the search area and locate the victim;

b. It is equipped with high-definition cameras and high-capacity illumination to transmit the sub-terrain information to the commander on the surface via video feed;

c. It is equipped with tracking capabilities to allow operators to geo-locate the ROV on Google Maps; and

d. It is capable of autonomous navigation by plotting of waypoints on Google Maps to set the search path for the ROV.

[2] Sonar stands for 'sound navigation and ranging'. More information on how it works can be found at https://bluerobotics.com/learn/understanding-and-using-scanning-sonars/

CONOPS with ROV

With the inclusion of the ROV in CONOPS, the ROV will be deployed first to confirm the presence of the victim and divers only later for subsequent retrieval and recovery. The ROV's multi-beam sonar imaging system allows it to provide a clear image of the underwater terrain despite the murky inland waters in Singapore. This allows the ground commander to have visual confirmation of the victim before deploying divers for search or recovery operations, thus minimising the risks to divers operating in waters with poor visibility.

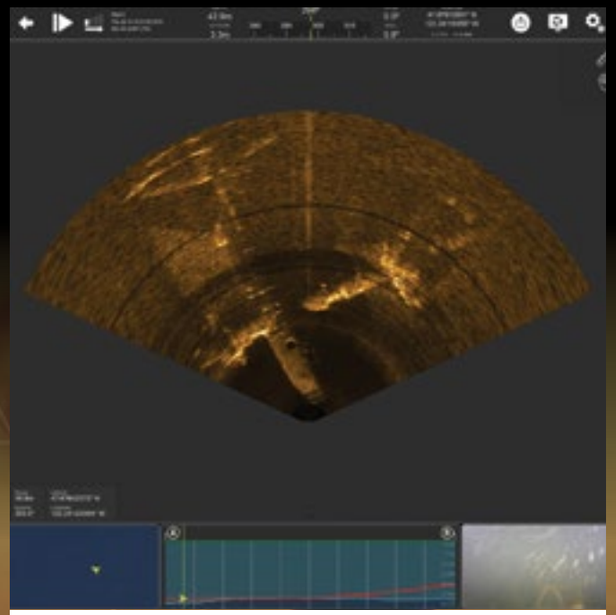


Image 4: Example of sonar image of underwater terrain

Several lessons have been learnt since the deployment of the ROV during actual operations and training:

a. Sonar imaging provides a clearer image. The ROV's multi-beam sonar imaging system allows it to provide a clear image of the underwater terrain despite the murky inland waters in Singapore. This would allow the ground commander to have a visual confirmation of the victim before committing divers for search or recovery operations.

b. Deployment of ROV from the onset. The ROV will be deployed when DART arrives on location, except for incidents where the victim is floating. The ROV will focus on underwater searches while a separate team consisting of four men will focus on surface searches. Divers are only deployed to investigate after the ROV detects something that resembles the victim from the sonar scan. The sonar and video images from the ROV will allow the ground commander to have an indication of the underwater terrain, hazards and to guide the divers to the victim. This enhances operational effectiveness while reducing the risks to divers.

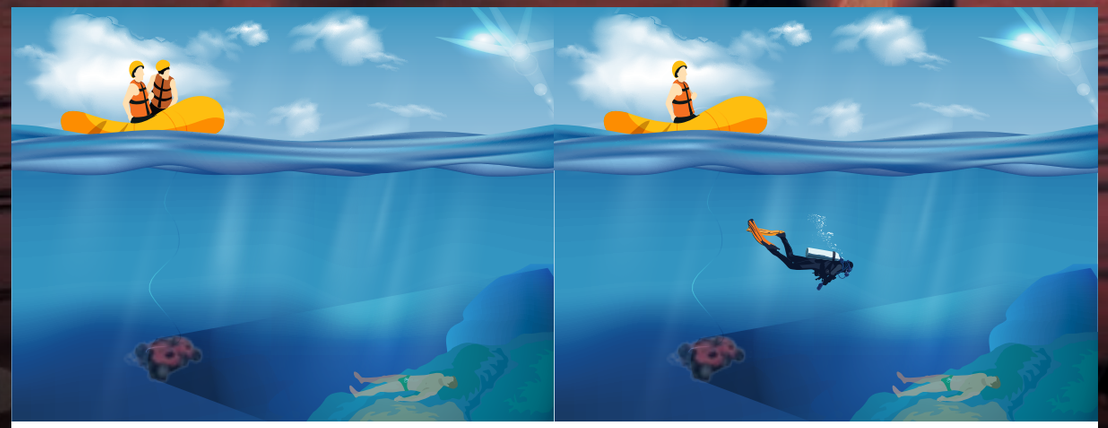


Image 5: Deployment of diver to retrieve victim after detection by ROV

c. To deploy ROV at victim's last seen location. To maximise the effectiveness of search operations, the ROV is deployed to conduct a scan at the victim's last seen location, based on eyewitness accounts or through CCTV footage where available.

d. ROV to observe movement and safety of divers. The ROV can provide a good sonar image of the underwater terrain, up to an angle of 130 degrees (horizontally), 70 degrees (vertically) and 30 metres ahead. For one of the search and rescue operations, the ROV hovered about three metres from the drowned victim, and the ROV Team guided the diver towards the victim (see Image 6). This coordination between the ROV and the diver ensured an effective search and recovery operation and, more importantly, the ROV Team was always able to observe the movement of the diver through the sonar images, ensuring safety during diving operations.

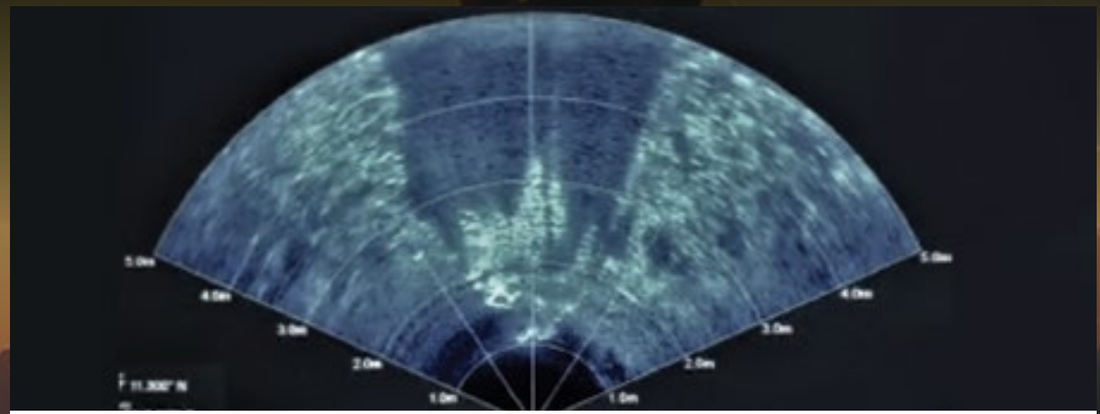


Image 6: The sonar images can be used to monitor and guide the diver to the victim

CASE STUDY

SCDF was tasked to retrieve the body of a member of the public who had jumped into a water body. SCDF was faced with several challenges at that time. Due to the timing of the call, the visibility was low and, furthermore, the presence of underwater debris in the area where the victim was reportedly last seen posed challenges for our divers. SCDF used the CCTV coverage of the area to determine the location of the victim. The ROV was used for the initial search and the location of the victim was quickly determined with the use of the sonar. A diver was then deployed, and the ground commander on the shore used the sonar images of the ROV to guide the diver to the location of the victim for the retrieval process.

Image 7: Image of the victim from the camera onboard the ROV showing visual confirmation of the victim

FURTHER DEVELOPMENTS

While the ROV has become integral to search and rescue operations and has enhanced the response to water mishap incidents, DART is constantly looking for ways to further improve CONOPS for better operational outcomes. Here are some of the initiatives it has taken:

a. Noise generated by other objects. In an incident at Lower Peirce Reservoir, the victim was embedded and concealed within a mass of seaweed. The sonar images could not display the victim's silhouette (see Image 8) due to 'noises' from the environment. In such cases, the images from the video camera of the ROV could be utilised to provide visual confirmation but this depends on the clarity of the water. Ultimately, divers would have to be deployed to physically search the area.

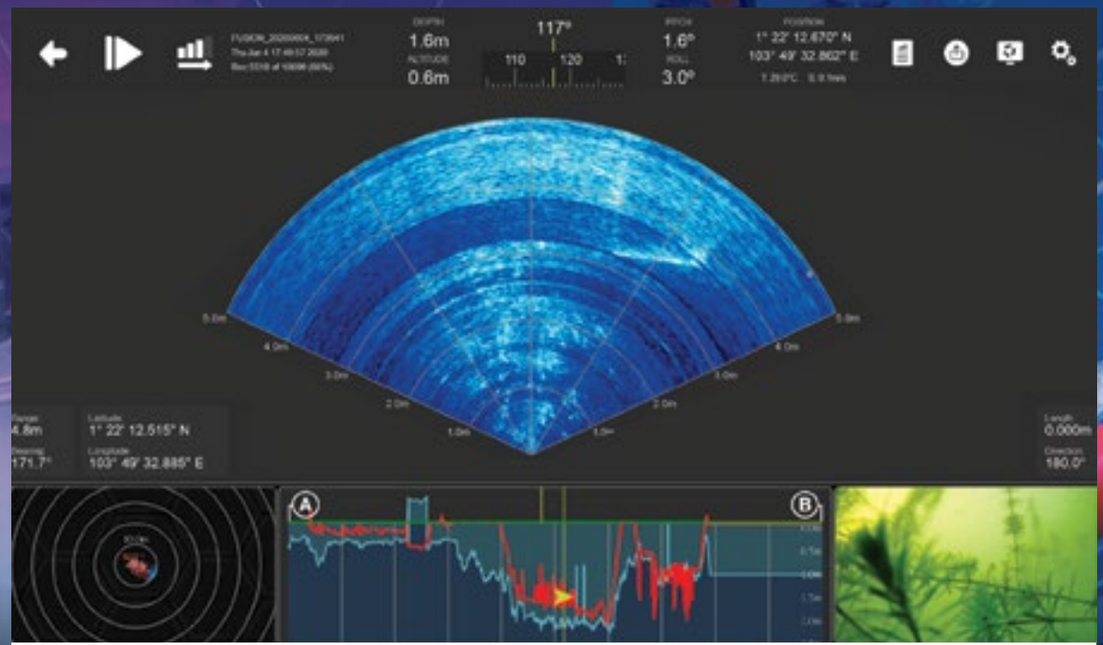


Image 8: Where sonar images may not show the silhouette of the victim, the video camera can offer some visual confirmation depending on the clarity of the water

b. Integration of aerial drone. The ROV has features which allow its real-time GPS location to be displayed on Google Maps on the handheld operating console. The aerial drone can offer real-time images of the operating terrain, and the integration will enhance the navigation accuracy of the ROV and improve planning and operation efficiency. The use of the aerial drone will be fine- tuned in accordance with the CONOPS guidelines on aerial drone usage.

c. Training aid. DART has prepared training aids based on the AAR for the operations where the ROV was deployed. The training aids, with sonar and video images for case studies and illustration, will ensure that DART continues to learn and harness the full potential of the ROV for underwater search operations.

d. Other ROV enhancement. DART is also exploring other auxiliary attachments for the ROV which could enhance its effectiveness. One example is the Sonar Trail Imaging unit, which could be mounted onto the ROV. It allows a 270° scan instead of just a frontal scan, thus covering a larger area within the same time. DART is currently arranging with the vendor for a product demonstration and will evaluate the viability and suitability of Sonar Trail Imaging for future ROVs.

CONCLUSION

ROVs have been deployed in several water mishap incidents since they began operating in September 2019. DART was able to quickly identify victims by using ROVs, which significantly expedited search operations in low visibility conditions and enhanced the safety of the divers. The use of ROVs for inland water search and rescue has improved the operational effectiveness of SCDF and DART.

RAISING THE BAR FOR FIRE SERVICE sUAS (DRONE) PILOTS

Alan Frazier
Senior Fellow
Georgetown University

Your agency recently purchased a small unmanned aircraft system (sUAS), commonly referred to as a drone. The chief assigned Firefighter Wright as the pilot because he professed to have "Hundreds of hours of model aircraft experience." Firefighter Wright possesses a Federal Aviation Administration Remote Pilot Certificate but has never completed any type of flying skills evaluation.

All is going well until Wright responds to a two alarm fire at an industrial complex adjacent to Interstate Highway 29 (I-29). The winds are a bit high, 15 mph (24 kph) gusting to 20 mph (32 kph), not impossible for a sUAS, but challenging. Wright is an enthusiastic young firefighter intent on impressing his company captain and the on-scene battalion chief. He launches the sUAS intending to stream video of the fire scene to the battalion chief. Five minutes into the flight, Wright receives a message on his sUAS hand controller indicating that the Global Positioning System (GPS) receiver in his aircraft has failed. Without GPS, Wright must "hand fly" the aircraft without the assistance of autopilot. Wright struggles with maintaining control of the aircraft, ultimately losing the battle and striking the windshield of a vehicle travelling northbound on I-29 at 75 mph (121 kph). The driver, blinded by the opaqueness of his suddenly shattered windshield, loses control of the vehicle, travels across the center median, and strikes a school bus traveling southbound. The final tragic toll is 14 fatalities (including both drivers and 12 students) and 26 injured students. Could this accident have been prevented? If so, how?

The utilization of small unmanned aircraft systems (sUAS) by U.S. fire departments has grown exponentially over the last six years. In 2014 less than 12 agencies had acquired sUAS. Today, an estimated 566 fire departments, and an estimated 1134 law enforcement agencies and search-and-rescue teams, are using sUAS. A number of factors affected this growth including the cost effectiveness of the technology when compared to traditional manned aircraft; a general realization that drone use in public safety is not inherently an invasion of people's privacy; and the Federal Aviation Administration's enactment, in August of 2016, of 14 CFR Part 107, "The Small UAS Rule". Part 107 created a new FAA certificate: Remote Pilot. Applicants for a Remote Pilot Certificate must: pass an FAA examination consisting of 60 questions covering 12 aeronautical subject matter areas and apply for the certificate in-person or online with the FAA. The FAA Remote Pilot Examination covers a broad spectrum of topics including airspace, aeronautical charts, meteorology, aeronautical decision making, and the specifics of Part 107 regulations. Interestingly, an individual can obtain an FAA Remote Pilot Certificate without ever having flown a sUAS!

SCALABLE TEST LANES (ALTITUDE = SPACING)

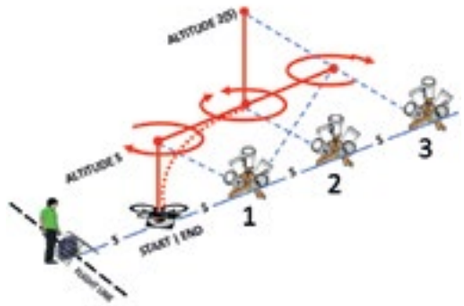
Test apparatus can be easily stored by stacking or, with hinged legs, collapsed into nylon golf club bags which are compliant with airline baggage rules.

Flying safely in our national air space requires knowledge and skill. While the FAA's Remote Pilot Examination is a good evaluation of remote pilot knowledge, the lack of a practical examination leaves a skill evaluation void that potentially increases the liability exposure of individuals and agencies using sUAS. There is a clear need for an accompanying skills evaluation to ensure the safety of the remote pilot, bystanders, property, and manned aircraft in the area.

According to Adam Jacoff, a project manager at the National Institute of Standards and Technology (NIST), "The first step toward credentialing remote pilot skills is to get everybody onto the same measuring stick. That's where standard test methods can play a key role. Especially across public safety, industrial, commercial, and even recreational pilots. All need to demonstrate essential maneuvers to maintain positive aircraft control while performing whatever payload functionality is necessary to successfully perform the intended tasks."

Adam Jacoff is leading an international effort to develop standard test methods for small unmanned aircraft systems. The initial suites for Maneuvering and Payload Functionality can be used to quantitatively evaluate various system capabilities and remote pilot proficiency. They are being standardized through the ASTM International Standards Committee on Homeland Security Applications; Response Robots (ASTM E54.09). They are also referenced as Job Performance Requirements in the National Fire Protection Association Standard for Small Unmanned Aircraft Systems Used For Public Safety Operations (NFPA 2400) and the ASTM Standard Guide for Training for Remote Pilot in Command of Unmanned Aircraft Systems Endorsement (ASTM F38.03 F3266-18).

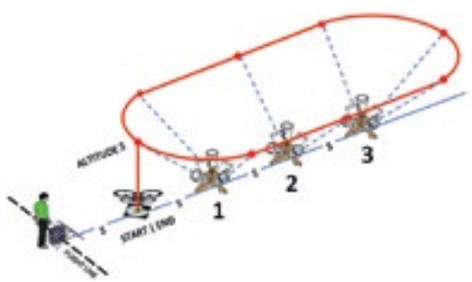
Test apparatus are easily fabricated using materials readily available at any large hardware store.



Positioning flight is the first stage of the Basic Proficiency Evaluation for Remote Pilots.

Participants in NIST's test method validation exercises learn how to fabricate apparatuses, conduct trials, and embed them into their own training and credentialing programs. The NIST test methods are already being used as the basis for state-wide credentialing of emergency responders in Colorado and Texas. Many other state and local emergency response organizations are also adopting the test methods. Canada is moving quickly to implement these tests as the basis for credentialing their emergency responders nationwide. Others will certainly follow. The Airborne Public Safety Accreditation Commission (APSAC) is strongly considering their adoption, as is the Civil Air Patrol, an auxiliary of the U.S. Force, as they seek to standardize their pilot credentialing across 52 wings consisting of over 1200 sUAS pilots.

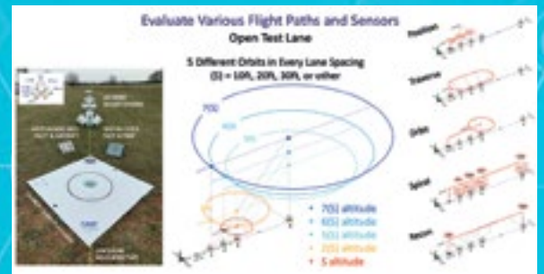
Ben Miller, Director of the Colorado Center of Excellence for Advanced Technology Aerial Firefighting, has followed NIST's sUAS Standard Test Methods project from the inception. "NIST was one of the very first evaluation groups to show interest during the early days of UAS in public safety. The rigor that today's Standard Test Methods show is a direct result of their years of work into the project. The applicability of the method supports acquisition decisions as well as employment considerations. The NIST sUAS Standard Test Methods produce data that can be used to answer the questions of what system do I buy and what system do I use for which mission?" The Colorado Center of Excellence for Advanced Technology Aerial Firefighting provides this certification process to stakeholder public safety agencies within the State of Colorado. To date, 16 agencies and 42 UAS operators have gone through the process.



Two transverse flight orbits are completed during the second state of the Basic Proficiency Evaluation for Remote Pilots.

The NIST sUAS Test Methods include four different "test lanes": Basic Proficiency Evaluation for Remote Pilots (Part 107 qualification); Open Test Lane; Obstructed Test Lane; and Confined Test Lane. These test methods can all be used to evaluate sUAS capabilities and sensor systems, or remote pilot proficiency for credentialing. The tests are easy to conduct alone or in groups, and inexpensive enough to set up multiple concurrent lanes. They are quick to perform, typically less than 30 minutes to conduct all the tests in a given lane. NIST has done an excellent job of creating a comprehensive user guide, scoring forms, and apparatus targets that can be printed and placed in the buckets. It's that simple. But the results are more than the sum of their parts. Fly the lane once and you immediately see how easy it is to evaluate precise station keeping (with or without GPS, downward image flow, windy conditions, etc.). There are various repeatable maneuvering flight paths, and tests for zoom lenses and any additional sensors. The flight paths get incrementally harder but all use the same essential bucket alignment tasks so you can evaluate yourself, know your range to various targets, then compare your results over time or against others.

The Basic Proficiency Evaluation for Remote Pilots (BPERP) is the entry-level test method. It is designed to complement the Federal Aviation Administration's Part 107 Remote Pilot Certificate by providing an inexpensive, easily duplicable, mechanism for assessing remote pilot flying skills. The BPERP can be administered in 10 minutes utilizing 3 omni bucket stands, a 50' tape measure, and a stop watch. The BPERP requires a compact test area of 50' x 20' so can easily be administered indoors or outdoors. The BPERP requires the remote pilot to conduct 3 takeoffs and landings from a 12" radius circle, climb to specified altitudes of 10' and 20' AGL, conduct yawing turns, and conduct forward, reverse, and transverse flight maneuvers. The goal is to



Additional flight maneuvers and tasks are incorporated into the open, obstructed, and confined test lanes.

capture still images of 36 targets that are placed within 2 gallon buckets that are fastened to three omni bucket test stands that are constructed from 2" x 4" and 4" x 4" lumber. The bucket stands are easy to assemble and can be transported in a couple of nylon golf club bags or simply stacked and placed in a vehicle. The test consists of one maneuvering phase and two transverse flight phases. Pilots earn one point for each accurately captured target image, two points for an accurate first landing, and one point each for accurate second and third landings. Scoring sheets are available from NIST. Agencies set their own benchmark scores for passing the test.

NIST Standard sUAS Test Methods represent an excellent way for organizations to "raise the bar" on their remote pilot credentialing with more rigorous and comparable evaluations. Fire agencies can also utilize them to get more informed about what different sUAS equipment can reliably do. The combination of pilot skills and equipment capabilities, with tracked scores over time, provide an essential measure of "readiness" for any given mission. Each set of tests, either conducted in a standard test lane or embedded into an operational training scenario, enables each pilot and organization to evaluate their readiness more rigorously, while practicing their procedures, data collection and logging. Quantitative scores captured in standard test methods can provide the rationale for changes that need to be made. By establishing minimum thresholds of remote pilot proficiency, agencies will further insulate themselves from potential civil liability by demonstrating due diligence in vetting their sUAS pilots. The NIST sUAS Test Methods can provide that missing element in every organization's training program, an easy to implement a "measuring stick" for systems and pilots. While almost nothing is certain, it is highly likely that the sUAS accident described in the preamble could have been prevented if Firefighter Wright had been subjected to a rigorous sUAS flying skills evaluation. Such an evaluation could have made him aware of shortcomings in his manual flight skills and encouraged him to improve those skills. Secondarily, implementation of a flying skills evaluation, such as the NIST sUAS Standard Test Methods, would be further evidence that Firefighter Wright's agency had been diligent in their pilot screening and training. Such evidence is extremely valuable in the defense of a civil liability lawsuit.

For more information, go to RobotTestMethods.nist.gov

Alan Frazier currently serves as a Senior Fellow at Georgetown University. He is working with the National Institute of Standards and Technology (NIST) to validate and implement these and other test methods with any interested public safety organization. He hosts "train the trainer" workshops and exercises to help such organizations get started. He is also involved in developing and validating new test methods for sUAS. Alan previously served as an Associate Professor of Aviation at the University of North Dakota. He is a 40-year law enforcement professional having served as a sworn officer and supervisor with city, county, state and federal law enforcement agencies. He founded, and served 10 years as the officer-in-charge of, the Northeast Regional sUAS Team in Grand Forks, North Dakota. He is an FAA Airline Transport Pilot rated to fly single and multi-engine airplanes, helicopters, gliders, and small unmanned aircraft systems.

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NEXT-GEN FIRE STATION ALERTING

Dominic Magnoni
Co-Founder
US Digital Designs

Radical new designs in fire station alerting technology are helping to save lives and property. It's an unfortunate fact that, every hour of every day, people find themselves in some form of danger. Luckily, however, in those instances, sophisticated new technology is proving itself capable of making a life-and-death difference.

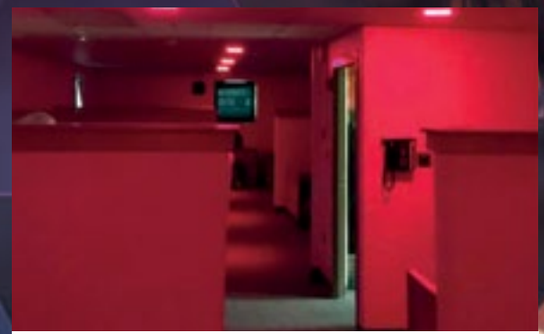
I refer to innovative new designs for fire alerting systems, which are showing dramatic improvements from older, more limited functionality methods, especially in such critical areas of emergency safety as response times, situational awareness and the health and well-being of first responders. In these areas, new systems are literally saving lives when fires and other similar calamities threaten.

The changing role of fire stations

Before we talk about the specifics of how emergency alerting systems have evolved, I think it's important to provide some context for that evolution.

The need for these advanced fire alerting systems was necessitated by the changing role of fire stations themselves. We all know the historical stereotype for firehouses, their use and function. In short, an alarm bell or siren blared, and firefighters scrambled to hit the fire pole. Then they donned their turnout gear before leaping onto one of the vehicles. It was controlled chaos.

Today, a fire station and its personnel have a far different role than in the past, and fire stations themselves have changed structurally and technically. Over time, by strategically altering fire stations' designs and locales, and by increasing station equipment and technology, firefighters have become more effective in their jobs. That means they can respond more quickly to emergencies.



G2 Illuminated Speaker awakens first responders with soft-start LED lighting and audio alerts.

Today's modern fire stations are both high-tech and high-functioning. They meet all government guidelines and regulations. And they're also comfortable. For the emergency personnel who inhabit them they are, in a sense, a home away from home. They're outfitted with all the comforts that better enable those on duty to rest when they are off duty. And, when they are on duty, they can hear and respond to calls quickly and effectively.

Just as important, communication networks, audio and lighting technology, and other automated improvements in these facilities are making a big difference. They have enhanced the health and comfort of the firefighters who spend a great deal of their lives in them.

Emergency alerting

Every firefighter and fire station administrator knows the mantra "The earlier you get there, the quicker you can save lives and property". Today's emergency alerting systems are designed to do precisely that. They cut down on response time, increase situational awareness and, hopefully, reduce the incidence of injury and loss of life.

How do they work? Briefly, when an emergency incident occurs, a computer-aided dispatch (CAD) system interfaces with a digital communications 'gateway' located at the dispatch processing centre.

The gateway receives alert data in two ways. First, it is sent directly from the system's interactive web-based interface. Secondly, it can be sent manually, from a dispatcher via an interface with an existing CAD host.

Thus, automated dispatch processing time is drastically reduced. Most of the alerting systems can deliver the dispatch to one or multiple stations in less than a second.

Meanwhile, at the fire station, the dispatch is received and read aloud via a digital 'voice'. This allows the first responder to quickly hear and understand the information. Then they can also read the dispatch via high-contrast message signs placed strategically throughout the station. This helps emergency personnel react promptly and efficiently to every call.

Importantly, fully automated dispatching awakens only on-call units, using what's called 'zoned alerting'. Most sophisticated alerting products will integrate ramped tones and lighting so that non-dispatched crews on rest can remain undisturbed. This ultimately reduces cardiac stress, anxiety, optical shock and, of course, sleep deprivation.

A component of the system sends alerts throughout the fire station, using any combination of room zones. They also make use of individual lighting, messaging and volume control in each zone. Additionally, there are many configurable peripheral devices that also serve to alert first responders at the station, using visual and/or audible messages. Another important aspect of the system has to do with its audible 'voice'. Messages are generated from an automated voice, devoid of any possible emotional pitch or tone that might unnecessarily confuse or agitate the responders.

G2 Two Stacked Message Signs displays dispatch text and turnout timer.

Positive performance

Because automated alerting systems have been operational for a decade or more, their records of performance are readily available. What's more, users of the systems themselves have been vocal in their praise, as well as their suggestions for fine-tuning the systems.

In the US, where adaptation of newer, more automated systems has been sweeping, the critical 'hot buttons' of emergency alerting and response are showing dramatic results.

With regard to response times, Bill Hawley, Fire Chief of a fire department in Texas, notes how crucial even a few seconds' difference can be in a fire emergency:

"Response times are very critical... In a fire, it will grow exponentially over time, so if we can shave off 30 seconds or a minute in our response, it may be the difference between just the sofa being involved in a fire, or the whole room, or possibly a large portion of the house. We are looking to save every second possible in the process..."

Chief Hawley went on to describe that, using the older alerting system, a responder on the receiving end was burdened by the system's limitations.

G2 Room Remote targets specific units or rooms with zoned alerting.

"A person who received the 911 call would be trying to do three things simultaneously," he said. "That is, talk to the caller, start alerting the fire stations and talk over the radio to the firefighters to tell them what was going on and where. At the same time, he had to also be going through flip charts, trying to give pre-arrival instructions to the bystanders on how to help [the victims] before we get there. Now, because the system is automated, as soon as key information is entered into the system by the dispatcher, it automatically sends that information to alert the firefighters in the stations and starts that process happening sooner."

Another fire station management official, Lisset Elliot, in Miami, Florida, had this to say.

"It would have taken [our] old system almost 27 seconds to send out alerts. The new system, however, is able to alert all stations simultaneously in one second, drastically improving response time. The new system also allows [our fire response team] to implement fewer jarring tones that are more 'heart-friendly'."

Asia Pacific applications

The United States isn't the only country that is adapting these new systems for optimal use. They're being identified, tested and installed in emergency response centres the world over.

Australia, for example, is embracing more sophisticated alerting systems. Following their implementation in several Australian communities, government studies are recording much quicker response times for Australian ambulance and firefighting personnel.

One such study was sweeping in its scope, examining the performance of emergency service agencies across Australia. Citing the results, Mick Gentleman, the Australian Minister for Police and Emergency Services applauded the efforts of Australian Capital Territory (ACT) paramedics and firefighters. He said: "The results are a credit to the professionalism of the women and men of...the wider ACT Emergency Services Agency." Gentleman particularly noted the ACT agency's record for having provided the best capital city and state-wide response times for fire events.

Future innovation

Our efforts to drastically trim response times are functioning very well in newly designed fire stations throughout the world. Thus, technology innovators are working on a host of additional improvements in emergency summoning systems. Among them:

- Mobile altering, which enables first responders' individual devices (such as phones) to provide up-to-the-minute details of the event.
- More sophisticated integration with CAD systems to provide additional incident management before, during and after the call.
- Greater levels of intelligence to improve situational awareness (e.g., local traffic, natural disasters, etc.).
- A greater focus on responders' health, wellness and safety, with an emphasis on ways to help alleviate hearing loss, heart problems and fatigue.

As always, those of us involved in the design and installation of these systems must be scrupulously vigilant of the needs of the professionals our systems serve. We must be mindful as well of the ways in which societies summon help for an increasing roster of vital emergencies.

As one of the system designers, we're trying every day to be at the forefront of our clients' needs.

For more information, go to stationalerting.com

An accomplished product development and engineering public safety expert, Dominic Magnoni co-founded US Digital Designs, which designs and manufactures the Phoenix G2, one of the world's leading fire station alerting systems.

G2 Message Sign displays single-line scrolling alert message.

High-resolution LCD multi-touch display for easily adjusting settings such as units to be alerted.

This article first appeared in the April 2020 issue of Asia Pacific Fire and is reproduced with the kind permission of MDM Publishing Ltd – www.mdmpublishing.com

POSTERS FEATURED IN AFAC CONFERENCE & EXHIBITION 2021

This section displays six informational posters that were developed by SCDF units and submitted to the Australasian Fire and Emergency Service Authorities Council (AFAC) Conference & Exhibition, Australasia's largest and most comprehensive emergency management conference and exhibition.

APPLICATION OF PSYCHOLOGICAL AND BEHAVIOURAL PRINCIPLES IN EMERGENCY RESCUE ORGANISATION

Swee Giang Khoo & Jasmine Chia
Emergency Behavioural Sciences and CARE Unit | Singapore Civil Defence Force

INTRODUCTION

The Singapore Civil Defence Force (SCDF) is a uniformed organisation with the mandate to provide firefighting, rescue and emergency medical services in Singapore. As first responders, SCDF personnel are exposed to potentially traumatic operational stress and other organisational stressors, creating stress which may result in emotional issues, physical or psychological conditions [1,2]. Recognising the need for the application of psychological and behavioural sciences to support SCDF's work, the Emergency Behavioural Sciences and CARE Unit (EBSC) was set up in 2013 to build up psychological support capabilities. It is staffed by psychologists, uniformed officers and research analysts to provide a range of evidence-based psychological services focusing on supporting the organisation, its operations and its personnel.

SUPPORTING ORGANISATION

Aside from the potential traumatic stress that comes with emergency rescue work, everyday occupational stress from other work conditions, (e.g., ambiguous work expectations, unreasonable workload, fatigue) also contributes to negative effects on personnel's personal well-being and their work performance [3].

Employee Engagement Survey

Research has long established the link between employee engagement and organisational performance [4]. The Employee Engagement Survey (EES) is a climate survey that is conducted once every two years to assess SCDF personnel engagement and their workplace concerns. Half-yearly pulse surveys, which are shorter than the Employment Engagement Survey and can be completed under 5 minutes, are also held to provide the organisation a quick sensing of personnel's perceptions and their issues. In addition to data collection and analysis, EBSC works with the SCDF management and other stakeholders to offer consultation in identifying gaps and developing follow-up plans. Communications on the surveys' purpose and their results are key to engaging personnel [4,5], hence EBSC takes active steps to work with units to reach out to their personnel.

Psychometric Assessment in Personnel Selection

EBSC supports the organisation via the provision of psychological assessment services in its recruitment and personnel selection process. Recognising the need for a dedicated tool to assess precise attributes specific to SCDF [6], situational judgment tests assessing personnel's job-related competencies were developed to form part of the psychological assessment battery. Information from these tools are used as additional data points when selecting personnel for leadership positions and specialist vocations (e.g., Disaster Assistance and Rescue Team), as well as selecting new hires to ensure job-fit with the organisation.

Applied Research Services

EBSC provides research services to the organisation to ensure that its interventions are empirically supported. EBSC research analysts and interns also work on applied research projects to enhance the robustness of EBSC's research services. Some recent examples of applied research conducted during COVID-19 include the study of personnel stress during circuit breaker and recruits' well-being during home-based learning. Upcoming works will include psychophysiological research to support the organisation's move towards leveraging smart technologies to optimise performance and recovery under the new Emergency Responders' Fitness and Conditioning Enhancement Lab (EXCEL).

SUPPORTING OPERATIONS

Mitigating the stress that personnel face in operations is crucial in preventing the onset of any post-traumatic stress [2]. SCDF adopts a three-pronged psychological support model to enhance personnel's resilience and mental health, thereby supporting SCDF's operations. These components are namely preventive, supportive and recovery.

Three-Pronged Psychological Support

Preventive measures focus on the provision of resilience training to frontline personnel to equip them with awareness of operational and critical incident stress, as well as skills on effective stress management. There are different training modules dedicated to personnel of different levels. For instance, those in frontline supervisory roles are trained in team resilience and how to support affected personnel.

Supportive measures include morale sensing and the application of critical incident stress management (CISM) to support affected personnel after a potentially traumatic incident during operations [7].

The maintenance of morale is paramount to personnel's workplace satisfaction and hence, better psychological well-being [8]. Morale sensing, an assessment of the morale levels of personnel, is conducted during major manday operations (e.g., National Day Parade, F1 Night Race) or incidents that impact the organisation (e.g., COVID-19). Personnel respond to questionnaire items relating to confidence in operations, morale and well-being. These inputs would then be channelled to the SCDF management for implementation of practical measures to address the concerns raised.

CISM guides EBSC in its crisis response to incidents that could result in high distress in personnel. Commonly-used strategies include crisis management briefing and group crisis interventions for affected personnel. In supporting SCDF's Operation Lionheart mission, EBSC

psychologists render psychological support to the 79-man contingent which is deployed overseas to provide urban search and rescue and/ or humanitarian relief assistance.

Recovery measures involve the follow-up interventions to support personnel beyond the immediate aftermath of a crisis. This includes continuous support for affected personnel and working with stakeholders to review operational plans and training programme to better safeguard the psychological well-being of personnel.

SUPPORTING PERSONNEL

SCDF personnel comprises a mix of regular uniformed and civilian officers and full-time national servicemen (NSFs) who are conscripted for two years. Recognising the impact that operational and organisational stress could have on the well-being of SCDF personnel, the Psychological Resilience Framework was developed.

Promote refers to outreach initiatives to bring about awareness on mental health issues and help resources. This is crucial in emergency response services like SCDF where mental health stigma often results in delay and barriers to help-seeking behaviour [9,10]. Information is regularly shared with personnel via e-mails, posters and social media to share mental health tips, as well as to normalise the act of seeking or giving help. The Fitness 4 Resilience Handbook was also developed to inculcate personal psychological resilience in personnel. Its contents were based on psychological principles and included tips on attaining resilience via physical, mental, emotional and social fitness. Training packages and a supervisory toolkit were also developed.

Prevent comprises counselling, crisis and peer support services provided to personnel in need. In addition to formal psychological support from EBSC psychologists, personnel can also reach out to the unit Paracounsellors (regular officers trained in basic counselling and crisis support skills) or NSF Peer Supporters. Having common shared experiences, these peer helpers are often more adept in establishing rapport [11] and are vital in filling the gap that cannot be filled by friends and family who are less familiar with the stress of emergency work [12].

Protect refers to the close partnership with supervisors, medical officers and mental health providers to ensure comprehensive care for personnel exhibiting psychological symptoms and require targeted support or intervention.

Progress highlights the potential for personnel to grow and "bounce forward" through psychological resilience.

CONCLUSION

Further evaluation is necessary to explore the efficacy of these programmes. SCDF seeks to offer a comprehensive package of psychological programmes aimed at addressing the differing needs of personnel. The combination of formal and informal programmes could contribute to a "psychological safety climate" that can enhance personnel's mental health [13]. Most importantly, the setup of a psychological unit and strong support for its programmes and services demonstrated the organisation's zealous approach towards caring for and protecting the psychological well-being of its personnel.

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FOR ENQUIRIES

PROFESSIONAL DEVELOPMENT THROUGH

CONTINUING EDUCATION AND TRAINING (CET)

AND DIGITALISATION IN SCDF

TRAIN AS WE OPERATE, LEARN AS WE INNOVATE

Transforming the Singapore Civil Defence Force (SCDF) into a high-performing organisation calls for the development of every member of the Force. We adopt the philosophy of "Train as We Operate, Learn as We Innovate" which ensures that operational training continues to remain steeped, and that training conditions accurately reflect real-world operations.

With evolving operational needs and policies, officers are required to constantly upgrade their skills and knowledge. A continuous learning and innovation cycle is thus key in tightening the Operation-Training Nexus.

SCDF'S CONTINUING EDUCATION AND TRAINING (CET) FRAMEWORK 1

SCDF has established a CET Framework that is instrumental to a robust and integrated Training & Learning (T&L) ecosystem, addressing these **critical skill sets**:

Training is infused with the principles of Blended Learning and Problem-Based Learning (PBL) while the Kirkpatrick Four-Level Training Evaluation Model is used as a guiding principle to evaluate its effectiveness.

ENHANCING TRAINING AND LEARNING (T&L) 2

SCDF aims to build a first-rate system of continuing education which will intertwine T&L with the world of work. Officers are expected to:

- **Take ownership** of their learning and development
- **Build and deepen their skills** throughout their career
- **Contribute to the Force** as they advance in skills and competencies

>45,000 Total Learning Hours in extra curriculum in 2020

The CET Credit Scheme

Following the CET Framework implemented in July 2019, SCDF introduced a complementary CET Credit Scheme in 2020 to systematically track and uphold the competency of our officers.

Why the CET Credit Scheme?

- A quantifiable credit scheme ensures that individual and organisational **training requirements are periodically tracked and fulfilled**.
- The use of points or credits is an **established policy among our industry counterparts** in fire safety, law, and healthcare for the maintenance of professional accreditation and licence-to-practice.

Benefits of the CET Credit Scheme

- Helps to **identify individuals' level of subject matter expertise,** and so guides decision-making in Expert and Specialist appointments, e.g. USAR Experts.
- Creates an organisational climate that **nurtures and rewards continuous learning**.
- Provides an **objective, methodical approach** to quantify learning, in view of plans to leverage technology and draw data-driven insights.

DIGITALISED COMPETENCY PROFILING AND ENHANCED TRAINING INFRASTRUCTURE 3

DIGITALISED COMPETENCY PROFILING

Technology is a key enabler in SCDF's pursuit of an enhanced T&L regime. SCDF has envisioned a **next-generation, integrated T&L system** that monitors the Force's training regime to respond dynamically to evolving operational and training needs.

Known as the "Training and Learning Enterprise System", or "**TALENTS**", it will aim to serve three key functions:

- **Monitoring and tracking of key performance metrics of officers**, e.g. physical fitness, mental resilience.
- **A learning management system** that monitors and tracks officers' learning and competency development throughout their career
- **Analytics to surface insights** into both individual and organisational performances for review and decision-making

ENHANCED TRAINING INFRASTRUCTURE

SCDF is **revamping our existing training facilities** between 2019 and 2023 to meet the ever-changing demands of the emergency response and management landscape. These include:

Training Infrastructure | Functions

SCDF The Life Saving Force

Have queries or feedback? Get in touch with us!

For more information about SCDF's work, watch our Civil Defence Academy redevelopment video.

A Nation of Lifesavers

ICE SLURRY INGESTION FOR IMPROVED ENDURANCE

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INTRODUCTION

The combined effects of environmental heat stress, high metabolic loads and thick protective clothing can impose severe heat strain and increase the risks of heat injury for firefighters, especially in a hot and humid tropical climate. Ingestion of ice slurry before an activity as a body pre-cooling strategy has thus received considerable attention due to its practicality in an operational setting. Studies have shown that the ingestion of ice slurry pre- and post-exercise can effectively reduce one's core body temperature under controlled environments (Lee et al, 2015). However, few studies have been conducted in an operational setting to assess the effectiveness of ice slurry on a responder's performance. As such, a study aimed at investigating the effects of ice slurry ingestion on the thermoregulatory responses and endurance capacities during routine outdoor training sessions among Singapore Civil Defence Force (SCDF) firefighters was conducted with positive outcomes derived. In light of the findings from the study, the Responders' Performance Vehicle (RPV), a mobile facility of the SCDF for on-site accelerated recovery will be equipped with an ice slurry module to enhance the recovery and thermoregulatory responses of our emergency responders.

BACKGROUND

CURRENT COOLING METHODS IN RPV

METHODOLOGY

PARTICIPANTS

48 MALES
24 ± 5 YEARS
1.71 ± 0.07 CM
70.3 ± 12.1 KG
23.9 ± 3.5 BMI

BREATHING APPARATUS ENDURANCE TRAINING (BAET)

DATA COLLECTION

*Thermal sensation on a 0-8 scale (Young et al, 1987)

RESULTS

PHYSIOLOGICAL READING

There was a drop of 0.22°C in the body temperature after the training activity among the group who pre-ingested ice slurry compared to the control group who consumed room temperature (RT) drink. No significant difference was observed for HR or SpO2 readings.

RPE RATINGS

There was a drop of 0.6 in RPE rating for thermal sensation among the group who pre-ingested ice slurry compared to the control group who consumed room temperature (RT) drink.

TIME TAKEN TO COMPLETE BAET

There was a reduction of 1.2 minutes in the time taken to complete the training activity among the group who pre-ingested ice slurry compared to the control group who consumed room temperature (RT) drink.

DISCUSSION

SMALLER DROP IN CORE TEMPERATURE
- In Siegel's trial (2012), trial participants who ingested ice slurry were reported to have a 0.43°C drop in body temperature
- Longer timeline activity in Siegel's trial
- In-ear temperature monitoring may be affected by ambient temperature
- Ingestion of ice slurry varied from 3 to 20 minutes, during which part of ice may have melted

LOWER THERMAL SENSATION
- Thermal sensation is lower in ice slurry group and comparable to literature

LARGER DATA DEVIATION
- Outdoors conditions vs controlled lab environment
- Participants' diet and sleep were not standardised
- Different ice slurry consumption rates

ADOPTION OF COOLING STRATEGY
- Provision of ice slurry in the Responders' Performance Vehicle as a supplement to the existing slew of cooling methods

CONCLUSION

FIRST REPORTED FIELD STUDY
- Possibly the first reported field study of pre-training ingestion effects of ice slurry in firefighting applications

EFFECTS OF ICE SLURRY INGESTION
- Results shows ice slurry ingestion effectively reduces the core body temperature, improves the thermal comfort, and shortens the time to complete the training
- Proves the effectiveness of the ice slurry ingestion as a form of pre-cooling strategy

IMPROVE EFFICACY
- Conventional method of ingesting ice slurry such as from a drink flask pose some challenges
- A faster and easier ingestion of ice slurry using a bespoke drink pouch is in development

REFERENCES: Lee et al. (2015) J. Strength Cond. Res. 29:11, 577-581; Siegel et al. (2012) J. Sports Sci. 30:1, 155-16; Young et al. (1987) J. App Phy. 63:3, 1218-23

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HTX

Have queries or feedback?

A Nation of Lifesavers

HARNESSING POSITIVE PSYCHOLOGICAL CAPITAL IN EMERGENCY RESPONDERS FOR ENHANCING PERFORMANCE AND WELL-BEING

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Diong Siew Maan | Centre for Advanced Psychological Sciences | Office of Chief Psychologist | Ministry of Home Affairs

NATURE OF WORK (PEACETIME & PANDEMIC)

In the Emergency Medical Services (EMS), EMS personnel experience a high stress load, which may result in organisational and/or operational stress (1-5). In addition, this stress has compounded with pandemic stress due to the COVID-19 pandemic. Studies have reported elevated stress and emotional exhaustion amongst frontline workers including paramedics (6,7). Clearly, EMS personnel face many stressors that may negatively affect work-related outcomes.

Organisational stress is associated with organisational culture (e.g. heavy workload, administrative duties).

Operational stress is associated with elements of working in an ambulance service (e.g. physical demands, shift work).

Pandemic stress is associated with additional COVID-19 duties (e.g. swab operations, convey COVID-19 cases to hospitals).

WORK-RELATED OUTCOMES

Organisational Commitment | Employees' commitment to their employers (8); found to predict higher organisational effectiveness and lower turnover rates (9, 10).

Work Engagement | Positive work state characterised by high energy and full concentration (15); reported positive associations with psychological well-being and job performance (11,12).

PSYCHOLOGICAL CAPITAL

Psychological capital (PsyCap) is a positive state exhibited during an individual's development, and is characterised by hope, self-efficacy, resilience and optimism (13). It is associated with increased work engagement, organisational commitment (14) and decreased job stress (15).

It can be theorised that PsyCap may improve EMS work outcomes. Optimism is fundamental in maintaining positive psychological tendency when approaching dangerous and potentially negative events (16), while resilience can buffer stress, even allowing them to flourish after setbacks. Sufficient levels of hope allows personnel to facilitate self-regulatory behaviours toward mission success, and those who are confident in their abilities are highly adaptable, allowing them to mobilise required resources in challenging environments to accomplish goals.

STUDY 1

PARTICIPANTS | 508 EMS personnel from the Singapore Civil Defence Force (SCDF).

PROCEDURE AND MEASURES | Participants completed these measures in August 2019: (i) 20-item Emergency Medical Services Chronic Stress Questionnaire (EMS-CSQ) (α = .93) (6); (ii) 6-item Organisational Commitment Questionnaire (OCQ) (α = .79) (8); 12-item Psychological Capital Questionnaire (PCQ-12) (α = .91) (17).

RESULTS | A hierarchical multiple regression analysis was performed to investigate the effect of work stressors and PsyCap (as a moderator) on organisational commitment. Analysing by individual predictors, Organisational Stress ($b = -0.21$, $t(505) = -5.66$, $p < .001$) and PsyCap ($b = 0.67$, $t(505) = 10.67$, $p < .001$) significantly predicted Organisational Commitment. Similarly, Operational Stress ($b = -0.12$, $t(505) = -3.60$, $p < .001$) and PsyCap ($b = 0.73$, $t(505) = 11.51$, $p < .001$) significantly predicted Organisational Commitment. Analysing the two-way interaction, moderation effect of PsyCap was not significant.

STUDY 2

PARTICIPANTS | 64 EMS personnel from SCDF. None tested positive for COVID-19.

PROCEDURE AND MEASURES | Participants completed these measures during the May 2020 circuit breaker: (i) 38-item in-house COVID-19 stress questionnaire covering personal stress, household stress, anticipatory COVID-19 stress, work stress, community stress (α = .90); (ii) 3-item Utrecht Work Engagement Scale (UWES-3) (α = .81) (18); (iii) PCQ-12 (α = .93) (17).

RESULTS | A hierarchical multiple regression analysis was performed to investigate the effect of pandemic stressors and PsyCap (as a moderator) on work engagement. Analysing by individual predictors, PsyCap significantly predicted work engagement ($b = .10$, $t(59) = 2.45$, $p = .02$), while Pandemic Stress did not significantly predict Work Engagement ($b = -.02$, $t(59) = -1.57$, $p = .12$). Analysing the two-way interaction, moderation effect of PsyCap was not significant.

DISCUSSION

Findings indicate that psychological capital has a positive effect on EMS work outcomes regardless of stress level experienced, and in both peacetime and pandemic contexts. As psychological capital is a state-like and malleable construct, findings show promise for further development of psychological capital in EMS personnel (19).

Even though peacetime stress negatively predicted organisational commitment, pandemic stress was not a predictor of work engagement in EMS personnel. EMS personnel may have viewed pandemic stressors as challenge stressors, which are positive forms of stress that promote goal achievement (20). A past study has also shown that stress perceived as a challenge rather than a hindrance generates a positive effect on work engagement by triggering positive emotions (21). Future studies can consider differentiating challenge stressors and hindrance stressors to understand the nuances of stress-work outcome relationships.

Although data was collected in a short period, information helped Emergency Behavioural Sciences and CARE Unit (EBSC), a psychological outfit within SCDF, obtain insight into the EMS experience in peacetime and pandemic contexts. Firstly, SCDF can enhance psychological capital in EMS personnel through structured training programmes. For instance, EBSC can conduct periodic stress management trainings and self-care workshops to increase EMS personnel's stress management skills. Secondly, SCDF can provide more tangible resources, such as time off from work, to increase perception of availability of stress-coping resources as well. Lastly, external stress-coping resources such as perceived organisational support can also be explored, particularly for EMS personnel who may not have sufficient internal resources.

CONCLUSION

Addressing the mental health needs of emergency responders is vital as pressure will endure as the pandemic continues. The present findings imply that PsyCap may be important in influencing work outcomes in EMS personnel. Developing PsyCap in our personnel will enhance our resilience in the face of any job-related and pandemic-related challenges that may arise.

SUMMARY OF RESULTS

STUDY 1 | Organisational and operational stressors negatively predicted organisational commitment. Psychological capital positively predicted organisational commitment.

STUDY 2 | Psychological capital positively predicted work engagement, while pandemic stress did not predict work engagement.

BOTH STUDIES | **Psychological capital has a positive effect on organisational commitment and work engagement regardless of stress level (peacetime/pandemic) experienced.**

REFERENCES

FOR ENQUIRY

APPLICATION OF PSYCHOLOGICAL FIRST AID PRINCIPLES FOR EMS PERSONNEL IN SINGAPORE CIVIL DEFENCE FORCE

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THE NATURE OF WORK OF EMERGENCY MEDICAL SERVICES (EMS) PERSONNEL

The work of EMS personnel is inherently meaningful yet challenging. They respond to a range of medical emergencies and incidents, where they may encounter patients and/or next-of-kin (NOKs) who may be in extreme emotional distress, shock or fear (Regehr & Millar, 2007).

Emotional distress may not always be as visible as physical injury, but may have a stronger impact. EMS personnel may find it challenging to attend to patients/NOKs' emotional needs. Previous studies had found that paramedics reported feeling inadequate in managing bereaved family members, as they were concerned about behaving in a manner that could be perceived as unsympathetic (Minnie et al., 2015).

Hence, in addition to medical competency, intangible skills (e.g., communication, ability to build rapport, ability to recognise signs of distress) are also crucial for effective patient management and delivery of patient-centered care (Roberts & Henderson, 2009).

INTRODUCTION TO PSYCHOLOGICAL FIRST AID (PFA)

WHAT IS PFA?

- Humane, supportive and practical assistance for people who are distressed (WHO, 2013)
- Widely recommended by mental health practitioners for providing short-term and early psychosocial intervention for people after crisis/disaster (Forbes et al., 2010)
- Can be provided by any individuals as long as they have been trained in its concepts

WHY PFA FOR EMS PERSONNEL?

- Attending to the needs of distressed patients and NOKs at incident scene or en-route to hospital
- Supporting fellow crew members in distress back at station

DEVELOPMENT OF PFA TRAINING PACKAGE FOR EMS PERSONNEL

Formation of workgroup comprising SCDF psychologists and paramedics across various Divisions in SCDF to conceptualise training package based on WHO's PFA framework. Reference was also made to EMSBlogs.com in contextualising PFA action principles to EMS context (Otto, 2012).

PFA FOR EMS

Adapted from WHO's PFA Framework

1. **Prepare**
   - Learn about severity of incident and possible impact on patients/NOKs
   - Be aware of safety needs of patients and crew members
2. **Look**
   - Introduce self to patient and assure that help will be provided
   - Assess for distress reactions
   - Assess for urgent basic needs (e.g., dignity, food, water)
3. **Listen**
   - Listen to needs and concerns of patients/NOKs
   - Use simple language and provide factual information of what to expect
   - Employ techniques to calm them down
4. **Link**
   - Provide basic instructions to patients/NOKs on how to cope
   - Help them connect with loved ones
   - Keep patients/NOKs informed when handing over at hospital

COMPONENTS OF TRAINING PACKAGE

- Lectures (PFA action principles contextualised to SCDF EMS nature of operations & attending to vulnerable groups like children, elderly, people with disability)
- Case studies (Discussion on previous incidents that SCDF EMS personnel responded to)
- Role plays (hands-on practice of PFA skills in simulated scenarios)

TRAINING FRAMEWORK

3 levels of PFA training conceptualised for frontline Emergency Medical Technicians (EMTs), frontline Paramedics (PRMs) and EMS key appointment holders who undertake supervisory responsibilities. The trainings were conducted between Aug-Nov 2020.

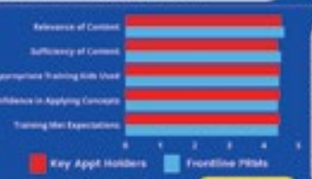
Personnel trained to different levels of competency, depending on level of interaction with patients/NOKs.

	Level 1	Level 2	Level 3
	Basic	Intermediate	Advanced
	Frontline EMTs	Frontline PRMs	EMS Key Appointment Holders
	• Intro to PFA • PFA action principles • Attending to vulnerable groups	• L1 training • Skills-based application (role plays) • Supporting affected crew members	• L1 & L2 training • Facilitation of PFA skills and coaching/supporting new staff in station

TRAINING EVALUATION

Post-training feedback was sought from EMS supervisors who attended the Level 3 training as well as frontline PRMs who attended the Level 2 training.

On a scale of 1 (strongly disagree) to 5 (strongly agree), personnel felt that the content of PFA training was relevant and sufficient, and they also felt confident in applying concepts taught. While the trainings were well-received, some suggestions for improvement include having more scenarios for case discussion as well as having longer role play sessions.



"Good knowledge received throughout the whole course, would love to do in-depth, much prefer if the trainers goes to explain and show some examples on how and what words to be spoken to the person in distress"

"The activities are very useful"

"Longer roleplay session"

"Maybe show a video or picture for people to better visualise the scenario"

CONCLUSION

The PFA training package developed was well-received by EMS personnel in SCDF, and enabled EMS personnel to attend to the emotional needs of patients and/or NOKs while providing medical treatment. In addition, PFA skills also enable EMS personnel to look out for and attend to fellow crew members who may require support after attending to challenging incidents.

To ensure EMS personnel continue to be well-equipped in responding to the psychological needs of patients and providing patient-centered care, SCDF will continue to review and refine the PFA training content for future subsequent training runs.

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For enquiries, scan the QR code below

Sustaining Emergency Responders' Commitment and Morale Amidst COVID-19 Pandemic: Experiences from the Singapore Civil Defence Force

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INTRODUCTION

Amidst a global pandemic, officers from the Singapore Civil Defence Force (SCDF) remained vigilant round the clock to perform critical functions and provide emergency services to the local community. The organisation took steps (e.g. operational readiness, welfare provisions, logistical support) to ensure that its staff remained resilient and steadfast during the COVID-19 pandemic at all levels.

Literature has highlighted the need to offer a series of psychological support throughout the various phases of a crisis (i.e. before, during and after) to help protect and promote emergency responders' mental health (Sim & How, 2020). The Emergency Behavioural Sciences and CARE (EBSC) unit, a psychological set-up within SCDF, initiated a holistic 3-pronged psychological support plan which focused on preventive, supportive, and recovery measures to safeguard the mental wellbeing, and maintain the confidence and morale of SCDF officers during this critical period.

3-Pronged Psychological Support

To assess the morale levels, and to build resilience among all personnel

To provide psychological support and interventions for staff affected by the pandemic i.e. in the course of work, quarantine

To support personnel in their recovery and help reintegrate them into the workplace

PSYCH SUPPORT

PREVENTIVE

Morale Sensing operations (ops) were conducted on a regular basis to gather officers' feedback and sentiments on their readiness and confidence to perform their duties. As the uncertainties caused by COVID-19 continued to disrupt work environments, morale sensing surveys provided leaders with insights on how they could improve their officers' mental health and morale. Surveys were disseminated either via online platforms or phone calls. The frequency of the morale sensing ops was calibrated based on the issues and concerns brought about by the prevailing pandemic. In the early phases of the outbreak, morale sensing was conducted on a monthly basis to detect issues quickly. As time passed, the COVID-19 situation improved in Singapore. Hence, these sensing ops were reduced to once every quarter.

The morale sensing surveys allowed officers to share their views anonymously with their leaders. Results gathered from previous morale sensing surveys revealed various feedback and concerns that were tracked at the senior management level and also in pandemic tracking meetings. This ensured that concerns and issues raised by officers were addressed with immediacy and expediency, which led to several improvements (e.g. regular provision of hand sanitisers, masks and food) observed across SCDF. The results were also monitored closely to look for any prevailing concerns within both the community and the organisation as the COVID-19 situation evolved.

Table 1. Common feedback and concerns over past surveys

POSITIVE FEEDBACK	CONCERNS
• Safe working environment due to comprehensive Safe Measurement Measures • Timely internal communication within SCDF • Provision of welfare items such as health supplements, food bentos, fruits and reusable masks	• Insufficiency of PPE provisions (e.g. N95 masks) at different intervals • Fear of infection • Frequent changes in Standard Operating Procedures • Lack of staff recognition; feel unappreciated • Fatigue due to reorganisation, backlogs and increase in workload due to COVID

Resilience Infographics and Messages were disseminated to all SCDF officers via email and social media platforms (i.e. Telegram) to raise awareness on resilience and provide stress management tips during the pandemic. Safe management measures such as social distancing and work-from-home arrangements were necessary to reduce the spread of COVID-19. At the same time, they can make officers feel isolated and in turn increase their stress and anxiety levels. Tips on healthy stress management aimed to enhance resilience of officers and help them cope effectively during the pandemic

Figure 1. Samples of resilience infographics disseminated to SCDF officers

Words of affirmation and support from SCDF leaders and commanders for officers during the pandemic were also incorporated in these infographics as part of the ***Leadership Resilience Series***. Senior Management leaders provided insights on self-care, work and safety, family, team management, adaptability, as well as how they personally coped and dealt with the challenges during the pandemic. These served as an inspiration and a timely reminder to all officers in the organisation.

Figure 2. Samples from the Leadership Resilience Series

SUPPORTIVE

The Mandatory Quarantine Order (QO) and the fear of contracting the virus can be stressful for officers. Recent data (Voo, Lederman, & Kaur, 2020) had emerged, suggesting that isolation and a fear of contraction were two major factors that contributed to a rise in anxiety levels and depression prevalence amidst the pandemic. To address this, EBSC has put in place some supportive measures.

Wellbeing Check-ins were put in place to establish contact with officers and to support them while they were on QO. Check-ins were usually conducted via phone calls to provide direct support for these officers. These phone calls were also meant to assess their psychological wellbeing. Officers were provided with simple tips on coping mechanisms during their quarantine. For cases where a large number of officers from a single cluster were placed on QO, group sessions via zoom were organised to check in and provide group support to the staff.

EBSC also recognised the psychological toll on officers if they were tested positive for COVID-19. Similar to the support provided for officers who were serving QO, check-in calls would be made at a higher frequency. The frequency of check-ins also depended on the officer's prevailing needs and situation such as whether he/she was hospitalised in the hospital or quarantined in a Government Quarantine Facility (GQF). Supervisors of these officers were also provided with tips on how to support the recovered officer upon their return to work.

RECOVERY

The anxiety and stress that comes with a COVID diagnosis can be significant, even for those who have recovered. There will be a psychological impact on the officers even if he/she has recovered. A new study by Oxford (Taquet et al., 2021) found that one in three people who have survived COVID-19 was diagnosed with a neurological or psychiatric condition within six months of being infected. The most common mental health conditions were mood disorders (such as depression), anxiety disorder, substance misuse, and insomnia. To better support SCDF officers who were tested positive for COVID-19, EBSC initiated wellbeing check-ins throughout the period of treatment until the affected officer recovered and returned to work.

Reintegration Calls were made to check up on the officer's readjustment to work and to assess for any need for further support. Follow-up online counselling sessions were arranged whenever necessary.

Figure 3. Example of wellbeing and reintegration check-in calls made for an officer who was tested positive for COVID-19

Supportive Measures During COVID-19 Singapore Circuit Breaker 2020

From 7 Apr to 19 May 2020, recruits from the National Service Training Institute (NSTI) were placed on Home-Based Learning Training Programme (HBL) in tandem with the nationwide COVID-19 circuit breaker period. They were required to stay at home, except for essential activities

To support and assess recruits' mental wellbeing during the HBL period, EBSC rolled out a series of activities and measures:

1) ***Structured Interview Guides*** *on how to build rapport, assess recruits' needs, and follow up with the necessary support were sent out to NSTI instructors*
2) ***Self-Care and Wellbeing Tips*** *on how to better handle the COVID-19 situation and the unique experience of Home-Based Learning during NS were shared with recruits*
3) ***Phone/ Video Counselling*** *support was provided to newly enlisted recruits based on instructors' referrals*
4) ***Weekly Resilience Surveys*** *were conducted online regularly*

Figure 4. Samples of self-care and wellbeing tips disseminated

CONCLUSION

It is of paramount importance to safeguard the mental wellbeing of emergency responders. Hence, EBSC had developed a series of psychological support measures throughout the various phases (preventive, supportive and recovery) to protect and promote SCDF officers' mental health. The 3-pronged psychological support plan was comprehensive and addressed officers' and supervisors' concerns. It allowed leaders to show care and support to their staff and illustrated the applications of various coping mechanisms to adequately address the needs of the organisation during the pandemic.

While SCDF officers were generally coping well during the pandemic, there is still a need to review, refine and devise new psychological resilience and coping strategies. One way is to adopt a positive reinforcement strategy by focusing on officers' strengths and behaviours, while paying attention to stress issues that may arise over time.

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