SCDF
The Life Saving Force

REaction

RESCUERS IN ACTION

TECHNICAL PUBLICATION FOR
SINGAPORE-GLOBAL FIREFIGHTERS & PARAMEDICS CHALLENGE

2014

URBAN DISASTER READINESS

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REaction: REscuers in action is the SCDF's annual technical publication that aims to be a platform to both invoke thought provoking discussions and to share knowledge and case studies. REaction will be issued yearly in conjunction with the Singapore-Global Firefighters and Paramedics Challenge (SGFPC).

By providing articles covering a myriad of subjects, we hope REaction will grow into a repository of knowledge for both academic and practicing readers in the emergency services fraternity.

We hope that you have gained new insights and found REaction beneficial to you.

Editorial Board

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REaction @ SGFPC 2014

URBAN DISASTER READINESS

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Foreword

On behalf of the Singapore Civil Defence Force (SCDF), let me welcome all our guests and participants to the Singapore-Global Firefighters and Paramedics Challenge (SGFPC) 2014. We are heartened by and truly appreciative of your overwhelming support for SGFPC 2014. The resounding support this year comes not only locally as manifested by the increased participation from the students, Emergency Response Teams from the companies and residential heartlands as well as the medical teams from several private ambulance operators but also from beyond the shores of Singapore, from our esteemed friends and partners within the Life Saving fraternity in the Asia Pacific region and beyond.

This year, the SCDF is striving to value-add to the global life-saving fraternity by putting together for the first time this publication which you are now reading. It is succinctly entitled '***REaction***', a short-hand that stands for '***REscuers in action***'; an apt description of our respectable and uniquely noble profession which we all share and can be proud of. In addition, the title reflects the adrenaline pumping actions and challenges of SGFPC 2014 which will peak on 13 September and above all, encapsulates the fighting spirit of all members of the emergency services – always poised and ever ready for the call of duty!

'***REaction***' is a short collection of articles and review of issues that are pertinent to our work in the domains of fire-fighting, rescue, HazMat mitigation and emergency medical services. In view of the rapid and at times unplanned expansion of cities[1] which has inevitably exposed people and economic assets to the risks of major disasters such as earthquakes, the SCDF, in partnership with UN INSARAG, has chosen *"Urban Disaster Readiness"* as the theme for SGFPC 2014. This theme reflects the challenges faced by urban fire and rescue departments due to the rising occurrences of disasters in metropolitan cities around the world. The articles featured in this publication have been specially selected to portray the challenges and intricacies of our rescue work in an urban city setting. Through the articles, we aspire to generate interest, drive discussion and hopefully, catalyse new solutions or insights on issues which are relevant and current to the emergency services.

This '***REaction***' publication will henceforth be a signature feature of the annual SGFPC and it will always be a work in progress, just as how the emergency services must always transform itself to stay relevant in its life-saving mission. On this note, I would like to put on record our deepest appreciation for the contribution of articles to this inaugural publication, especially to our overseas contributors namely Mr Stephen Glassey from the University of Canterbury, New Zealand, and Dr Greg Henry and Mr Simon Harrison from the Department of Fire and Emergency Services, Western Australia. The SCDF looks forward to more articles contributed by our local and international friends and partners in fulfilling our quest to make '***REaction***' a reputable annual publication by the Life Saving fraternity for the fraternity.

I wish everyone an engaging read and a memorable SGFPC 2014!

COMR Eric Yap
Commissioner
Singapore Civil Defence Force

[1] Based on an Urban Risk Assessment Report published by The World Bank in 2012, it was discussed that cities around the world are facing the highest disaster risk due to the large population and congregation of buildings and infrastructures.

SGFPC Organising Chairman's Preface

We had a very bold dream in the early stages of planning for SGFPC 2014 to assemble a publication on issues relating to firefighting and rescue in an urban setting. We felt strongly that the exchange of knowledge should not be limited to the competition arena. The result is this inaugural edition of '***REaction'*** – a technical publication discussing the best practices on skills and techniques, as well as topical issues that various services and departments are currently grappling with.

We've assembled a collection of related articles that we hope would benefit participants from the SGFPC fraternity. As this competition is only into its third year, we felt it would be useful to give everyone an overview of the growth of the competition that has its roots as a local, SCDF-only event in the 1990s to one that is now a growing regional platform. Separately, we also saw it useful to lay out the concept and design of the '*Braveheart*' challenge: the signature contest in SGFPC. In this piece, we share how the components of '*Braveheart*' work together in a grueling test of firemanship skill, physical fitness and sheer tenacity.

In this inaugural issue, we are honoured to have two articles from our overseas friends. Mr. Stephen Glassey from the University of Canterbury, New Zealand, reviews the INSARAG (International Search & Rescue Advisory Group) marking system and its application by various USAR teams at the 2011 Christchurch earthquake.

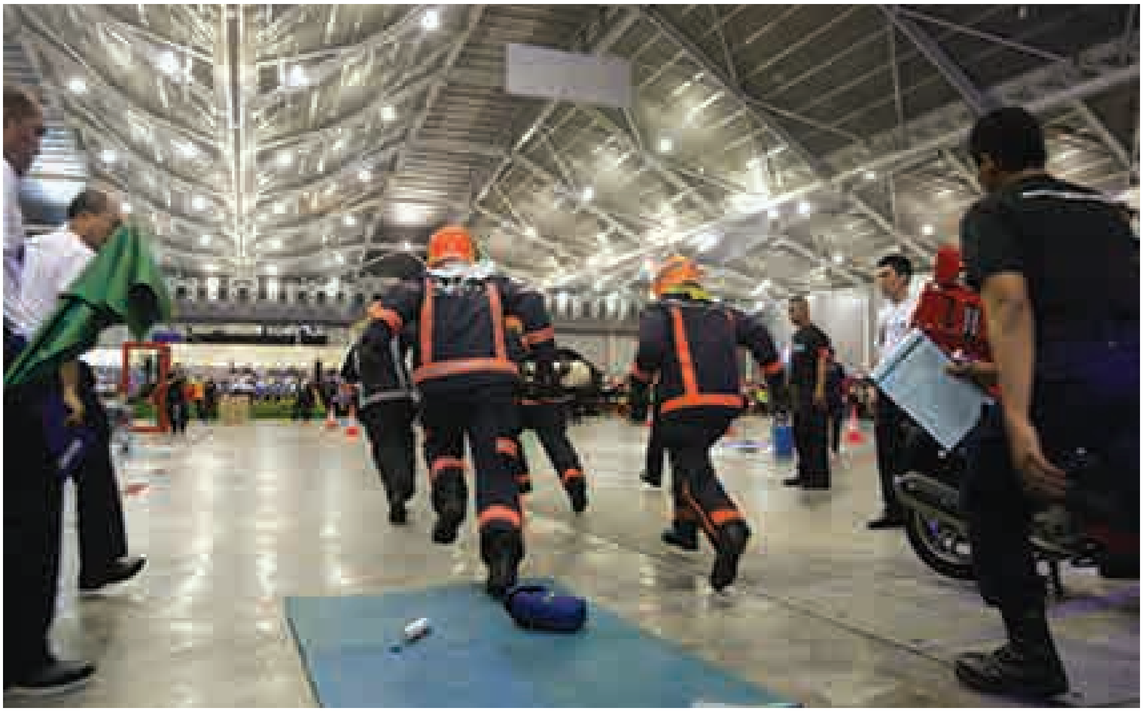
Dr. Greg Henry and Mr. Simon Harrison of the Department of Fire and Emergency Services (DFES), Western Australia, discuss best practices in scene management during road traffic accidents. The SCDF is also contributing a thought piece on its current research findings into the science of responder rehabilitation and offers recommendations on how recovery cycles for rescuers could be more effectively managed at the incident site.

The publication ends with an article on the evolution of SCDF's Light Fire Attack Vehicle (LFAV) – known fondly in Singapore as the *Red Rhino* – and traces its history from when it was first unveiled in 2000. Today, three successive generations of the firefighting appliance have since been rolled out. Plans for the Fourth Generation (4G) version of the LFAV as well as some of its latest technological capabilities are also covered.

These are early days yet for '***REaction'***, but we envision this to be a publication truly dedicated to leveling up the capabilities and know-how of the SGFPC fraternity. Over time, we envision this journal growing in terms of technical depth with each successive SGFPC. We wish everyone an insightful reading experience, and we welcome feedback at SCDF_CDA@SCDF.gov.sg on what you would like to see being covered here, or how we could improve as a publication.

Finally, I would like to thank the ***REaction*** editorial team for their hard work and dedication to the realisation of this very first publication issue.

COL Teong How Hwa
Organising Chairman
SGFPC 2014



RESCUERS IN ACTION

SINGAPORE-GLOBAL FIREFIGHTERS & PARAMEDICS CHALLENGE

RESCUERS IN ACTION

"I find these games are very exciting to the firefighters. This is an opportunity to share the skills with the other countries!"

- Hong Kong Fire Service Department

"We thoroughly enjoyed the game, but more importantly, it's very significant to us to be able to exchange information and best practices as there are a number of international teams here... There are a lot of tactical levels and techniques and it's always good to see how differently people do things differently to achieve the same objectives..."

- Department of Fire and Emergency Services
  Western Australia

SGFPC 2013

SGFPC

SINGAPORE-GLOBAL FIREFIGHTERS AND PARAMEDICS CHALLENGE

THE HISTORY OF SGFPC

1993 The Birth
Civil Defence (CD) skills competition was the first skills-based competition in Singapore. This was an internal event with the main objective of raising core competencies and promoting camaraderie among its responders.

2000 Beyond Singapore
CD Skills Competition was opened for participation from related agencies in the Association of Southeast Asian Nations (ASEAN) region to foster closer cooperation among fire, rescue and emergency services departments. The pioneer overseas participants were Malaysia, Brunei and Indonesia.

2012 Rebranding
The CD Skills Competition was rebranded as the Singapore Global Firefighters and Paramedics Challenge (SGFPC) to reflect its growing international profile, to foster strong networks and sharing of technical knowledge and skills with teams within and beyond the Asia Pacific.

2013 Gone Public
Held at a public arena for the first time to bring this competitive spectacle into the community to promote the message that emergency preparedness is a shared responsibility for both the professionals and the public.

2014 Even Bigger
Comprises the SCDF Day Parade, the SGPFC, the 28th International Fire Chiefs' Association of Asia (IFCAA) General Conference and the Fire Safety Asia Conference (FiSAC).

THE LOGO

The **Logo**
composed of the images of a firefighter and a paramedic protectively overlooking the globe.

The **Figurines**
signify the twin pillars of emergency response and their common life-saving mission anywhere in the world.

The **Color**
Red reflects the passion and blue reflects passion of these everyday heroes who lead extraordinary lives in a noble and sacrificial calling.

The **Globe**
the interlocking red and blue tiles represent the strong bonds of professional and personal friendship that the SCDF shares with the international fraternity of emergency responders.

CATEGORY OF CHALLENGES

INTERNATIONAL CHALLENGE

Held among emergency responders from more than 16 international emergency services, pitting their firemanship skills and physical abilities to the test.

LOCAL CHALLENGE

Firefighters, rescuers, paramedics and Emergency Medical Technicians from the 4 SCDF divisions gather to pit their skills in fire and rescue, HazMat, and medical response against one another.

PUBLIC CHALLENGE

Grassroots organisations and the community come together to showcase the readiness of Singapore in crisis management.

THE FLAGSHIP CHALLENGE

8:16 Fastest Timing

BraveHeart

Comprising eight stages, each is made up of a series of tasks designed to test and stretch the participants' physical endurance, agility and firemanship skills.

2013 SGFPC

16 International Emergency Services

450 Participants

7000 Visitors

Background of the SGFPC Logo

The Singapore-Global Firefighters and Paramedics Challenge (SGFPC) logo is composed of the images of a firefighter and a paramedic protectively overlooking the globe. The two figures signify the twin pillars of emergency response and their common life-saving mission anywhere in the world, while the colours reflect the passion (red) and dedication (blue) of these everyday heroes who lead extraordinary lives in a noble and sacrificial calling. The interlocking red and blue tiles in the globe represent the strong bonds of professional and personal friendships that the SCDF shares with the international fraternity of emergency responders.

Singapore-Global Firefighters and Paramedics Challenge (SGFPC) Overview

COL Teong How Hwa and **LTC Daniel Seet**
Singapore Civil Defence Force

Brief History

In 1993, the Singapore Civil Defence Force (SCDF) planned and organized its first skills-based competition for its frontline units. This was an internal event with the main objectives of raising core competencies and promoting camaraderie among its responders. Known as the Civil Defence (CD) Skills Competition, the games were designed around the themes of fire-fighting, rescue, HazMat (Hazardous Materials) mitigation and medical trauma response. Since the start of the CD Skills Competition, SCDF's Civil Defence Academy[1] (CDA) has been entrusted with the responsibility to coordinate, plan and organize the annual competition.

In 2000, the CD Skills Competition was opened to participation from related agencies in the Association of Southeast Asian Nations (ASEAN) region to foster closer cooperation among fire, rescue, and emergency services departments. The pioneer overseas participants were firefighters and rescuers from Malaysia, Brunei and Indonesia. Having seen the event mature over the decade as the main regional competition of its kind for emergency responders, the SCDF felt it was timely to broaden the game's outreach beyond ASEAN to encompass emergency services agencies from the wider Asia Pacific and Middle East regions given that many of them have participated in CDA's international courses. In 2012, the CD Skills Competition was rebranded as the Singapore-Global Firefighters and Paramedics Challenge (SGFPC) to reflect its growing international profile as well as to foster strong networks and the sharing of technical knowledge and skills with teams within and beyond the Asia Pacific. The inaugural edition of the SGFPC took place behind closed doors and saw 10 international departments[2] participating.

As part of the continued evolution of the games, the 2013 edition of the SGFPC was held at a public arena for the first time as SCDF sought to bring this competition into the community to promote the message that emergency preparedness is a shared responsibility for both professionals and the public alike. Held at the Singapore Expo, the event featured teams from 15 international departments and drew close to 7,000 visitors over two days. The 2013 event was also notable for being combined with another major annual SCDF event known as the

[1] The SCDF's Civil Defence Academy (CDA) is well recognized in the region as a premier training institution, providing specialized training in the field of civil defence for its own officers, related government agencies, the general public as well as the emergency services from the international community. To date, CDA has trained over 4,000 international participants from more than 120 countries.

[2] Australia, Bangladesh, Brunei, Hong Kong, Indonesia, Macau, Malaysia, Myanmar, Philippines and Thailand

SCDF Day Parade, which is held to celebrate and recognise officers and SCDF stakeholders for their contributions to the national emergency preparedness efforts. The combination of these two events at a public venue allowed the general community to participate in our activities and celebrations, thus capitalising on the same event venue to create a larger spectacle.

Following the success of SGFPC 2013, the 2014 edition will again be held at the Singapore Expo. This year, SCDF will be organising four events within the vicinity of the same event location in the same week to reap the greatest benefits from the synergy created, such as having a stronger overall impact, better economies of scale as a result of the pooling of resources, more co-ordinated publicity efforts and better public education outcomes. This "4-in-1" event comprises the SCDF Day Parade, the SGPFC, the 28th International Fire Chiefs' Association of Asia (IFCAA) General Conference and the Fire Safety Asia Conference (FiSAC).

The overall game design for the SGFPC will be centred on disaster response in an urban setting, hence its theme "Urban Disaster Readiness". This theme aims to position and raise the profile of emergency services agencies as a force that is always ready to lead, respond and manage consequences arising from any disaster in an urban city environment.

Friendly competition is just one facet of the multi-dimensional design of the SGFPC. The SCDF recognises that this platform can also provide a novel and alternative approach to create a learning environment for the participants over and above the conventional settings of an exercise arena. In recent years, the SGFPC has also developed strategic partnerships with renowned organisations such as the International Search and Rescue Advisory Group (INSARAG) under the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA). With the support of INSARAG to promote international partnerships through the sharing of professional USAR skills, a special segment will be included this year in the SGFPC to propagate the adoption of INSARAG guidelines when rendering overseas assistance.

In addition to the competition and the INSARAG segments, the SGFPC is also incorporating community engagement activities and exhibitions in this year's event. There will be an equipment display segment to showcase some of the SCDF's latest vehicles, technologies and operational capabilities, as well as educational games and fun-filled activities to entice the public to pick up emergency preparedness skills. Apart from opening the doors of the event to the walk-in public, organised visits will also be held for community folks and students. To generate awareness among the community for the SGFPC, SCDF is leveraging its existing island-wide fire station open house programme held on Saturday mornings to extend its public outreach.

Broadly, SGFPC 2014 will have 3 key segments, namely:

1 *Responders' Challenge* for international, local and community responders;

2 "Exercise Urban Elite" for international teams that are trained in INSARAG guidelines; and

3 "Life Savers Connect", a community engagement event comprising exhibitions and activities for the public.

Figure 1: Guard of Honour Contingent Commander MAJ Kenneth Mak offering a salute during the SCDF Day Parade 2013.

Highlights of Responders' Challenge

International Responders' Challenge

"*Rip-It-Off*" depicts a road traffic accident scenario where teams will be judged based on scene assessment, vehicle stabilisation, extrication techniques and medical intervention. In the 2013 edition, the event was won by the team from the Department of Fire and Emergency Services, Western Australia in a record time of 6 minutes and 36 seconds while the average time taken was 9 minutes and 24 seconds.

Figure 2: Participants in action for "RIP IT OFF".

"*Braveheart*" is the flagship individual challenge of the SGFPC and is one of the event highlights. This challenge is designed to test the participants' physical endurance, agility, firemanship skills and more importantly, their ability to plan and pace themselves to complete the course in the best possible time. The sequence and parameters of this contest shall be kept constant so that each year, participants taking up the challenge can attempt to break records that have been set previously. The inaugural event was won by SCDF's SSG Azmir Ali in a record time of 8 minutes and 16 seconds while the average duration was 11 minutes and 33 seconds.

Figure 3: Rescuer in action for "Braveheart".

Local Challenge

In this segment, firefighters, rescuers, paramedics and Emergency Medical Technicians (EMTs) from the SCDF territorial divisions will gather to pit their skills and competencies in three core

Figure 4: Participants in a Chemical Agent (CA) rescue scenario during the Local Challenge.

areas of fire and rescue, HazMat, and pre-hospital medical response. This segment will also provide a visual demonstration to the public of the diverse operational scenarios that SCDF responders are capable of dealing with, as well as showcasing the SCDF's latest equipment and operational capabilities.

Community Responders' Challenge

The *Community Responders' Challenge* segment comprises of competitive skills-based challenges designed for Company Emergency Response Teams[3] (CERTs) and volunteers from the general community. These challenges serve as an opportunity for the CERTs and community volunteers to showcase their readiness in an emergency while forging closer interactions between SCDF and the general public.

Figure 5: Participants in action for the Community Responders' Challenge.

Community Engagement

For this year, the *Community Engagement* segment "Life Savers Connect" will comprise an extensive showcase of SCDF emergency appliances and capabilities, as well as games and fun-filled activities for different ages. The games are specifically designed to reinforce emergency preparedness messages (EP) and also to encourage members of public to pick up life saving skills and knowledge in a fun and engaging manner. The community engagement activities serve to give visitors a rich, all-round understanding and experience of being in the SCDF, as well as to engage and entertain them during lull periods in between competitions.

[3] Community Emergency Response Teams (CERTs) are an organised group of volunteers equipped with special training for first response to an emergency and assist the community in the recovery process. The main role of the CERT is to strengthen the emergency response capabilities of the local community. Being closer to the ground, they can attend to an emergency even before the arrival of the authorities and help to mitigate the circumstances by controlling a fire from escalating, rendering basic first aid, as well as evacuation and crowd control.

Figure 6: Members of public learning Cardiopulmonary Resuscitation (CPR) at the Community Engagement segment last year.

Moving Forward

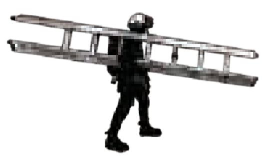
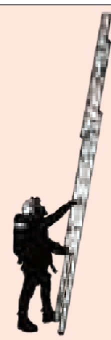
The SGFPC has come a long way since its humble beginnings. The challenges and lessons learnt along the way have contributed to the development of the event over the years. The overarching goal of SGFPC is to provide a platform for participating agencies and departments to share and advance our collective skills and knowledge in the fields of firefighting, rescue, and pre-hospital emergency care. Through the wide outreach of CDA's training courses and the collaboration with our international partners, SCDF has the bold vision of promoting and developing SGFPC as the premier platform for the global fire and rescue fraternity to form strategic partnerships and push the life saving profession to greater heights.

Deconstructing the Braveheart Challenge

LTC Alan Toh
Commander, Disaster Assistance and Rescue Team
Singapore Civil Defence Force

"Braveheart" is the pinnacle event in the SGFPC which aims to promote and inspire firefighter fitness and demonstrate the physical demands on a firefighter. Comprising of eight stages, each is made up of a series of tasks designed to test and stretch the participants' physical endurance, agility, and firemanship skills. The stages are in sequential order. The tasks to be completed are highly physical in nature. The participants are also expected to plan and pace themselves so that they can complete the physically demanding challenge.

The following pages will explain in specific detail the nature and design of the course in its various components and the intended test objectives of each segment.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
1	Participants donned in their Personal Protective Equipment (PPE) comprising of helmet, gloves and full body harness will carry out the following tasks:		This stage serves to test the firemanship skills of the participant in (i) the donning a Breathing Apparatus set and (ii) the ability to correctly pitch a triple extension ladder (the requirements of having two rungs above the railing at a correct angle is an exercise of safety protocol) all by oneself. It also tests the speed and strength of the participant during the dash towards the tower while carrying a medium amount of load (i.e. the SCBA and the ladder).
(a)	Put on a Self Contained Breathing Apparatus set (SCBA) weighing 11.7 kg.		
(b)	Carry a triple extension ladder (21kg) and run 40m towards the Height Tower.		
(c)	Pitch the ladder to the first floor of the tower with the base of the ladder set within a stipulated yellow box. There shall be a minimum of two rungs above the railing.		

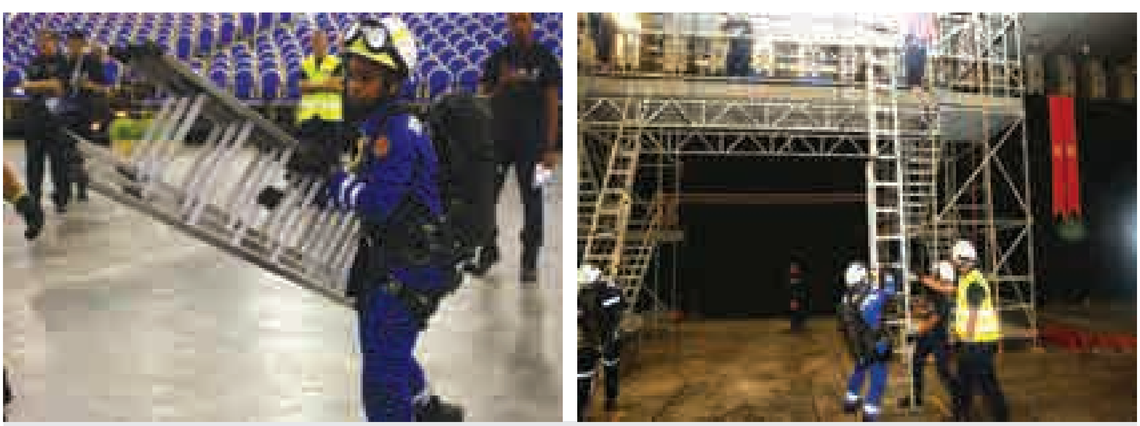


Figure 1: Participants in action for Stage 1.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
2	Participants donned in their PPE with SCBA (unplugged) will carry out the following tasks:		This stage is designed to mimic common fireground operations : (i) overcoming the resistance when straightening and subsequently (ii) recovering the two lengths of hoses using the Dutch-roll method. Timings will be taken and this stage will subject the participant to a medium intensity workout due to the weight of the hoses, the technique needed to execute the Dutch-roll (i.e. this method will require strength in the lower back and quadriceps) and the Breathing Apparatus set on the back.
(a)	Pull and straighten two lengths of 64mm hoses (30m, 17.5kg each) back towards the starting point.		
(b)	Recover the hoses by applying the Dutch-roll method (once completed the two coiled hoses will be at the starting point of the Braveheart course).		

Figure 2: Participants in action for Stage 2.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
3	Participants donned in their PPE with SCBA (unplugged) will carry out the following tasks:		This stage is designed to test the participants' firemanship skills in tying a good rescue knot to secure the two rolled-up hoses (with gloves on, which adds to the challenge). It also tests the individual's technique and strength in hoisting up the two hoses to the second floor (height of 7.3m). Participants are advised to use more of their body weight and less of the arm muscles in order to conserve energy for subsequent tasks.
(a)	Carry the 2 rolled-up hoses towards the tower and tie a rescue knot to secure the hoses using a 11mm diameter Kernmantle Rope.		
(b)	Climb the ladder to reach the first floor (4.3m) and proceed via the staircase to second floor (7.3m).		
(c)	Hoist both hoses to the second floor with the hoisting line passing through a pre-set pulley system.		

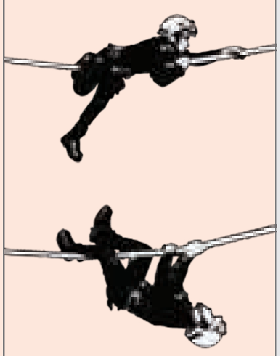
Figure 3: Participants in action for Stage 3.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
4	Participants donned in their PPE (and having removed the SCBA set) will carry out the following tasks:		This stage is designed to test the participant's firemanship skills in (i) properly rigging up the rappelling lines, and (ii) to adopt a good L-shaped posture and conduct a smooth rappel to the ground floor with the casualty. The safe handling of the casualty will also be monitored during the execution of the manoeuvre
(a)	Move towards the rappelling lines which are pre-set, secure the rappelling lines to the personal body harness using a Figure-of-Eight Descender device and a Carabina and rappel to the first floor of the Height Tower.		
(b)	Secure the 'casualty' (a 25kg Rescue Randy with articulated joints) to the body harness and use the 'Buddy Rappel' method to bring the casualty safely to the ground floor. This stage is completed when the casualty is released from the body harness.		

Figure 4: Participants in action for Stage 4.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
5	Participants donned in their PPE will carry out the following tasks:		Arguably the most critical stage in the entire course, this segment sets out to test the strength, endurance and technique of the participant in scaling up the rope. Apart from good body coordination, it requires the use of extensor (forearm muscle) and abdominal muscles. It is unlikely that the participant would be able to rely purely on his arm muscles to scale the rope at this stage, especially after the contestant has endured the previous four stages. Using a proper leg-lock technique will help.
(a)	Recover the triple extension ladder and set it on the ground.		
(b)	Climb a 30mm diameter manila helm rope to reach the first floor (4.3m).		

Figure 5: Participants in action for Stage 5.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
6	Participants donned in their PPE will carry out the following tasks:		This stage will test the ability of the participant to traverse across a rope using any method. A lot of body coordination is required in this manoeuvre. By far, the 'Commando Crawl' method appears to be the fastest among all the means.
(a)	Securing themselves to a preset safety line, participants are to mount onto a horizontal manila helm rope, manoeuvre 5m across the rope, dismount the rope and release the safety line. Any technique of traversing is allowed on the rope.		

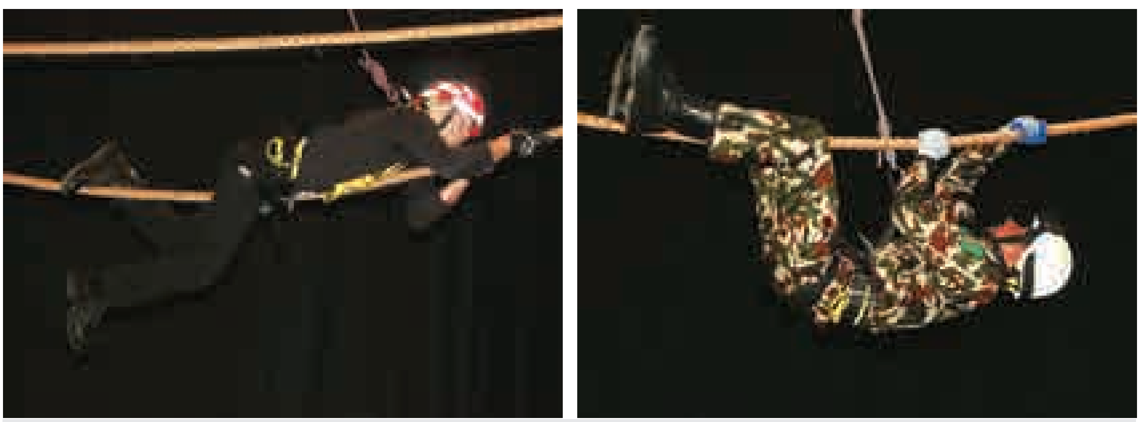


Figure 6: Participants in action for Stage 6.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
7	Participants donned in their PPE will carry out the following tasks:		This is the stage that differentiates the finest among the fittest. Participants without the necessary fitness levels would have difficulty reaching this point of the course. Here, with the entire body suspended in mid-air, the manoeuvre along the 35m rope requires tremendous lower back and arm muscles strength, not to mention sheer determination over a rapidly fatiguing body.
(a)	Secure themselves to a down-sloping hem rope (30mm diameter), traverse 35m towards a platform (any method) and, upon reaching the platform, disconnect from the rope.		

Figure 7: Participants in Action for Stage 7.

Stage	Tasks	Pictorial representation of Tasks	Tactical Analysis of Stage
8	Participants donned in their PPE will carry out the following tasks:		This final stage is purely mind-over-matter as it calls on participants to give their all to finish the course in their best time. To be able to fireman-lift the 25 kg casualty requires upper body strength, strong quadriceps and a hearty serving of tenacity.
(a)	Run towards the casualty (25 kg) that was laid down at the foot of the Height Tower in Stage 4, execute a fireman lift of the casualty and race towards the finishing line (start point of the challenge). The course is completed once the participant rings the bell that is mounted to the platform.		

Figure 8: Participants ringing the bell to signify completion of the Challenge.

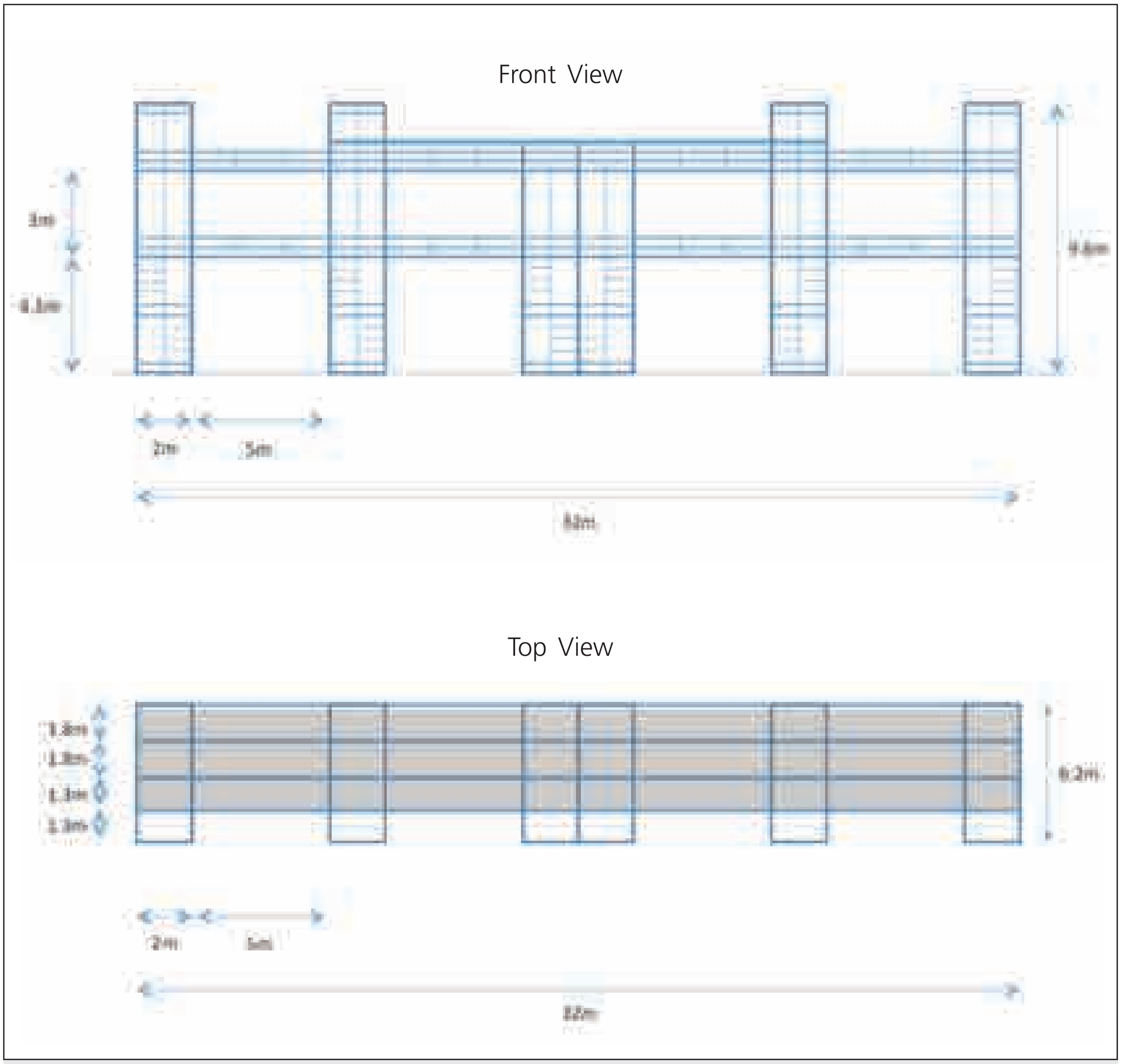


Figure 9: Schematics & Specifications of the height tower used for the Braveheart Challenge.

A review of Urban Search and Rescue markings applied following the 22 Feb 2011 Christchurch earthquake and recent revision of the INSARAG search marking system

Stephen Glassey
University of Canterbury
New Zealand

Introduction

At 12:51pm on Monday 22 February 2011, a shallow magnitude 6.3 earthquake struck at the heart of the Christchurch, leading to 182 fatalities, hundreds of injured [1], over 156,000 insurance claims and damages in excess of NZ$5bn [2] making it one of New Zealand's worst disasters in history. The earthquake left hundreds of buildings severely damaged with people trapped inside. This led to New Zealand's first national state of emergency being declared [3] and prompting a massive international urban search and rescue effort with teams afar as the United Kingdom, United States of America, Japan, China, Taiwan, Singapore and Australia deploying to assist (Figure 1).

Figure 1: Map of countries that deployed international rescue teams to Christchurch earthquake (Map source: Google).

The formal global mechanism to standardise such response efforts is provided by the United Nations through guidelines established by the International Search and Rescue Advisory Group (INSARAG) under the authority of United Nations General Assembly Resolution 57/150 [4] of which New Zealand was in favour of [5]. INSARAG published guidelines include capacity development, standardised tactics, search methodology, team classification and search marking systems. In 2001, New Zealand formally established the national urban search and rescue project [6] which gave effect to the resolution. The multi-agency Steering Committee included officials from the Ministry of Civil Defence & Emergency Management, New Zealand Fire Service and local government. Over the following years, urban search and rescue task forces were established (NZTF1 in Palmerston North, NZTF2 in Christchurch and NZTF3 in Auckland) by the New Zealand Fire Service. These taskforces were augmented by the development of locally based volunteer civil defence rescue teams nationally audited and registered as New Zealand Response Teams. Following the February 2011 earthquake all three task forces and eighteen response teams were deployed to the affected area, making it the largest national disaster rescue deployment in New Zealand's history. The central business district was one of the worst affected areas and became the focal point for rescue personnel to search some 4,000 buildings in the cordoned zone, later to be known as the *Red Zone*. In accordance with the INSARAG Guidelines and Methodology (herein the guidelines) a structural marking (Figure 2) is applied to collapsed structures [7]. The guideline has been continually updated through input at annual INSARAG Team Leader Meetings and prior to the February earthquake the Victim Marking system (Figure 3) was removed (T. Skavdal, INSARAG Secretariat, personal communication, October 2011). Indeed the victim marking concept was not included since the July 2006 edition of the guideline, but published in the General Rescue Manual of March 2006 [8]. The purpose of the marking system is to provide a standardised method to indicate search progress and to clearly indicate whether potential or actual victims remain inside the collapsed structure to avoid duplication of search effort and prevent heavy machinery being accidentally used where casualties remain. It is important that all responding agencies understand the marking system along with other protocols outlined in the guideline to avoid confusion. Beyond the work of Morris [9], there is a void of empirical research relating to INSARAG activities. This study explores the application of the INSARAG structural markings used following the February earthquake through evaluating quantitatively the adherence to the guideline using a newly developed tool and offers an appraisal and recommendation for future application of disaster search markings.

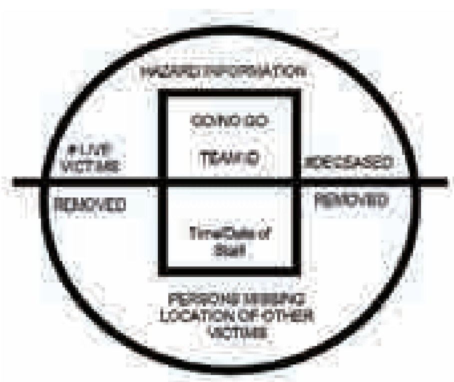


Figure 2: INSARAG Structural Marking.

Figure 3: INSARAG Victim Marking (discontinued).

SGFPC 2014

Method

A sample of images (n=153) containing search markings applied within the following ten days of the 22 February earthquake were finalised from several hundred photographs supplied by social media and other network requests, along with images from the internet. The majority were geotagged or displayed adequate building features to allow confirmation that they were from the affected central business district. According to the Canterbury Earthquake Recovery Authority (CERA), there are approximately 4,000 buildings in the central business district. Images were visually assessed and given a Search Marking Adherence Score (SMAS) and additional data was also captured. The qualitative data results have a margin of ±7.77% at the 95% confidence level based on the sample (n=153) and population (n=4,000) sizes.

Search Marking Adherence Score

A simple quantitative grading system was developed as part of this research project to enable comparative analysis of search markings applied following the February earthquake. The pertinent characteristics of search markings for the INSARAG structural assessment were identified (Table 1). Based on these characteristics, the Search Marking Adherence Score (SMAS) (Table 2) was then applied to images of search markings. The simplicity of the tool enables benchmarking of search markings to occur. In operating the tool, SMAS is converted to percentage, excluding criteria unable to be evaluated. Fields that are unable to be evaluated are counted and noted next to the percentage as the adjustment factor in superscript i.e. "SMAS: 85%^{2}"

Table 1: Pertinent characteristics of INSARAG search marking systems

Characteristics	INSARAG
Colour	International Orange
Size	1m x1m
Placement/Positioning	Near point of entry
Usage	USAR teams
Entry Recommendation	Go or No Go
Reporting	Yes to OSOCC
Team ID	Yes
Date/Time Start	Yes
Date/Time Finish	Yes
Hazard Info	Yes
Missing Persons	Yes
Live Victims Rescued	Yes
Dead Victims Extricated	Yes
Completed to Capacity	Circle around entire marking
Confirmed as Clear	Horizontal Line

The Search Marking Adherence Score (SMAS) was peer reviewed then piloted and refined with a small sample (n=20/13%) before being applied to the entire sample.

Table 2: Search Marking Adherence Score (SMAS)

Criteria	Major Non Adherence (1)	Minor Non Adherence (2)	Adherent (3)	*Example*
1. Colour (compulsory)	Difficult to read	Colour choice able to read	International Orange	*3 (International Orange)*
2. Size (compulsory)	<20% 1x1m UN Or no box	±5-20% 1x1m UN	>5% 1x1m UN	*2 (1.2x1.2m)*
3. Placement/ Positioning	Not on Structure	On Structure	Front of Structure	*2 (side of structure)*
4. Entry Recommendation	Well outside specification or Incorrect location or not included	Correct location and near specification (G or NG)	Correct location and within specification	*2 (NG, rather than No Go)*
5. Reporting	Not reported	Reported outside parameters (delayed)	Reported within parameters	*- (Blank/unable to verify)*
6. Team Identification	Unable to Identify country or team	Difficult to Identify country or team	Easy to Identify country or team	*3 (NZ-RT23)*
7. Entry Time	Well outside specification or not given	Near specification	Within specification	*1*
8. Exit Time	Well outside specification or not given or unable to read	Near specification	Within specification	*3 (Date given 22FEB 13:15)*
9. Hazard Info	Well outside specification or unable to read	Near specification	Within specification (including Null)	*- (Blank)*
10. Victim Data	Well outside specification or unable to read	Near specification	Within specification (including Null)	*3 (0 on left and right of box)*
11. Completed to Capacity	Well outside specification	Near specification	Within specification	*3 Box circled*
12. Confirmed as Clear	Well outside specification but noted otherwise	Near specification	Within specification	*3 Line through box*

Limitations

The SMAS is limited to generating quantifiable data on the adherence to the INSARAG marking system. It is not capable of measuring the rationale for deviation, so therefore it provides a score solely on adherence to the criteria, as opposed to acknowledging the operational demands that may require such non-adherence. The sample size, when viewed collectively, provides a fair margin of error. The population size is likely to be exaggerated in this study as not all buildings within the Central Business District would require a search marking under the guideline and by doing so the results may have a lower margin of error accordingly. There are, however, limitations with the data; in particular low daily samples at the beginning and end of the date range in particular days 1 (n=2), 2 (n=3), 9 (n=5) and 10 (n=1). Individual teams or countries were unable to be negatively identified as part of the ethical requirements for this study, consequently a number of images have their team identification removed. This limits segregation of results to allow comparison between individual teams and data is based on three team types, rather than specific entities.

Results:

General Observations

Of the sample population (n=153), 66.01% of the markings were applied by International Teams, 24.84% by NZ Task Forces and the remaining 9.15% were applied by NZ Response Teams. No markings by other team types such as New Zealand Fire Service (Non-USAR), Red Cross or Land Search and Rescue were observed. 24.84% (n=38) used the figure zero to indicate a null field (figure 6).

Search Marking Adherence Score

There was an overall trend of improvement of search marking adherence as the incident progressed (Figure 4). The quantitative data in isolation does not provide any valid explanation for the minor increase in the scoring trend.

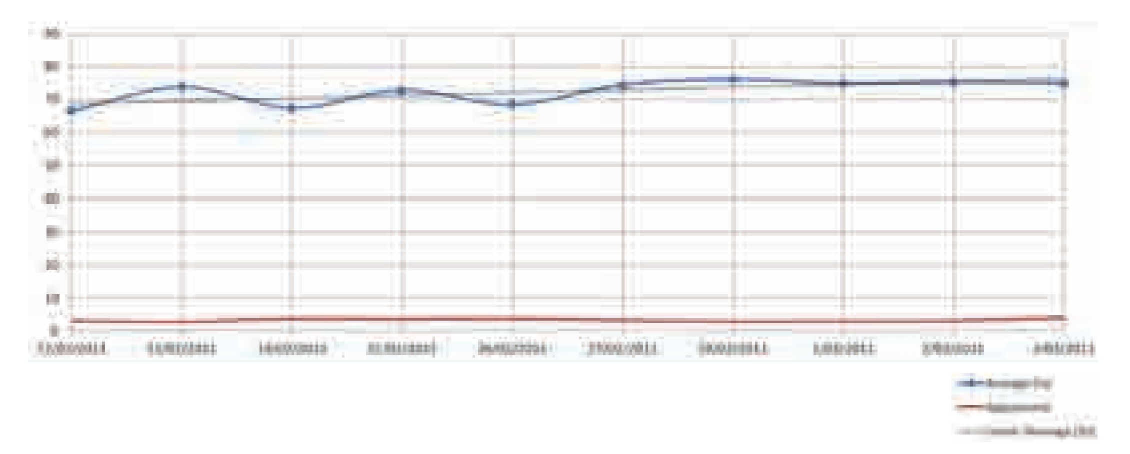


Figure 4: SMAS trends.

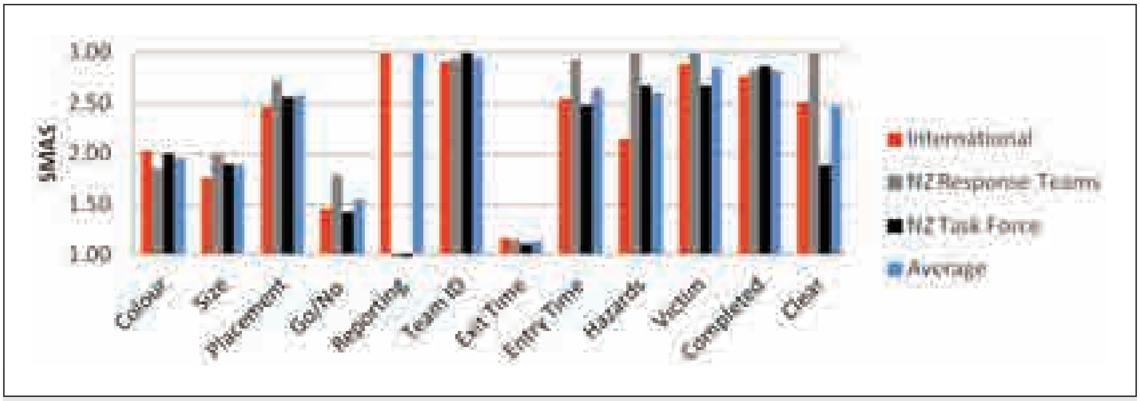


Figure 5: SMAS average by team type.

In analysing the colour application of the sample, only 4% (n=6) used the specified *international orange* colour to apply the search marking. The next prevalent colour selected was other shades of orange, including fluorescent types (40%, n=61) meaning 44% (n=67) of all search markings were a shade of orange. Following orange types, pink (39%, n=59) appeared to be the closest rival. Other colours included yellow (8%, n=13), red (5%, n=8) or green (4%, n=6). No other colours were observed in the sample. In respect to the SMAS *colour* criteria (figure 5), international teams averaged 2.02, NZ Task Forces 2.00, NZ Response Teams 1.86, with an overall average of 1.96.

In the scoring of *size* (figure 5), the international teams slightly under performed under these criteria (1.76) against their NZ Task Force (1.89) and NZ Response Team counterparts (2.00) with an overall average of 2.00. An illustration of a marking being oversized is provided in Figure 8.

Placement scores also had marginal variation with NZ Response Teams having a high adherence to the guideline (2.71). Remaining team types followed with NZ Task Forces (2.55), International Teams (2.47) and an overall average of 2.58. In application of the markings, 80.39% (n=123) were applied on the collapsed structure near the point of entry in accordance with the INSARAG guideline. The remaining markings were applied to the fence 6.54% (n=10), footpath 10.46% (n=16) (Figure 9) or on a sheet or similar non structural element 2.61% (n=4).

Scoring of *Go/No Go* criteria showed a distinctive variance between NZ Response Teams (1.79) and International Teams (1.45) and NZ Task Forces (1.42), with an overall average of (1.55). The guideline requirements specified in F13.6 [10] both in the text descriptor and example illustration clearly prescribe "Go" or "No Go", however International and NZ Task Force team types were more prone to abbreviate these to "G" or "NG" (Figure 7).

Reporting was difficult to accurately score as it was not possible to interview each person responsible for the sampled marking to ascertain whether the assessment result was reported immediately to the OSOCC as specified in the guideline [10]. Only one confirmed instance of reporting assessment result from the image sample population was available. Although the SMAS does take into consideration all criteria of the INSARAG structural marking, this criteria was omitted under the Adjustment Factor in close to all instances (99.34%) under this analysis.

All team types consistently scored high under the *Team Identification* criteria. NZ Task Forces scored the maximum average of 3.00, followed by NZ Response Teams (2.93) and International Teams (2.91) with an overall average of (2.95) making it the most highly scored criteria across SMAS analysis. There appeared to be no major issues with identifying the team whom applied the search marking.

Entry and *Exit Times* were problematic with discrepancies within the guideline. The guideline requires a start (entry) date and time under F.13.6(3.4) and a finish (exit) date and time under F.13.6(3.5). However the example illustration only provides for start time/date and no finish date/time is provided [10]. Based on example illustration within the guideline, where only one date/time was provided, it has been assumed as the *start* date and/or time. Due to this there was significant underperformance of *exit* criteria across all team types (International 1.16, NZ Response Teams 1.14 and NZ Task Forces 1.11) with an average of 1.14. In contrast, the use of at least an *entry* date or time in the image sample was very high (average 2.65) with NZ Response Teams being scoring highly (2.93). International Teams (2.54) and NZ Task Forces (2.47) following behind. 10.46% (n=16) of markings used the US date format system (Figure 6) contrary to local format and all of the US date formats were applied by International Teams.

Hazard information scores varied considerably from 3.00 (NZ Response Teams), 2.67 (NZ Task Forces) and 2.14 (International Teams), average 2.60. Figure 8 illustrates on example of incorrect placement of "water basement" hazard information which should have been outside the box at the top if to applied in accordance with the guideline [10].

Figure 6 (International Team): Example of foreign date format. The size and location of the date is also non-compliant. Zero fields for victim information are also applied. Photo by Stuart Fraser.

Figure 7 (NZ Task Force): Example of abbreviated Go/No Go, correct placement of hazard information, limited date/time, and incorrect indication of "clear" (line through marking not applied). Photo by Stuart Fraser.

Figure 8 (International Team): Marking that misplaces and abbreviates "No Go". Incorrect placement of "water basement" hazard. Zero fields for victim identification are also applied. Photo by Peter Seager.

Figure 9 (NZ Response Team): Marking applied not on the structure, abbreviated "Go" and oversized. Note use of letters to denote month to avoid confusion with foreign date format. Horizontal line drawn through marking to mark as clear. Photo by Alan Keeber.

Victim Data adherence scored well with an overall average of 2.85 (NZ Response Teams 3.0, International Teams 2.89, NZ Task Forces 2.67). The use of the figure zero used (24.84%, n=38) to indicate a null field was mainly used by international teams and predominantly for victim data (Figures 6 and 8). Despite the removal of victim markings (Figure 3) from the guideline prior to 2006, there appeared to be a trend for some teams, both domestic and foreign to still apply these (Figures 10 and 11).

All team types generally adhered to the guide to mark a structure as *Completed* (NZ Task Forces 2.87, NZ Response Teams 2.83, International Teams 2.76. Overall average 2.82). Again between 2002 and 2006, there appeared to be another change to the guideline introducing a horizontal line to indicate as *Clear*. The difference here is that *Completed* was to indicate that the structured had been searched to the team's capacity and indicated by a circle being drawn around the entire marking [11]. The new step of using a horizontal line through the entire marking to confirm the absence of any further remain (or *Clear*) was the addition[11]. There appeared to be significant variation in adherence to the guideline by teams marking a structure as *Clear*. NZ Response Teams showed high adherence to the guideline for confirming a structure had no more victims remaining (3.00), followed by International Teams (2.52) and NZ Task Forces (1.89).

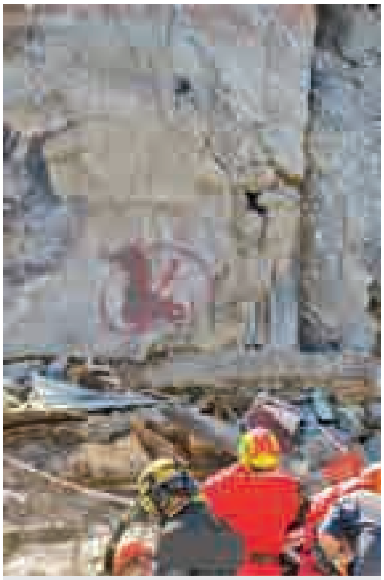


Figure 10: Victim marking. Photo by NZ Defence Force.

Figure 11: Victim marking. Photo by Phil Parker.

Although the research will not negatively identify specific task forces, during the analysis of pictures it was observed that the Singaporean and Australian international teams scored very high in their adherence to the INSARAG guideline.

Overall, NZ Response Teams had the highest adherence to the guideline with an average SMAS of 77.46%$^{3.36}$, followed by International Teams 71.55%$^{3.38}$ and least adherent was NZ Task Forces 69.87%$^{3.32}$ (SMAS Average across all team types 73.00%$^{3.35}$,n=153).

Discussion and Implications

General

The INSARAG marking system proved to be a useful tool in the aftermath of the Christchurch earthquake. Although there was variation across the team types and country of origin, the system worked reasonably well when applied correctly. There did however seem to be a general theme that many teams were not aware of the revised structural marking and the removal of the victim markings from the guideline. The standardisation and consequential correct interpretation of search makings should lead to a more effective rescue response through minimising duplication of search efforts, safer working environment for rescuers, improved detection and retrieval rates of victims and improving international interoperability across rescue teams, which all lead for better outcomes for the affected community.

Application performance

There was a slight increase in adherence scores in the days following and this is likely to be attributed to verbal pollination of the guideline's understanding between team members. New Zealand Response Teams scored the highest in their application of search markings, even above the average of internationally accredited INSARAG teams. This is likely to be contributed to by their culture of regular USAR specific training as volunteers (albeit at a light level) and an autonomous interest to follow changes of the guideline regardless of the lack of information or updates from the country's focal points. International teams were second in their adherence scoring, reflective of the need to ensure all operational members are familiar with the guideline as part of their accreditation. The New Zealand Task Forces scored the lowest which may be caused by a lack of regular ongoing training and exercising in comparison to the other team types and lack of information or updates from the country's focal point (such as changes to the guideline).

Key recommendations

Structural Markings

The guideline for the structural marking should be revised as follows:

1. Clarify that the size and colour of the marking is only a recommendation.
2. Recommend that a universal date format being adopted (i.e. 22 FEB 2011).
3. That only one time (entry or exit) is listed to decrease paint consumption.
4. Placement of the marking ideally should be on the front of the structure; however other options including on the structure's footpath or fence may be less preferred alternatives, noting that liquefaction and traffic may affect the survivability of footpath placed markings.
5. That the structural assessment (Go or No Go) should be abbreviated (to G or N) to decrease paint consumption and reduce encouragement of public to re-enter buildings safe for rescuers, but not safe for public.
6. Consider standardised international team naming conventions to allow for country and level to be included. For example NZ1M (New Zealand Team 1 – Medium), US2H (USA Team 2 – Heavy), FJ3F (Fiji Team 3 First Responder). This would allow the "completed to team capacity" circle marking to be better understood in context to the team's level of capability (First Responder, Light, Medium and Heavy).
7. That null values (such as victim data) not be used to decrease paint consumption
8. The horizontal line is the indication of clear and once applied the structure should not be re-entered by rescue personnel.

Training and Competency

9. The guideline and in-country training guidelines for urban search and rescue should mandate periodic search marking competency tests for rescue personnel.

Information Sharing

10. The guideline should include Terms of Reference (TOR) and for INSARAG country focal points (political and operational) and develop a mechanism to ensure guideline updates and other relevant information resources and opportunities are promulgated to all stakeholders (accredited and non-accredited actors).

Rapid Clearance Mark (RCM)

11. The guideline needs to include a simple marking able to be used by non-USAR first responder to mark buildings as clear. This could also be used by USAR practitioners to note that non-structural search areas (vehicles, caravans, boats, small sheds, collapsed walls etc) have been cleared. To distinguish this from property owners or occupiers, a circle with a horizontal line could be used (i.e. ϴ) as suggested by one respondent. The marking of "clear" could be left as a common sense application for use by property owners and lay-persons.

Low Damage Search Marking (LDSM)

In particular when searching suburbs with minimal damage, consideration should be given to an alternative means to mark the structure other than spray paint. Several options have been put forward by the sample group including coloured card and waterproof paper, stapled to the fence with the search assessment marking applied using a permanent marker. Such a placard based system (figure 12) has already been used, including following the Bastrop Fire (E. Macaluso, personal communication).

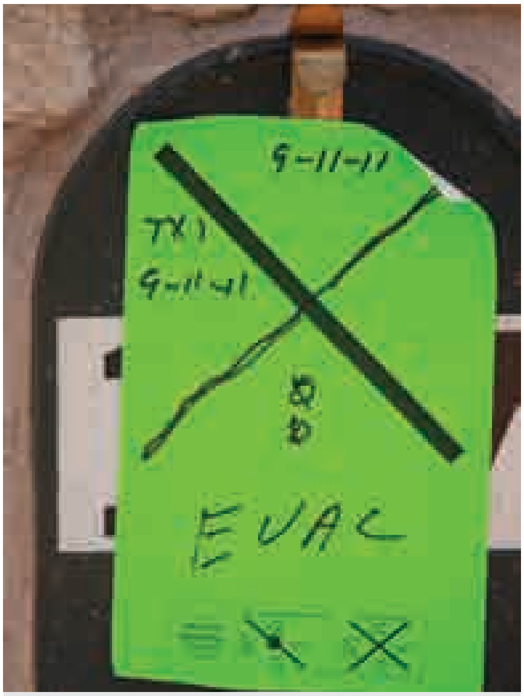


Figure 12: FEMA search assessment marking in use by Texas Task Force 1, Bastrop Fire, 2011.

Some countries have developed post-response building evaluation systems that include the use of coloured cards [12]. However, the use of coloured cards as a search marking may be problematic given potential conflict with such engineering assessment placards systems.

12. The INSARAG guideline should suggest the use of waterproof paper (A4 or Letter size) being affixed to the structure or fence seems with the structural marking information being written on in permanent marker. The structure's address should also be placed on the header in case the marking sheet separates from the structure.

These sheets could be pre-printed with base information (i.e. box and team identification, as per Figure 12) to expedite search operations. However should a building be collapsed or damaged, the standard (spray painted) structural marking should be used instead making the property easy to identify.

Victim Markings

There was a lack of data pertaining to victim markings which were used following the Christchurch earthquake, despite the victim marking system being removed from the INSARAG Guideline. The victim marking system has been revised and included in the current FEMA USAR Task Force Field Operations Guide [13].

13. The INSARAG guideline should include the revised victim markings or at least provide commentary and reference resources in which personnel can refer to in order to decode such markings if deployed to countries which domestically use these.

Recent changes to the INSARAG Search Marking System

Overview

The INSARAG Training and Standards Working Group has announced changes to the search marking system including the replacement of the traditional box search assessment marking (figure 2) with a new system based on *Assessment, Search and Rescue* (ASR) levels [14]

ASR Level 0: Research of affected area before arrival on site
ASR Level 1: Wide Area Assessment
ASR Level 2: Sector Assessment
ASR Level 3: Rapid Search and Rescue (worksites)
ASR Level 4: Full Search and Rescue (worksites)
ASR Level 5: Total Coverage Search and Recovery

Structural Markings

The ASR based search marking example (Figure 13) illustrates that the Australian Task Force 1 (AUS-1) has completed a Sector Assessment (ASR 2) for Sector (Charlie) at Worksite (5) on the 19th of October. The same Task Force carried out full search and rescue on the 21st of October. The marking does not provide the same level of detail that the former box method such as hazards, quantity of casualties or deceased removed, times of entry or departure. Although the ASR level provides more confidence and clarity around whether a building has been fully cleared, the new ASR based structure marking appears to be a major deviation from what has a successful system in the past. As the new ASR based system deviates significantly from former INSARAG search marking system, it is no longer compatible with the SMAS, so therefore a new evaluation tool for search marking compliance will need development. The considerable change will also mean significant updating of training to the thousands of responders globally that given the evidence to suggest that dissemination of previous editions has not successful, will likely result in further confusion at future incidents over the search marking system. It would be more prudent to update the traditional box method to include the ASR element, through removing the circle, strike through line and times whilst adding the ASR level inside the box under the team name. Reducing the date stamp to the completion date would also make sense (figure 14). This would also allow only minor changes to the SMAS allowing for longitudinal research on search marking effectiveness to occur.

Figure 13: Example of new ASR based search marking (INSARAG, 2012).

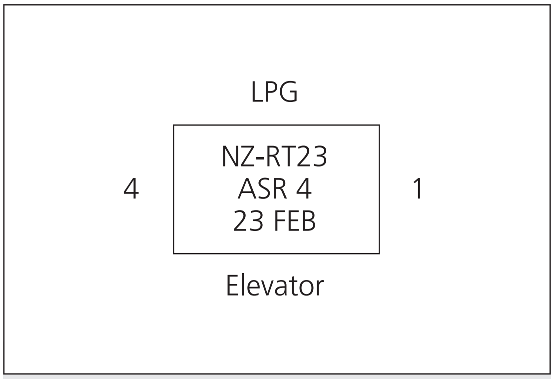


Figure 14: Recommended revised search assessment marking

Victim Markings

The revised guidance note also re-introduces Victim Markings which should improve effectiveness in future urban search and rescue operations. However, though similar the Victim Marking system appears to re-introduce the former INSARAG victim marking system which is not compatible with the Victim Marking system as laid out in the 2014 edition of the National Fire Protection Association Standard 1670 (Standard on Operations and Training for Technical Search and Rescue). There appears to be a disconnection between INSARAG and NFPA over the development of search markings and though technically the NFPA is a national standard within the US, it is seen as a default standard in many countries. Given that the US is a signatory in 2002 to the General Assembly resolution (57/150) their national standards should be consistent to agreed international conventions. Further work is required between INSARAG and NFPA to agree upon standards for search and rescue markings.

Rapid Clearance

The introduction of the new Rapid Clearance marking (figure 15) is an improvement consistent with earlier recommendations. The specifications in the guidance note specifies the marking to be 20x20cm, which is rather restrictive given research indicating that larger specifications for markings are required to allow for spray painting and writing of text. It is recommended that Rapid Clearance markings are increased to approximately 50x50cm or as conditions require. The Rapid Clearance marking can be applied or made from a range of materials which provides flexibility in disaster response conditions. As stickers and waterproof cards can be used, the Rapid Clearance marking could also be used to replace the recommended Low Damage Search Marking (LDSM).

Figure 15: Rapid Clearance marking

Conclusion

The evolution of the INSARAG guidelines appears to give good effect to standardise operational methodology including search marking systems within the international community. It will always be important that end user practitioners are involved in the review of such systems and more importantly, the changes being promulgated effectively. The evaluation of search marking adherence to the INSARAG guideline in this article is not necessarily a reflection of the actual effectiveness of search and rescue operations following the 22 February 2011 Christchurch earthquake. Further consideration is needed around the interpretation, application and adjustment of the INSARAG structural assessment marking by the international working groups responsible. Some team types need to spend more attention to ensure basic markings are understood and applied in accordance with current guidelines to see an improved level of response in the future. The recent changes have a mix of advantages and disadvantages. The wholesale change to replace the traditional box method is likely to cause further confusion unless member states have robust dissemination methods for updates to the INSARAG guidelines. Minor alterations to a generally proven approach using the box method could yield better results with less implementation risks. The introduction of the Rapid Clearance marking addresses practitioner concerns, but again its effectiveness will largely rest on an effective dissemination strategy. Further research is needed and should focus on the effectives of international search and rescue programmes (in particular their benefit in comparison to local capacity building and risk reduction programmes), effectiveness of victim markings and recent changes to the marking system.

Acknowledgements

This paper has been largely adapted from an earlier article entitled "Analysis of urban search and rescue markings applied following the 22 February 2011 Christchurch earthquake", Journal of Search and Rescue, Edition 1, Volume 1, 2013.

Abbreviations

CDEM	Civil Defence Emergency Management
FEMA	Federal Emergency Management Agency (US)
FOG	Field Operations Guide
ICP	Incident Control Point (aka Incident Command Post)
IEC	INSARAG External Classification
INSARAG	International Search and Rescue Advisory Group
LDSM	Low Damage Structural Marking
MCDEM	Ministry of Civil Defence & Emergency Management
NDMO	National Disaster Management Office
OCHA	Office for the Coordination of Humanitarian Affairs
OSOCC	On Site Operations Coordination Centre
NZ	New Zealand
NZFS	New Zealand Fire Service
NZRT	New Zealand Response Team (Registered)
NZTF	New Zealand Task Force (part of New Zealand Fire Service)
RCM	Rapid Clearance Marking
SHE	Structural/Hazard Elevation
SAM	Search Assessment Marking (FEMA)
SMAS	Search Marking Adherence Score (Glassey, 2011)
TOR	Terms of Reference
UN	United Nations
UNDAC	United Nations Disaster Assessment Coordination
USAR	Urban Search and Rescue

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Road Crash Rescue: Taking a casualty-centered approach

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Introduction

The underpinning principles of all rescue incidents are similar, or at least fit the same template, and usually it's only the environment, equipment and complexity that differ. Notwithstanding that, no two rescue incidents ever seem the same and therefore these incidents tend to be an exercise in problem solving, where responders apply the skills, knowledge and experience developed through education, training and attendance at a broad range of operational incidents. In this article we aim to add to this body of knowledge by discussing some of the main principles of rescue specific to Road Crash Rescue (RCR). There are many effective vehicle access and casualty removal techniques that can be applied to RCR incidents and this article is not an exhaustive discussion on all of these, nor is it a criticism of them. It simply provides further insights and promotes discussion into topics such as scene management, glass and other hazard management; developing a casualty-centered extrication plan and some interesting new ideas to help improve access in new, more highly strengthened modern vehicles.

To begin, the main overriding principles we apply to rescue incidents are that it is casualty-centered and safe. Firstly, a casualty-centered approach means that the primary purpose is to extricate someone from a dangerous and precarious position, in which they cannot get out by themselves due to the environment or injuries, such as from car, truck, train, building or machinery accidents. Consequently, we need to remove them, without exacerbating their injuries and get them to medical assistance as quickly and safely as possible. Secondly, safety refers to the safety of the rescue team and that of the casualty, as well as any other bystanders and personnel involved. Consequently, our actions as rescuers should build out from the injured person like ripples on a pond, and early scene and casualty assessments are critical to the development of an appropriate rescue and extrication plan.

To achieve this, a systematic approach is necessary, so that whatever time of day or night, or whatever the nature of the rescue incident, the procedure will be simple, clear and automatic. Most experienced rescuers would be aware that initial actions at RCR incidents should include:

- securing the incident site;
- assessing the situation;
- establishing operational zones;
- ensuring fire safety precautions are in place;
- considering primary vehicle stabilization; and
- accessing and assessing any casualties [1]

Scene safety – Establishing work zones

The establishment of safety and work zones at any operational incident is a crucial step in stabilizing the incident scene and ensuring a safe, controlled and systematic approach to the rescue is possible. This process should begin with a 360° scene assessment and size-up from approximately 5-10m (outer circle) followed by a closer inspection from 2-3m (inner circle) [2]. The primary aim of this initial assessment is to check for hazards and provide a preliminary indication of casualty positioning. Hot, warm and cold zones should then be determined, followed closely by the establishment of various staging areas (Figure 1) [3,4].

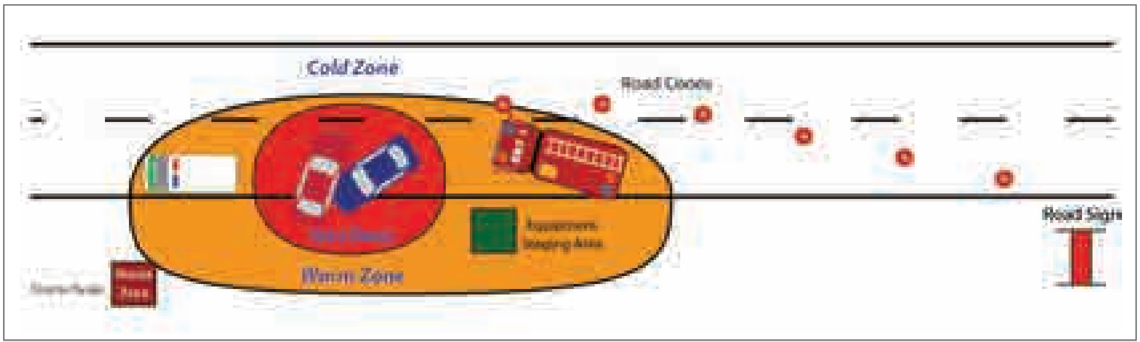

Figure 1: Rescue scene organisation.

Cold Zone – After parking first responding appliances in the fend-off position, warning signs, road cones and warning beacons should be placed at least 30m ahead of the accident to give oncoming traffic time to change lanes and not create another accident [3,4]. On high-speed roadways this distance should be extended accordingly, or alternatively the roadway may be closed to traffic completely [4].

Warm Zone – Rescue personnel and Incident controllers should identify equipment staging areas and a separate debris dump zone. Additional rescue vehicles should be parked in an appropriate place to defend from hazards, such as fire and explosion yet close enough to play an offensive role in the rescue process through easy access to the necessary equipment. Where possible, the ambulance equipment and staging area should be on the side where the casualty will be removed toward and the rescue appliances and equipment staging area on the opposite side.

Hot zone – This zone should have a radius of 3-5m around the vehicles involved and only personnel and equipment directly involved in the rescue and extraction effort should be allowed into this inner zone. This is the rescue personnel's work bench, or work place, and a clear and clean work bench is always the most efficient place to conduct operations.

Incident controllers should periodically re-evaluate and reassess these zones for effectiveness (e.g., How does "the bigger picture" look? Are there any tweaks to the setup required to improve operations or enhance safety?) Generally, however, if the big picture looks good to the trained eye then it is probably right. However, prior to the termination of operations Incident Controllers should consider an expanded search of the outer scene (cold zone) to survey for anything that may have been missed, like a casualty that has been ejected from the vehicle (e.g., use a thermal imaging camera for heat signatures on passenger seats), or a pedestrian hit and thrown but not initially identified.

Concurrent to the setting up of the incident zones the more specific scene hazards should be considered and mitigated. For example, some (but not all) hazards at RCR incidents include:

- Leaking fuel- initially remove ignition sources, disconnect battery;
- Consider gas powered and other alternate fuelled vehicles;
- Look for damaged power lines;
- Wire rope safety barriers;
- Consider whether dangerous goods are being potentially being transported in the vehicle, both declared and undeclared; and
- Glass - broken and unbroken, we all know how easy it is to cut ourselves on broken glass, not to mention the potentially carcinogenic effect of glass dust

Glass management

Glass management is an important, yet often overlooked, safety issue (for both the responders and the casualty) that all rescue personnel should be aware of, and manage! Glass shards can present a laceration hazard to both rescuers and casualties alike, therefore care should be taken to cover and protect the casualty with a soft clear protective sheet [3]. Additionally, the potential health hazard posed by breathing in glass dust is also an important consideration. Therefore, in addition to gloves and eye protection some form of respiratory protection, such as a dust mask, is recommended when glass is to be cut. Nevertheless, glass should only be broken if necessary, and cut as a last resort. Glass management should also always be methodical and planned so as to avoid it breaking unexpectedly [4]. There are many methods and products available to help manage glass and they all have strengths and weaknesses, from tape, shaving cream to water and oil sprays on cut lines, and specifically designed products such as Packexe Smash.

Figure 2: Use of soapy liquid to manage glass dust.

There are two basic types of glass encountered during RCR; tempered safety glass and laminated glass. Tempered safety glass is generally found in windows other than the front windscreen, where laminated glass is usually found. When shattered, tempered safety glass crazes and can then be quite efficiently managed by pulling the glass outside of the vehicle (using a tool rather than the gloved hand), and sweeping the remainder under the vehicle. Alternatively, sandwiching the glass between sheets of plastic (hard or soft) protection sheets and pulling the glass out as one is also a useful technique. In contrast, laminated front glass can be more problematic in that it rarely breaks cleanly, often leaving jagged edges, which although largely held together with the bonding to the internal plastic, can still present a significant hazard. Traditionally, when performing a full roof removal laminated glass is most often managed by cutting it. This however releases fine glass dust into the air [4], potentially introducing an additional hazard. Managing this, through a difficult proposition, which can either be done by containing it in between two layers of plastic shielding [4] and/or using an atomizer spray pack with soapy water (Figure 2) to create a mist to dampen and contain the dust.

Nevertheless, not all these methods completely eliminate the potential for the release of glass dust and so, to further minimize exposure, personnel should also take the added precaution of wearing a dust mask. However, eliminating the hazard of glass dust by not cutting glass in the first place, unless absolutely necessary is a more effective control method. Wherever possible, it is advisable to consider a forward (Figure 3) or backward roof fold instead of a full roof removal. Importantly, in keeping with modern occupational hygiene practices, where there is a possibility that turnout clothing may be contaminated with glass dust, it should be decontaminated according to your departmental policies, rather than being stuffed into gear bags or worn on the appliances.

Figure 3: Forward roof fold.

Developing the Extrication Plan

With a key aspect of a casualty-centered approach being to get the patient to hospital in the shortest time possible without exacerbating their injuries, it is important that responders minimise any un-necessary cutting of the vehicle as this will only lead to increased scene times. Therefore, a clear extrication plan must be developed early and in consultation with paramedics or medical personnel on-scene. This will ensure that injuries are understood and not aggravated by the removal process. Furthermore, it is crucial that the extrication plan and removal path is communicated to all essential rescue and medical personnel to ensure that the collective effort is directed toward the same plan, and that the equipment and personnel are positioned effectively e.g., having paramedics positioned on the side that the patient is removed to. From there, appropriate vehicle stabilization can be put in place and the access tunnels or openings can be made to facilitate the extraction.

When planning of the extrication path, the rescue personnel must decide between a "spine-friendly" method or a rapid extrication through the nearest opening [1]. Taking the casualty-centered approach to patient management means that methods that maintain correct spinal alignment should be considered first, particularly then where there is the potential for spinal injury (based on the mechanism of injury). The primary principles of such an approach are [2]:

1. Maintain spinal alignment
2. Minimise body twist

Because this approach recommends spinal alignment is maintained, the path of patient removal is usually indicated by the direction that the long axis of the spine is pointing [2]. Nevertheless, rescue personnel should always have an alternate plan (Plan B) in case the patient's condition deteriorates and the operation becomes "time critical". In these cases, or where medical personnel have confirmed there are no indicators of spinal injury, rescuers can then consider rapid extrication. This is a compromise between the principles of maintaining spinal alignment and removing the patient through whichever path is available for immediate evacuation (often the nearest door or window that is open).

Historically, rescue personnel would cut the biggest hole possible (e.g., remove the whole roof) in the vehicle to get as many people around the casualty to then lift them out to safety. However, with modern casualty handling equipment a lot less space is necessary for a safe and effective extraction. This can result in reduced scene times (less un-necessary cutting) and a decreased possibility of creating further injuries to both casualty and, importantly, manual handling injuries to the rescuers. The use of modern casualty transfer boards and casualty-handling straps are revolutionizing patient care and extrication by facilitating the development of faster, simpler extrication plans. For example, the ability to use straps and long boards means that initial extrication plan can often allow for relatively simple extrications via the path indicated by the alignment of the spine, often out the back window if the patient is found sitting upright in the driver's seat (Figure 4).

New car technology

Traditionally, creating openings to form extrication paths has been achieved using hydraulic rescue equipment such as cutters, spreaders and, to a lesser extent, rams. Experienced rescuers will appreciate that there is a vast array of different and effective techniques that can be applied to vehicles damaged in various ways and with patients trapped in any number of different scenario's. However, with the increased use of strengthening members around the passenger cell in modern vehicles the selection of areas to be cut or spread becomes more important to get the desired result. For example, simply cutting the B pillar to create a side opening may not be as easily achieved in some vehicles today as it once was, even though rescue tool manufacturers are constantly developing more powerful and effective devices. Therefore, creating or enlarging openings by disassembly and distortion are becoming more commonly used techniques. One example is the removal of doors by undoing the hinge bolts (Figure 5), which, in certain circumstances, can be quicker than traditional cutting and tearing. Moreover, this method often

Figure 4: Rear window extrication.

removes the need for glass management, thereby reducing that particular hazard.

Figure 5: Using an Impact wrench to remove doors and the hinges.

Additionally, every time we use hydraulic rescue equipment to cut or tear through sills or structural members there is the potential to compromise some of the supplemental restraint systems' pyrotechnic devices and, in so doing, introduce another potential hazard to our workspace (regardless, remember to always peel and peek under the plastic trims to look for cylinders or other SRS systems). In contrast, the removal of doors or body parts (fenders and guards) of the vehicle by disassembly counters this and in most cases it can be quicker, quieter and more controlled. Tools of choice in disassembly have historically been socket sets and spanners. However with the introduction of cordless impact wrenches the speed and effectiveness of disassembly has increased dramatically. Indeed, local trials have shown that teams with minimal training on this equipment can consistently remove two car doors and a front fender in 2 to 3 minutes.

Therefore, because new car technology has increased the structural support around the B pillar in many new vehicles, a double door removal that exposes the B pillar to be cut out at the desired height (above any seatbelt pre-tensioners etc.), or for the roof to be cut or torn from the top of the B pillar, may be somewhat quicker and more reliable methods of access. Similarly, roof folds (forward or backward) are becoming a safer choice in casualty access and removal, along with increasing the size of the rear window opening to allow the easy use of casualty transfer boards.

Conclusion

A casualty-centered approach to road crash and other rescue incidents means response personnel aim to get the casualty to hospital in the shortest time possible without exacerbating their injuries. In addition, personnel must always ensure the operation is conducted safely for both the rescue personnel and the patients. To achieve this, and to reduce scene times, we must aim for maximum on-scene efficiency. This begins from effective training, to visualizing the whole setup in the mind's eye when responding, to arrival on scene and conducting an effective assessment, creating clear and effective rescue zones, recognizing and mitigating any hazards and most importantly developing an efficient and safe extrication plan. Such plans aim to remove casualties via the path that minimises any further injuries, in particular any spinal injuries.

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The Science and Concept of Responders' Rehabilitation

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Introduction

During emergency response, firefighters race against time to prevent or minimize the escalation of consequences. The physical body is subjected to heavy loads, e.g. the carrying of fire-fighting and rescue equipment required for mitigating the incident, as well as the donning of Personal Protective Equipment (PPE) that combines several layers of materials to offer protection against various hazards. Inevitably, this increases the core body temperature. In some cases, the rise in core body temperature can lead to heat cramps, heat exhaustion or heat stroke. However, there is a clear distinction between rehabilitation and treatment for heat injury. This article presents the concept and science of rehabilitation for responders with the aim to reduce heat injuries.

Research Review

Recognizing the heat and physical stress faced by the firefighters, the Technical Committee on Fire Service Occupational Safety and Health acknowledged the importance of rehabilitation and established the National Fire Protection Association (NFPA) 1584[1] "*Standard on the Rehabilitation Process for Members during Emergency Operations and Training Exercises*" in 2008 [1]. This standard had since been widely adopted as guidelines by established fire departments in their implementation of rehabilitation. Giesbrecht et al [2] found evidence that active cooling of hands and forearms in 10°C and 20°C water was more effective than passive cooling[2], and forearm cooling presented the highest heat loss as compared to hands and upper arm cooling.

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1 NFPA 1584 is a standard that establishes the minimum criteria for developing and implementing a rehabilitation process for fire department members at incident scene operations and training exercises. It also describes the rehabilitation process for members operating within an incident management system [1].

2 Passive Cooling is defined as the process of using natural evaporative cooling (eg. sweating, doffing PPE) to reduce elevated core body temperature [1].

3 Vasoconstricton is the narrowing of the lumen of a blood vessel, due to contraction of the smooth muscle in its wall, mediated by neural (autonomic) control, local or blood-borne chemical factors, or fall in temperature [9].

Casa et al [3] found that the use of cold water is effective in decreasing the elevated core body temperature. The study also refuted the hypothesis that cold water immersion would prevent cooling down and/or even heating up of body due to peripheral vasoconstriction[3] and shivering. Rather, hands and forearm immersion could bring benefit in relieving heat strain, increase responder safety as well as reduce the duration for fatigue recovery. Cold water immersion (CWI) provides a better cooling rate of at least 0.2˚C/min as compared to other modalities and is recommended to be adopted as part of hyperthermia or Exertional Heatstroke (EHS) treatment to bring the temperature of an individual down to 39˚C in the initial 10-15 minutes that is critical for recovery. Colburn et al [4] showed that forearm immersion in water of temperature 20.9 ± 0.4˚C had a slightly higher cooling rate as compared to using a cooling vest or applying passive cooling measures during a 30-minute recovery period following a 20-minute bout of fire suppression in a training academy setting. On the practical application of active cooling, Phoenix Fire Department in the United States of America (USA) had developed a Rehabilitation Unit with misting fans [5]. Separately, the Fire and Rescue Department of New South Wales had deployed active cooling devices like the Kore Kooler chairs for hands and forearm immersion in their Innovative Rehab Pod [6].

SCDF's R4 Framework for Responders' Rehabilitation

SCDF's rehabilitation framework is based on the concepts of **R**est, **R**epair, **R**eplenish and **R**edeploy (R4). REST allows "time-out" for responders to exit the incident scene and enter the rehabilitation area for passive cooling with the removal of PPE and the Self-Contained Breathing Apparatus (SCBA). REPAIR is the phase where responders undergo active cooling with monitoring of their physiological parameters and are sent for medical treatment if necessary. REPLENISH refers to the intake of fluids, and food if necessary, to replace loss of water content, electrolytes and calories. REDEPLOY prepares the responders to rejoin operations.

Responders' Performance Module (RPM) Prototype

A major enhancement in the REPAIR process of the rehabilitation framework is the development of the Responders' Performance Module that provides active cooling devices within a customized environment for firefighters' recovery. The prototype module is 4.5 m wide, 6.6 m long and 2.4 m high. It has two zones – Rapid and Deep Cooling. The rapid cooling zone provides shade and cooling from evaporative cooling fans that utilize KÜÜL Pad technology to produce cool air that will allow heat exchange with the body surface to enhance surface evaporation of perspiration. The deep cooling zone of the RPM is fitted with more active cooling devices such as air-conditioners to create a cool environment to enhance heat exchange between the cool dry air and body surface, the aluminium rehabilitation chair which allows heat conduction from the body surface and hand and forearm immersion in chilled water. With a maximum capacity of 24, personnel will be streamed into the respective zones based on the individual's physiological parameters. Besides rehabilitating physiologically, the RPM also aims to provide a comfortable and conducive environment for resting via the use of light and bright colours such as blue, white and orange. The colours blue, white and orange were chosen to create a conducive mood for rehabilitation.

Figure 1: RPM mounted on Multi Utility Vehicle (MUV) transport platform.

Figure 2: Interior layout of RPM showing the rehabilitation chair.

Test Methodology

The first experiment was conducted to evaluate the effectiveness of three types of cooling: passive, rapid and deep. It involved 24 firefighters where 4 personnel were identified as the "control group" and underwent passive cooling by resting under a shaded area. 14 personnel were streamed into the rapid cooling zone where two 16" evaporative cooling fans provided air that is approximately 6˚C [7] lower than the "control group". The remaining 6 personnel were streamed into the deep cooling zone that is an air-conditioned environment at 21 ± 3˚C and complemented by ergonomically-designed rehabilitation chairs made of aluminum to help dissipate body heat. The chair is also installed with a fan that directs cool air at the neck and back of the responder, and comes with chambers for the immersion of hands and forearms in water at 20 ± 2˚C. A second experiment was carried out to ascertain the difference in effectiveness of hands and forearm immersion. It involved 12 firefighters where 10 of them underwent deep cooling without hands and forearm immersion. The remainder 2 firefighter underwent full deep cooling.

In both experiments, firefighters were first put through a Heat and Humidity (H&H) exercise as part of their training. The exercise comprised 45 minutes of intense physical action with PPE and SCBA. The activities included a 700 metres walk with a 90kg casualty dummy as the load, a climb up the staircase of a nine-storey building, unrolling of 3 sets of "Swiss Roll" fire hoses and other exercises in a sauna room at 65-80˚C, 60% humidity.

Vital parameters such as body temperature, pulse rate and oxygen saturation level of the firefighters who underwent the H&H were recorded by an in-ear probe thermometer and oximeter in three stages – (i) before the start of activity to obtain baseline readings; (ii) after completion of the H&H exercise to observe the level of heat strain sustained; and (iii) during rehabilitation to record progress of body cooling at 2 minute intervals. Although three parameters were recorded, the focus was on body temperature as the key evaluation parameter as it is not easily affected by external stimuli, e.g. unlike pulse rate which could fluctuate with a change in air temperature, body position, emotions, body size and use of medication [8]. Nonetheless, pulse rate and oxygen saturation levels were used as supporting parameters as these are indicative of heat illness such as tachycardia, hyperventilation and tachypnea.

Results & Discussion

The cooling rates obtained from the first experiment for passive, rapid and deep cooling were 0.08˚C/min, 0.12˚C/min and 0.22˚C/min respectively (see Figure 3). The deep cooling zone had a cooling rate that is 1.8 times (175%) faster than passive cooling and 0.8 times (83%) faster than rapid cooling. Passive cooling has the lowest cooling rate because it is highly dependent on external conditions such as temperature, humidity and wind conditions. Higher ambient temperature, higher humidity and slower wind speed will reduce surface evaporation of perspiration, leading to a longer recovery time. On the other hand, the deployment of active cooling devices, especially in a temperature-controlled environment, will enhance the surface evaporation of perspiration and cooling of the body regardless of external conditions.

The results from the first experiment are also indicative that active cooling devices can lower core body temperature efficiently in a short period of time for hyperthermic individuals due to the higher cooling rate. The RPM's rapid cooling rate of 0.12˚C/min is also consistent with the findings by Casa et al [3]. The cooling rate for cold water immersion in 20˚C (deep cooling) is highest, followed by fan and shade (rapid cooling), and lastly air and water (passive cooling).

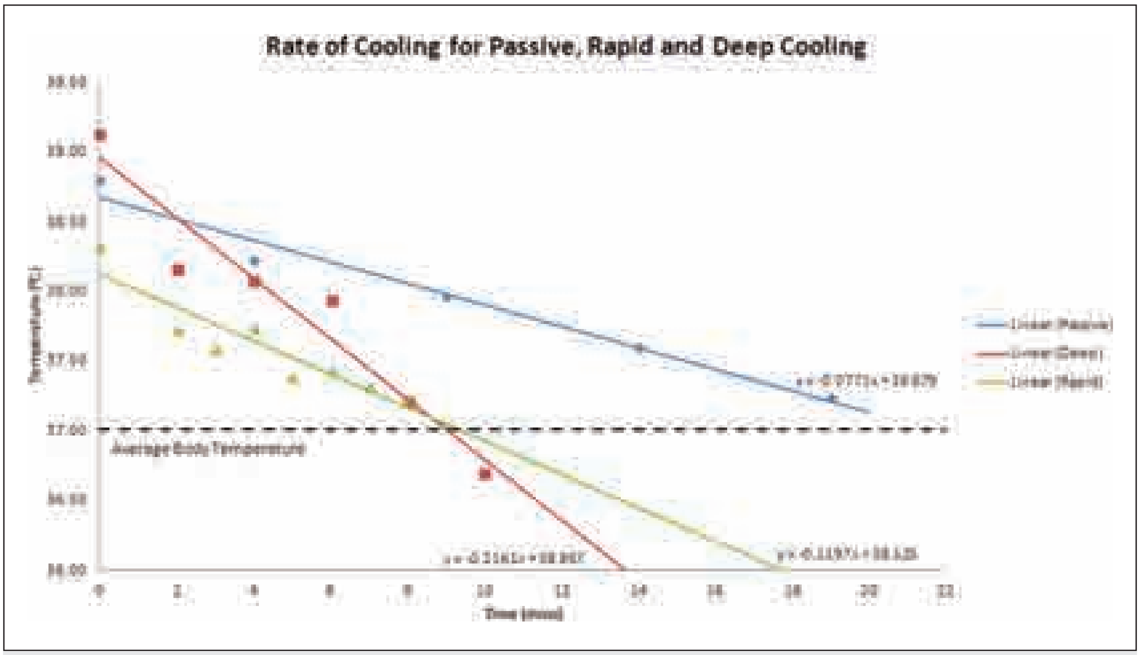

Figure 3: Graph shows rate of cooling for 24 firefighters who entered into their respective cooling zones; passive, and rapid and deep in RPM according to their vital parameters.

The second experiment obtained a cooling rate of 0.16˚C/min for deep cooling without hands and forearm immersion (see Figure 4). Comparing this result with the cooling rate of 0.22˚C/min for full deep cooling, the immersion of hands and forearms in 21˚C water in an air-conditioned room of 20 ± 2˚C resulted in a 0.06˚C/min (31.7%) increase in the cooling rate. This result is in close agreement with those obtained in other research experiments. Giesbrecht et al [2] obtained a cooling rate of 0.05 to 0.08˚C/min in the initial ten minutes of cooling in all hand and forearm immersion conditions in varying temperatures. The experiments by Colburn et al [4] produced a cooling rate of 0.05 ± 0.04˚C/min during 30 minutes recovery with forearm immersion in 20.9 ± 0.4˚C water following a 20-minute bout of fire suppression action.

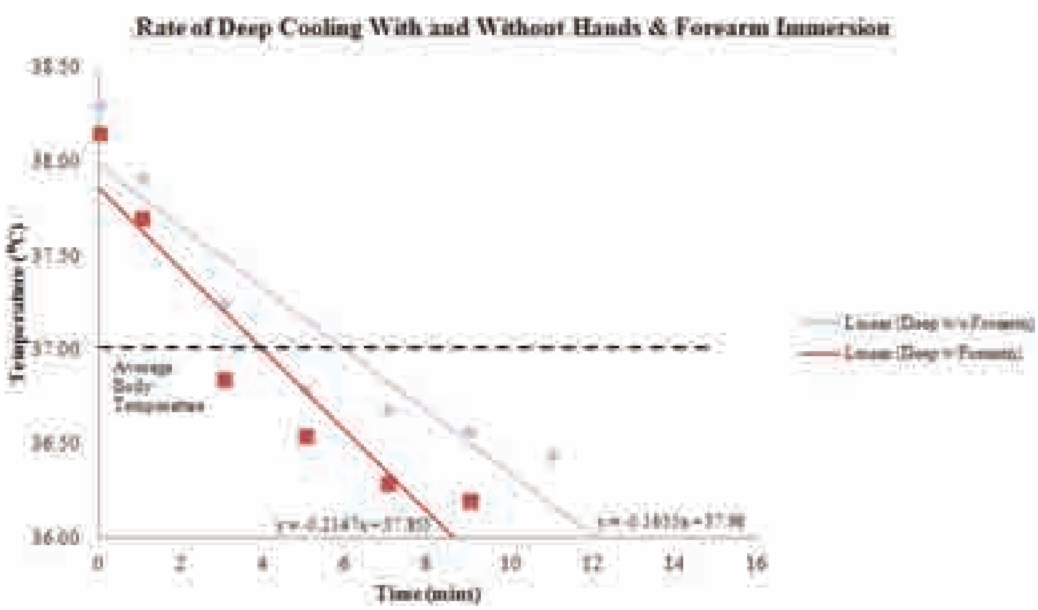

Figure 4: Graph shows rate of cooling with and without hands and forearm immersion in the deep cooling zone of RPM.

Application of Cooling Rates

The results of both experiments are summarized in the table below (see Table 1). Taking reference to the NFPA 1584 standard, the cooling rates obtained from the experiments above could provide guidelines for the REPAIR process in the rehabilitation framework. For example, assuming an initial core body temperature of 39˚C, if the recovery time given was 10 minutes, the rehabilitation procedure for the firefighters would be full deep cooling (see Figure 5). On the other hand, if the recovery time was 15 minutes, the firefighters could undergo either (i) 15 minutes of deep cooling without hands and forearm immersion, or (ii) 2 minutes of full deep cooling followed by 13 minutes of rapid cooling, or (iii) 5 minutes of deep cooling without hands and forearm immersion followed by 10 minutes of rapid cooling. Firefighters could undergo only rapid cooling alone if recovery time is 20 minutes.

Table 1: Summary of cooling rates and cooling duration for various modalities derived from the two experiments conducted

Cooling Modalities	Cooling Rate (˚C/min)
Full Deep Cooling (shade, aircon, and rehab chair with hands and forearm immersion)	0.22
Deep Cooling without Hands and Forearm Immersion (shade, aircon and rehab chair)	0.16
Rapid Cooling (shade, air and evaporative fan)	0.12
Passive Cooling (shade and air)	0.08

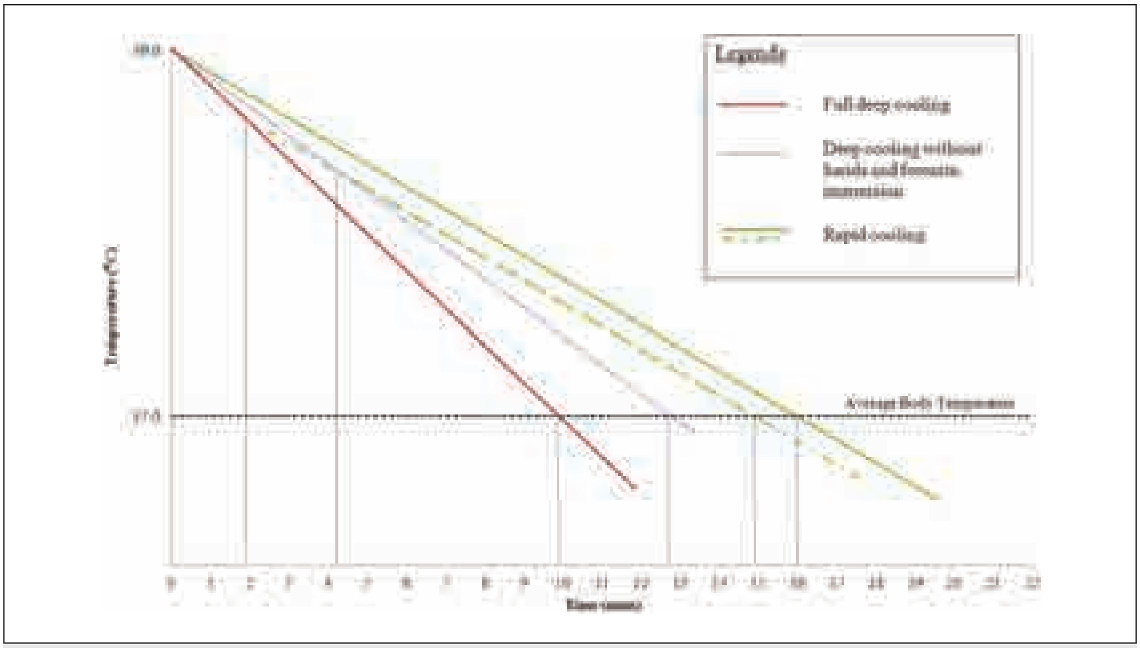

Figure 5: Graph shows the cooling rate of various modalities with magnitude of 2.0˚C.

Practical Considerations in RPM Design

While cooling rates associated with the various modalities provide the basis for cooling effectiveness, practical considerations (see Figure 6) must not be neglected in the design of the RPM. For instance, the adoption of different types of cooling modalities would have an implication on the capacities of the deep and rapid cooling zones. For example, the omission of hand and forearm immersion would see the removal of the water tank, chiller and other accessories. This could free up about 9% of space in the deep cooling zone and about 3% of space in the machinery area for other purposes. To quote another example, with a cooling time of 15 minutes or longer, it is opined that full deep cooling zone may not be cost effective if it were utilized for 2 out of 15 minutes per rehabilitation cycle.

On the other hand, if the priority is to cool the body at the fastest rate, more deep cooling rehabilitation chairs with hand and forearm immersion would have to be installed which in turn will increase the size of module and concomitant energy capacity to provide chilled water for cold water immersion. Manpower requirements to deploy and operate the module can be reduced by streamlining operating procedures, as well as the utilization of more self-service and automated features. Thus, it is important to balance the efficacy of the different active cooling modalities with the practical considerations in the design of the RPM.

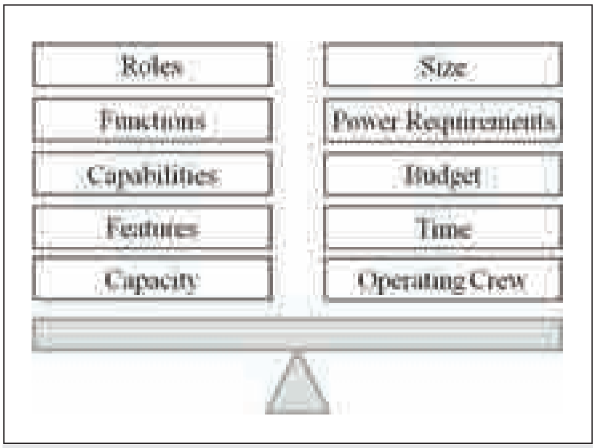

Figure 6: A balanced relationship between purpose of rehabilitation and resources to maximize its potential in responders' fatigue recovery.

The RPM prototype was put into operations on 15 June 2013 and had since been deployed to various exercises and also to an actual factory fire on 24 Aug 2013 which lasted 8 hours. The responders who had the opportunity to use the RPM since its implementation gave positive feedback; in particular, that it enhanced their rest and recovery.

Conclusion

The need for responder rehabilitation for emergency services like SCDF is essential as they are likely to be exposed to high heat stresses during operations. Following the development of the rehabilitation framework and the RPM prototype, SCDF's studies and experiments in the different modalities of active cooling have yielded results that are in close agreement with other research. Active cooling is proven to be effective and efficient in rehabilitating responders through the quick removal of heat from the body. The cooling rates obtained for rapid cooling and deep cooling with or without hand and forearm immersion will provide the basis for the future design of the RPM to enhance the rehabilitation process and maximize the performance of responders in prolonged operations.

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Developmental Journey of Singapore's Red Rhino Firefighting Vehicle

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Introduction

The conventional fire engine, also known as the pumper in SCDF (also called the fire appliance, fire apparatus or fire tender in other places) is iconic of any fire department the world over, including Singapore [1]. Its main functions include transporting equipment, water and crew to an incident site. The size of the appliance (and thus the capacity of its fire pump and space available for equipment stowage) does matter when it comes to projecting firefighting capability, especially in a large scale commercial or industrial fire. However this is a challenge in modern cities as the built-up terrain and congested roadways do present accessibility issues for the larger fire appliances from time to time.

Addressing the problem in Singapore

In 1999, SCDF started looking into limitations that its pumpers were facing while operating within the local terrain. The rapid pace of urban development in the city had been placing a strain on the SCDF's response times and mobility was identified as the most critical issue to be addressed. In this light the introduction in 1997 of the versatile firefighting bike, which carried a basic set of firefighting and rescue equipment, was indeed useful in bridging response times and providing an initial response before the arrival of regular resources on scene. However, fire bikes had obvious limitations given its lack of storage space.

Figure 1: Fire Bike as a fast response vehicle for responders.

Conceptually a cross between the fire bike and the regular fire engine seemed to be the desired hybrid platform, and the project team started pursuing the idea of a fast and highly mobile fire appliance that would complement the existing capabilities of the fire bikes and that of the conventional fire engines while bridging the gap in-between.

SCDF started looking into the possibility of having a customised all-terrain vehicle that was suited to firefighting operations in housing estates that make up a significant part of Singapore's urban landscape. Another key consideration was the possibility of forward deployment of this smaller vehicle within housing estates to address the problem of response time from the fire station to the incident site. It had to be sufficiently small to be parked within housing estates without inconveniencing residents and also be nimble to take advantage of pedestrian walkways, pavements and even grass slopes to reach an incident site quickly. It should carry sufficient firefighting and rescue capabilities, including a smaller fire pump, in order to hold its own during an operation. Such a vehicle should also be designed to take advantage of Singapore's highly comprehensive and accessible firefighting hydrant network.

The project team worked with local industry players to develop the concept and requirements of the new category of firefighting appliance. As the vehicle had to meet all the necessary statutory requirements (Table 1 shows the Vehicle Classifications under Singapore's Road Traffic Act), a key challenge of the project team was to fit it within the Class 3 category to avoid the additional training that would be needed for a Class 4 licence[1]. However, technological limitations back in 1999 and the eventual load that the appliance had to carry (i.e. a small fire pump, a water and foam tank and other equipment) saw it greatly exceed Class 3 thresholds. The project team eventually had to adopt a Class 4-type chassis in order to move the project forward – thus birthing the first prototype Light Fire Attack Vehicle (LFAV), or *Red Rhino* as it is affectionately called in the SCDF.

Table 1: Vehicle Classification under the Road Traffic Act [2]

Vehicle Class	Description
3	Motor tractors and other motor vehicles of unladen weight not exceeding 2500 kg.
4	Heavy motor cars and motor tractors, the weight of which unladen exceeds 2,500 kg

[1] Under statutory requirements, one is required to have a Class 3 qualified driving licence before applying for, and undergoing all the requisite preparatory exams in order to earn a Class 4 licence. Furthermore, because it was a fire engine, the operator also had to undertake additional training to acquire the EV (Emergency Vehicle) Class 4 licence in order to be allowed to drive the firefighting vehicle.

Introduction of the 1st Gen Light Fire Attack Vehicle (1G *Red Rhino*)

In terms of size, the 1st Gen (1G) *Red Rhino* was about one-third the size of a conventional fire engine. This gave the LFAV a distinct edge in terms of mobility. Not only was it designed with the narrower streets and alleyways in mind, the vehicle was also able to mount pavements and overcome the grass slopes that are a common feature in Singapore's public housing estates to reach the incident more quickly.

The compact sized LFAV also proved instrumental in the establishment of a new forward deployment arrangement- Satellite Fire Post (SFP). Response times had hitherto depended much on the travel speed of the appliance from the conventional Fire Station to incident site. The increasing volume of traffic over time in Singapore roads made this ever more challenging. SFPs became strategically located extensions of the fire stations to alleviate the delay in response times. These SFPs which are located at the void decks of Singapore's public housing estates costs 90% less than that of a conventional Fire Station. Logistically, the LFAV could also be parked at any normal parking lot within the housing estate, thus facilitating its ease of deployment.

Figure 2: LFAV and Fire Bike deployed at a SFP located within a public housing estate.

Its four-man design was also revolutionary for the SCDF in terms of frontline processes and manning efficiency because back then, in the early 2000s, its mainstay pumpers were still operating based on a six-man crew. In terms of technical performance, the 1G LFAV's water pumping capacity and flow rate (2000lpm) was naturally lower than that of conventional fire engines given its smaller pump (see Table 2 for a comparison of the LFAV and the traditional pumper). However, despite the capability tradeoff, the LFAV was still able to tackle most small fires and simple rescue incidents that contribute to SCDF's annual workload. About 60% of annual fire and rescue incidents are handled by the LFAVs. (See Table 3 for a breakdown of the fire and rescue calls attended by the LFAVs).

Table 2: Comparison between a Conventional Fire Engine and Different Generations of the LFAV

Vehicle Type	Fire Engine (Conventional)	1G *LFAV* (2000)	2G *LFAV* (2003)	3G *LFAV* (2012)
Vehicle Class	4	4	4	3
Gross Unladen Weight (kg)	10,160	4,020	3,780	2,100
Chassis Size (L x B x H)	8.7m x 2.5m x 3.4m	5.5m x 2m x 2m	5.5m x 2m x 2m	5.3m x 1.9m x 2m
Firefighting Medium	2400L (water) 1200L (foam)	50L (water) 50L (foam)	50L (water) 50L (foam)	No water tank. 150L foam
Pumping Capacity (litres per min) [lpm]	4,546	2,000	2,000	2,000
Main Water Output options	• Fixed Monitor • Hosereel system	• Detachable Monitor • Water Mist Gun system	• Detachable Monitor • Water Mist Gun system	• Detachable Monitor • 2 Compressed Air Foam (CAF) Backpacks

Table 3: Breakdown of Fire & Rescue Calls attended by the LFAV

Year	Total Number of Fire Incidents	Fire Incidents attended by LFAV	Total number of rescue incidents	Rescue incidents attended by LFAV
2009	5235	2345 (44.8%)	2508	938 (37.4%)
2010	4600	2673 (58%)	1748	1122 (64%)
2011	4470	2772 (62%)	1965	1283 (65%)
2012	4485	2706 (60%)	2011	1235 (61%)
2013	4136	2616 (63%)	2169	1372 (63%)

Figure 3: 1G Light Fire Attack Vehicle (circa 2000).

Figure 4: The water monitor of the LFAV being put in action during an industrial fire.

Improvements leading to the 2nd Gen Light Fire Attack Vehicle (2G *Red Rhino*)

Soon after the delivery of the 1G LFAVs to the frontline, the SCDF was already starting to look ahead. From 2000-2002, SCDF gathered feedback from the operators of the 1G LFAV with the aim to refine the ergonomics of the vehicle and further reduce the vehicle weight to improve on its mobility and maneuverability. The design of the 1G LFAV was then reviewed to see if the next generation could be retrofitted onto a lighter, more maneuverable version without comprising on its existing firefighting and rescue capabilities. With the introduction of a smaller, lighter and more efficient water pump that could match the performance of the systems utilized on the 1G LFAV, the 2G LFAV was launched in 2003.

Figure 5: 2G Light Fire Attack Vehicle (circa 2003).

The Next Leap – the 3rd Gen Light Fire Attack Vehicle (3G *Red Rhino*)

In 2012, SCDF embarked on a project to renew its ageing fleet of LFAVs. The efforts back then to push towards a lighter vehicle built around a four-man operation was proven to be effective in countless incidents and the LFAV had already established itself as the vanguard of SCDF's emergency services delivery. Building on this blueprint, the SCDF was ready to make the next innovative leap forward. Leveraging the availability of public and private firefighting hydrants in Singapore to supply water during an incident, the SCDF studied the possibility of retaining the pumping capability while removing the 50L water tank on board previous generations of the LFAV. The goal was to further trim the size and weight of the vehicle to fit within the requirements of a Class 3 vehicle (≤ 2,500kg) while retaining and sharpening its original capabilities. The outlook of the vehicle was also given a massive makeover, and the result was the introduction of the 3G LFAV (see Figure 6) that was significantly lighter (40%) as compared to the previous generation of the vehicle (see Figure 7 for an overview of the three generations of LFAVs). The migration from a Class 4 to a Class 3 categorization was pivotal as it meant the optimization of manpower resources and training as a shorter cycle was required for personnel to be equipped to operate this generation of the LFAVs. The water tank was also stripped and replaced with a larger foam tank (150L vs. 50L previously) to enhance the capacity of firefighting operations. In addition, the Water Mist Gun (WMG) system that was a mainstay in the earlier versions of the LFAV was also replaced by two Compressed Air Foam System (CAFS) backpacks as this technology was found to be even more effective and efficient in dealing with incipient fires that the 3G LFAV crew could rapidly deploy.

Figure 6: 3G Light Fire Attack Vehicle (circa 2012).

Figure 7: Overview of the 3 Generations of LFAVs.

Conceptualising the 4th Gen Light Fire Attack Vehicle (4G *Red Rhino*)

The next development of the LFAV, the fourth in the series, will see several enhancements to its design and operating concept. One conspicuous change will be the addition of an additional seat to house a crew of five instead of the usual four. This is to cater space for the inclusion of either an Emergency Medical Technician (EMT)[2] or SCDF Operationally Ready National Servicemen[3] on duty at the fire station. With this additional crew it will give the SCDF both scalability and flexibility in terms of operations and manpower optimisation. In tandem with this, the new LFAV will also be fitted with a remote controlled water monitor (as

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[2] Previously, fire and rescue incidents were responded by firefighting trained personnel while medical incidents were handled by paramedics in ambulances or fast response bikes. The introduction of the EMT scheme in the SCDF in 2013 will see Fire and Rescue Specialists being cross-trained in basic paramedical skills to provide a first line of medical response to stabilize patients until paramedics arrive with more advanced pre-hospital medical care. With this evolution of its capabilities, it also created an opportunity to review the crew composition on our frontline appliances.

[3] Known as the Fire Station (Operationally Ready National Servicemen) or simply as the FS(ORNS), these are servicemen who had formerly served about two years of conscription duty at the fire stations under Singapore's National Service (NS) programme. After the two year active duty, every NSman has to serve an additional duration of about 10 years as a reservist and he may be called up to reinforce his parent unit in times of emergencies. Annually, these NSmen are also deployed for active duty with their respective fire stations for the duration of their yearly In-Camp Training (ICT).

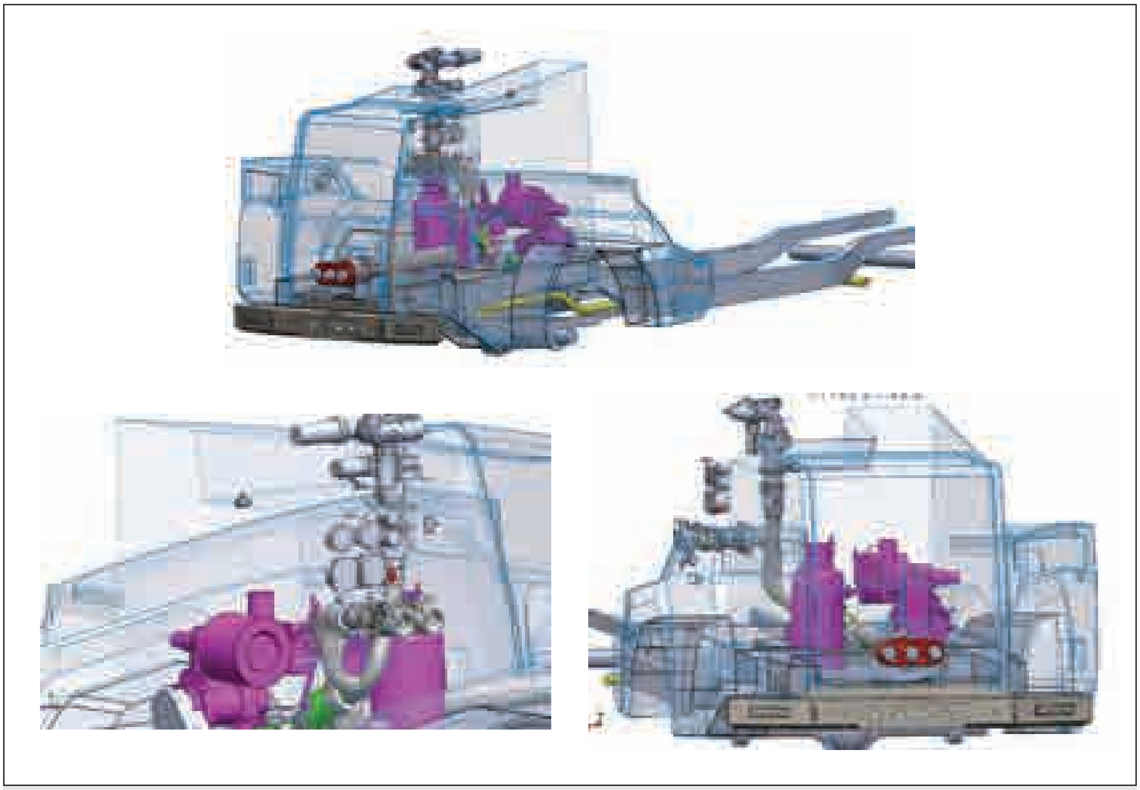

Figure 8: Diagrams of computer simulation graphics to visualise the array of pump and its associated equipment that needed to be loaded into the small volume available on the chassis during the design process for the 4G LFAV [3].

compared to the current manually operated one) to enable one man to operate both the pump and control the water supply while at the same time adjusting the throw and stream required of the monitor.

In addition, the 4G LFAV will be fully integrated with a CAF pump System, the first of its kind in the world for such a compact firefighting vehicle. However the CAFS pump, at 170kg, is 5.6 times the weight of the pump in the current series of LFAVs. Coupled with provisions made for an additional responder in the 4G vehicle, extensive lightweight engineering was done using computer simulation and modeling (see Figure 8 for some software simulation on the design of the 4G LFAV) to achieve even weight distribution and vehicle stability while ensuring compliance with Class 3 requirements.

Figure 9: Prototypes of the proposed 4G LFAV in the design phase [3].

Conclusion

The *Red Rhino* has proven to be a game changer for the SCDF since its introduction about 15 years ago. Lessons have been learnt from its deployment to countless firefighting and rescue operations and the vehicle has been undergoing regular concept and design enhancements and innovation to continuously adapt to Singapore's urban environment. The vision of first reducing and then finally omitting the water tank was a radical move but this has in turn laid the blueprint for the next generation of LFAVs to be unveiled. The SCDF remains confident that the 4G LFAV will make the desired impact in frontline operations, and just as importantly, plant the seed for the next wave of service, process and technical innovation to take place.

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