Two Tension Or Not To Tension

Much Ado About 4 Meters

By Mike Gibbs and Kevin Koprek

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Technical rope rescue has had a long, rich history of healthy debate and disagreement regarding device selection as well as techniques. A current debate that generates robust discussion involves the similarities and differences between Dual Capability Two Tensioned Rope Systems (DCTTRS) and Single Main, Separate Belay (SMSB) rope management approaches. Our intention here is to employ a Systems Analysis approach to evaluating these systems. We will offer detailed critical analysis, citations from testing and other literature, and personal observations as trainers and rope rescue practitioners. We will demonstrate and anticipate that the reader will agree that:

- The differences between DCTTRS and SMSB are minor, albeit still important
- The similarities are numerous

Additionally, we will provide a summary of the key catalysts that drive decision making for choosing one approach versus the other. Our rope rescue training seminars are well regarded for their depth and breadth of inquiry. We cover this topic in great detail in nearly every one of our training events - but you have to be in attendance to benefit. Due to the large number of email and phone-based inquiries for clarification on the key talking points of the debate, we felt that it was time we provided a written position on the subject matter.

Ultimately, we seek to provide you with some critical analysis and clear methods to better answer the question: Two Tension or Not To Tension? And we intend to demonstrate that the ongoing debate in the rope rescue community between DCTTRS and SMSB is truly Much Ado About 4 Meters.

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System Definitions

The list of existing terminology that identifies technical rope rescue systems is lengthy. Some terms have clear and agreed upon definitions. Others are either colloquial or a derivation of a similar term – typically with similar qualities, just different names. Examples include TTRL (two-tensioned rope lower), SMSB (single Main, separate Belay), Twin Tension, Shared Tension, Dual Tension, TTRS (two-tensioned rope system), Mirrored System, DMDB (dedicated Main, dedicated Belay), DCTTRS (dual capability two-tensioned rope system), etc. And the list likely goes on.

Here we limit our discussion to two systems: DCTTRS and SMSB. DCTTRS as defined by *Dual Capability Two Tensioned Rope Systems, ITRS 2016, Kirk Mauthner.* The following are typical characteristics and components for the two respective systems:

DCTTRS:

- Dual Capability is a specific form of Two Tensioned Rope System technique whereby each system is simultaneously Capable and Competent as both a mainline function as well as a back-up function to the other line.
- A capable and competent mainline is further defined as being able to handle a full working load of 1-4 kN, with the idea that each rope in a DCTTRS can take the full load at any time without requiring a friction change on the Descent Control Device (DCD).
- A capable and competent backup is further defined as being able to pass the BCCTR 1m drop on 3m of 11mm rope with 200kg mass, having no more than 12 kN maximum arrest force, with no more than 1m stopping distance, the system must remain functional and have at least 80% residual rope strength.

SMSB:

A literature review of rope rescue terms reveals no true consensus in terms of a SMSB definition. Typically, the rope rescue community refers to simply Main and Belay as the independent components in a 2-rope rescue system. The differences in devices utilized, rope tension philosophies, and general operational nuances likely contribute to a lack of rigid adherence to a strict definition.

In many respects SMSB could be considered a decision-making continuum as opposed to a rigidly defined system. However, for the purpose of clarity in providing compare/contrast analysis of the system features, we will define SMSB as follows:

- A primary mainline controlled by a descent control device (DCD) and including a self-actuating hands-free-stop component
- A backup belay line capable of passing the BCCTR BCDTM criteria and including a DCD feature to be engaged after consistent rope tension has been achieved

It is recognized that there are numerous permutations of DCTTRS and SMSB. For example, both DCTTRS and SMSB can be operated utilizing parallel raising systems. However, for the purpose of this compare/contrast, we are focusing on the above characteristics.

The reader may be curious about the absence of the term DMDB (dedicated main, dedicated belay). The first time we heard the term was at ITRS, 2016 in Albuquerque, NM. The author introducing the term did not provide a definition. The term DMDB is also used in the 2016 EMBC Report, but again no specific definition is provided. The use of the word *dedicated* implies stasis in the rope rescue system (i.e. exclusively allocated to or intended for a particular service or purpose). For over 10 years now, many rope rescue teams have been morphing their SMSB systems by adding descent control to their belay line after the initial edge transition. And those same rescue teams have been including a self-actuating component to their mainline operations, like a Prusik. In essence, SMSB is a hybrid system or a continuum of rope rescue line management – we will explore those details in greater depth later in this paper.

DMDB is a term that seems to be an unnecessary addition to an already robust number of similar terms. If DMDB is meant to imply that the belay component is to be managed hand-tight for an entire rope rescue operation, then it is our opinion that term is addressing an outmoded method of rope rescue line management. Using a hand-tight belay beyond 30m was demonstrated as poor risk management many years ago, due to excessive rope stretch (Mauthner, IKAR, 2005; Gibbs, ITRS, 2007). Many rescue teams address that elongation risk by incorporating a DCD in their belay system at the appropriate juncture.

<u>Systems Analysis for Rope Rescue</u>

A thorough examination of any technique involves a rigorous *Systems Analysis*. A Systems Analysis used by Rigging for Rescue includes the following:

I. Whiteboard Analysis

- Drawing the system out in great detail and critically analyzing key criteria:
  - ✓ Static System Safety Factor (e.g. 10:1)
  - ✓ Critical Point Test (i.e. is there one failure point that would cause the live load to go to the ground? <u>Note:</u> easily avoided in any 2-rope system)
  - ✓ Whistle Test (i.e. does the system include a self-actuating quality?)
  - ✓ Other important factors (e.g. commonality of equipment)

II. Comparative Analysis

- Developing a pro vs. con list
  - ✓ Comparing the pros/cons of the new technique/device to your current practices
  - ✓ Assessing training requirements for adoption
  - ✓ A complete cost/benefit analysis

- Field Trials
  - ✓ Looking for step-change improvements vs. your current practices
  - ✓ Be wary of adopting new equipment or techniques just for the sake of change (i.e. what difference does a difference make if all it makes is a difference?)
  - ✓ Ensuring that there is no inherent safety issue with the new technique (<u>Note</u>: this is very difficult to assess with minimal field trials and is better suited to a well-designed Failure Analysis)

III. Failure Analysis

- Destructive Testing
  - ✓ Do the backups work as intended?
  - ✓ Does the test methodology replicate a credible event? (i.e. can it be reproduced in the field of use?)
  - ✓ Ideally, including human factor tests as well. Rope rescue systems require human beings to operate. Therefore, testing/data that is absent human trials is limited in scope

A convincing argument for a given technique can often be made based upon a well-delivered (albeit partial) Comparative Analysis. A long list of pros vs. cons can sway our decision making towards a given approach. However, does the Comparative Analysis include a robust number of field trials? Or is it limited in scope to merely an abstract approach? Additionally, a proposed system change needs to also defend itself in a Failure Analysis – ideally, including trials with human operators.

A thorough Systems Analysis is likely underutilized in the rope rescue and rigging community. Considering the presence of non-event feedback loops in our rescue systems, we probably rely too much on purely anecdotal evidence that our system is “fine” and we have “never had a problem.” As rescuers, we are in the business of risk management. Therefore, we should rigorously examine how our techniques and practices either mitigate risk or introduce risk to our operations. A well thought out and thorough Systems Analysis can aid in that process.

TTRS & SMSB – a brief history

DCTTRS is a specific type of TTRS with its own identifying qualities. However, TTRS as a broader category are not new. Much like Single Main and Separate Belay, TTRS have been used in rope rescue for decades. Some TTRS employ a common litter bridle focal point; other TTRS use a two-bridle scaffolding system. A number of rope rescue practitioner manuals include illustrations and descriptions of these different TTRS. There are also differences in devices utilized in both TTRS and SMSB.

In the early 1980s, the province of British Columbia, Canada commissioned a group to look further into rope rescue systems - developing standards & best practices. The British Columbia Council of Technical Rescue (BCCTR) was comprised of various leaders from SAR teams in British Columbia. The BCCTR's work included many notable achievements during their active years (1980s), but perhaps their most well-known is the Belay Competence Drop Test Method (BCDTM) standard for examining rope rescue back-up systems (i.e. 1m drop on 3m of rope with a 200kg test mass). The failure analysis testing conducted by the BCCTR in the 1980s to the BCDTM criteria was instrumental in shaping rope rescue practices around North America.

One of the results of the BCCTR testing was the refinement of the Tandem Prusik Belay (TPB) as the backup component in a SMSB. At that time, certain TTRS and SMSB methods performed poorly against the BCDTM criteria. John Dill's paper, "Are You Really on Belay?" is a worthwhile read from that time period.

However, the TPB in the SMSB system has always had its fair share of detractors. Are the Prusiks snug enough? Can the human operator defeat them? What about all that slack rope between your hands? What about when there is 30m of rope-in-service (RIS)? Won't the rope elongation be excessive?

And so the debate between the merits/deficits of TTRS and SMSB has perpetuated for a very long time.

In the early to mid-2000s, a couple of new devices came to market: the 540 Rescue Belay and the MPD. These devices were the first mechanical devices for managing back-up lines (i.e. Belay) specific to the rope rescue community. Prior to these devices, rope rescue teams employing mechanical devices were using products such as the Petzl I'D, which was originally designed for only 1-person loads. Also during this time, new research reported the benefits of adding tension to back-up lines in a SMSB system (to mitigate excessive elongation should the back-up rope arrest the fall in a failed Mainline scenario). At IKAR 2005, Kirk Mauthner presented "Maximizing the Effectiveness of Rope Rescue Back-up Systems" and recommended using a TTRS approach once 30m of rope was in service. At ITRS 2007, Mike Gibbs presented "Rescue Belays Long Lowers" and shared drop testing footage illustrating as much as 15% rope elongation using low-stretch rescue rope and a top-rope fall arrest on a hand-tight-only SMSB system (Note: 200kg test mass). Given 30m RIS, that equates to 4.5m of stop distance on a top-rope fall arrest!

It was becoming evident that with increased RIS, a hand-tight belay in a SMSB loses its effectiveness as a safe rescue system due to increased stopping distance caused by rope elongation. The remedy was to trend towards favoring a TTRS if the operational height was going to be of any considerable length (i.e. >30m RIS).

And so another evolution in SMSB began and teams started to morph their SMSB systems into TTRS approaches if they were going to meet or exceed 30m RIS. Over the next several years, proactive practitioners began to recognize that there really was not any compelling reason to wait until you got to 30m RIS. Why not go to TTRS shortly after the initial edge transition? And that became the SMSB rope management progression that many rescue teams have employed for the better part of a decade now.

So why not abandon SMSB entirely if TTRS is where the rope rescue community has been trending to for many years now? This depends on the specifics of the TTRS being operated and what performance limits have been identified as acceptable.

The SMSB utilizing TPB was recommended by the BCCTR in the 1980s as a result of favorable drop testing results against the BCDTM examination. Some TTRS using human grip only on the remaining rope/device (should one line fail) proved to be marginal in their effectiveness (i.e. not passing the Whistle Test aka hands-free stop). The risk management concept of having a capable fail safe in your two-rope system became a valued risk management consideration. But that capable fail safe becomes a moot point if rope elongation alone causes the rescue load to hit terrain features.

Currently there seems to be little disagreement in the rope rescue community that SMSB systems need to employ a means of addressing rope elongation prior to introducing too much RIS. The mitigation method for many years has been to utilize a DCD on the back-up line immediately following the execution of a technical edge transition; and to include a self-actuating component on the primary (i.e. Mainline) descent control system (e.g. friction hitch). In other words, each rope system should include the qualities of a DCD and a hands-free stop. Relying solely on human grip on either system has lower margins for successful fall arrest and therefore, higher risk. Rigging for Rescue’s ITRS 2004 presentation on TTRS - using a mechanical hand to replicate the human grip - illustrated some of the limits of a positive-grip-required system for reliable fall arrest.

While there are clear benefits to TTRS in general and DCTTRS specifically, there are situations whereby a SMSB system offers a proven track record - technical edge transitions – and may mitigate certain risks better than DCTTRS. Maintaining a SMSB approach for technical edge transitions provides a number of important benefits including:

- Optimizing the fail safe qualities of your back-up device/system (i.e. not defeating the fail safe mechanism or self-actuation mode)
- Good control of the live load utilizing one tensioned line and one device/operator; thereby avoiding the inconsistent in-feed of rope when attempting to coordinate

two tensioned lines to one load – perhaps causing a stumble when you can least afford one.

At ITRS 2014, Kirk Mauthner presented drop test videos of various rope systems over a sharpened steel edge. The examination sought to compare TTRS vs. SMSB. The testing was limited in scope (small sample size). Under the testing conditions utilized, the results indicated that TTRS performed more favorably than SMSB with regard to rope trauma due to a sharp edge. As a result, Mauthner recommended changing from a SMSB approach to TTRS for the entire operation, including the initial edge transition. This represented a major paradigm shift for SMSB teams.

At ITRS 2015, Mike Gibbs of Rigging for Rescue presented drop-testing results from both MPD testing and sharp edge testing. The MPD testing utilized human operators running a two-rope "Mirrored System" (Note: system moniker used prior to the name change to DCTTRS) with both MPDs in descent control modes. Testing results indicated that there were numerous human factors that could affect the reliability and resulting stopping distance on the remaining MPD system, should one line fail. The primary conclusion was that a rope management approach that intentionally overrides the fail-safe mechanism in a device contributes to less reliable fall arrest results.

Gibbs also conducted drop tests over a very sharp rock edge using both SMSB and TTRS. An unprotected rock edge resulted in catastrophic results for both SMSB and TTRS. A properly protected rock edge also illustrated no difference in performance- both SMSB and TTRS ropes were unharmed given adequate edge padding in place (Note: test used one fire hose combined with one Conterra rope guard). Gibbs stated there may be a difference in sharp edge performance between the two systems but it involves margins - requiring a specific edge quality, padding quality, and velocity combination to identify those margins. Mitigation measures to manage exposure to this set of circumstances included the following recommendations:

- Pick a different edge, when possible
- Utilize vertical litter orientation with a 2-point bridle and slide through the transition (thereby managing the fall factor & resultant velocity)
- Use adequate amounts of edge padding

Also at ITRS 2015, Mike Forbes offered a presentation on sharp edge examinations – The Sharp End of The Edge. Forbes' tests appeared to indicate that once three layers of canvas were in place (or the equivalent), there was minimal difference in performance between SMSB and TTRS over a sharp edge. The differences occurred with less robust edge padding in place.

And finally, at ITRS 2016, Kirk Mauthner presented some highlights from the Emergency Management British Columbia (EMBC) testing conducted the previous January. Since that presentation was given, the EMBC has compiled and published the data and recommendations from that test series (*EMBC Rope Rescue NIF Equipment Testing Summary Report 2016*). In Mauthner's presentation he introduced the term Dual

Capable Two-Tension Rope System (DCTTRS) as a replacement of Mirrored Systems for rope rescue vernacular.

And so now here we are at the beginning of 2019. The debate between SMSB and DCTTRS is in the opinion of Rigging for Rescue principals, solely about the terrain between the completion of the Edge Approach phase of the operation and the completion of the Edge Transition. Approximately two body lengths or around 4m of linear distance. For the Edge Approach phase, both systems must allow the load to approach the edge in a secure, but unobstructed manner. After the completion of the Edge Transition phase, both systems utilize similar methods – specifically, descent control combined with a self-actuating system component on both ropes regardless of Main or Belay designation. It is only between those two points that a difference exists. The difference is based on how you ascribe importance or value to the parameters in play.

System Qualities

To begin our critical analysis, we will explore various Rope Management System qualities. It is not intended to be an exhaustive list, but simply represent fundamental qualities commonly emphasized in the rope rescue community. A number of the qualities may be identified by slightly different terms depending upon local, regional, and cultural lexicon. We will explore the qualities in depth such that potential misunderstandings in vocabulary might be mitigated. Our objective will be to highlight the desired intent of each system quality, in principle. In addition to terminology, significant differences likely exist with regards to how the qualities are prioritized from one organization to the next. The reader is encouraged to refrain from attempting to rank order the qualities, but rather individually view them as existing on a continuum. An example of this is the concept of sound equalization for your favorite musical number. The listener can adjust the Bass, Treble, or Mid level frequencies to achieve a balanced sound preferable to their desires - just as the practitioner, team, or agency will address prioritization of system qualities within their Rope Management System.

- Redundancy - <——————> +
- Independence - <——————> +
- System Strength - <——————> +
- Hands-Free Stop (Whistle Test) - <——————> +
- Usability-Ease of Rigging, Inspecting, & Operating - <——————> +
- Smooth, Controlled, and Predictable Movement of the Load - <——————> +

Redundancy

Redundancy has long been a desirable system quality for many teams as evidenced by choosing to employ two-rope systems, the notion of the *Critical Point Test* during *Whiteboard Analysis,* and electing to utilize multi-point anchoring techniques, to name a few. Some definitions of the word include:

- Not, or no longer needed; superfluous
- Not strictly necessary to functioning but included in case of failure in another component
- The duplication of critical components or functions of a system with the intention of increasing reliability of the system, usually in the form of a back-up or fail-safe (engineering – en.m.wikipedia.org)

The purpose of redundancy in our systems is to prevent *performance decline* from exceeding specified limits. An example of this would be performance characteristics associated with the Belay Competence Drop Test Method (BCDTM). It assumes the Main or Primary line, responsible for moving the load up or down the cliff face, has failed and the Belay or Secondary system must arrest the falling load. After free-falling 1m onto 3m of host rope, the 200 kg test mass must not be subjected to a force greater than 15kN; also, the fall must be arrested within an additional 1m of travel. Following the drop test, the fall arrest rope segment is taken to a slow-pull machine and tested to failure for residual strength (>80% to pass). The BCDTM has been the widely accepted benchmark for examining rescue belay backup systems since the early 1980's in North America. It is also well understood this particular evaluation does not include human operators. If there is a compelling reason to amend the BCDTM Standard, (e.g. injuries are occurring or equipment is being damaged because of unacceptable limits as defined by *"Performance Decline")* then the greater community should consider developing and vetting such changes. If not, caution must be exercised when electing for devices and systems that attempt to further optimize one variable or a component of a variable. It is a common occurrence that selective optimization can lead to adversely affecting other variables or components - thus, making system interactions potentially more complex.

In his book, Normal Accidents: Living with High Risk Technologies, Charles Perrow warns against redundancies with potential to increase complexity of system interactions. Beyond our discussion of Redundancy as a rope rescue system quality, we will revisit this concept of complexity of interactions as they relate to other qualities later in this paper.

Exploring redundancy a little deeper we can consider it's possible functions; a literature review suggests several functions are common in the systems engineering world. As with many things in the rope rescue, specific definitions vary slightly from source to source. We feel en.m.wikipedia.org offers a relevant description of Passive & Active Redundancy that adequately meets our needs:

"Passive Redundancy uses excess capacity to reduce the impact of component failures." Employing multiple pieces of rock climbing protection to construct a suitably strong

(20kN) anchor system could be an example of Passive Redundancy. A potential limitation of this function relates to the non-linear or more complex nature of the relationship between the component parts. DCTTRS relies on this function of redundancy.

“**Active Redundancy** eliminates performance decline by monitoring that of individual devices or systems.” Depending upon the specific type of system, this monitoring and selection for a given system is achieved by a form of *voting logic*. With the SMSB system example, voting logic could be as simple as:

> ***If*** the load experiences an abrupt and unexpected acceleration,
> ***Then*** the Belay system is activated.

Practitioners must critically analyze to what extent they value the quality of *Redundancy* in their system. Is your Team or Organization employing an adequately correct function of *Redundancy* to protect against unacceptable *Performance Decline*? Or, are you adding complexity of interactions under the premise of system improvement? Every choice we make is an investment regarding either mitigation or introduction of risk in the rope rescue system.

<u>Independence</u>

Independence is a commonly applied principle germane to numerous aspects of a rope rescue system. Given the opportunity, many practitioners would choose to construct two completely independent anchors for their respective rope systems. Typically, we see independent inspections of various rigging components. Some organizations choose to tie the operational ropes together at the load using long tail interlocking bowlines. At a fundamental level, high degrees of *Independence* reduce the risk of a failure in one component negatively impacting another component. It guards against the chain reaction. In this respect, *Independence* is very closely linked to *Redundancy*.

Our inquiry into *Independence* seeks to move beyond the simple relationship between physical components. We return once again to the work of Charles Perrow:

> *High reliability systems tend to function as a series of linear rather than complex interactions. The greatest degree of reliability generally exists when independent systems with linear interactions operate parallel to one another.*

An example of this is during the edge transition phase of the lowering operation. The Main Line System has 100% control of the descending load and the Belay System is functioning as a competent back-up. Feedback within this system flows in a linear fashion back and forth between the load and the operator controlling the DCD. Should a failure occur within the Main Line System causing the load to suddenly and unexpectedly accelerate, the well-operated Belay System should be expected to self-actuate and reliably arrest the fall. This is a concept we will cover in additional detail when we consider the Hands-Free Stop quality of our systems.

Alternately, strict adherence to DCTTRS with a focus on the risk of rope trauma due to sharp edges requires significant levels of **inter**dependence between the systems. The desired premise, as laid out in the EMBC Summary Report, is for each system to share the load as close to 50/50 as possible. It is not clear, based on data provided in the Summary Report, how quickly the benefit, on sharp unprotected edges, erodes away when tension is not shared 50/50 between the two systems. It is our experience, conducting over 120 training seminars since the EMBC report was released in 2016, rarely do practitioners achieve equally shared tension. Additionally, several series of human factor tests conducted by Rigging for Rescue in 2017 focusing on Two Tension Rope Lowers (and associated video) further supports this notion. When they do actually get closer to 50/50 sharing, it is typically well past the edge transition phase of the operation. It appears to take time to get in sync with each other. Perhaps this is an area for further testing?

Separate of how well the operators share tension when utilizing DCTTRS, an important consideration is: Readily available information from the fields of Systems Reliability and Human-Machine System Analysis does not support the notions being inferred in the EMBC Summary Report regarding the interactive nature of DCTTRS. There is a robust amount of peer-reviewed literature available on this topic. Two excellent sources include books by James Reason (The Human Contribution) and Charles Perrow (Normal Accidents: Living with High Risk Technologies).

We find it interesting the EMBC report, which so strongly advocates for a strict DCTTRS approach during the edge transition, and speaks broadly to the topic of human factor influences, appears to de-value the significance of *Independence* within the system. Yet, only Series 1 examinations in the 2016 EMBC testing project involved actual human operators. During the Series 1 tests, the operators were not asked to coordinate their action with another operator/system, nor was a 200 kg mass utilized. The mass was cut in half to 100kg, supposing the system being tested was supporting half the load; then the operator was asked to offer a subjective assessment regarding how difficult/easy the system was to operate. The Series 1 results, combined with testing conducted by Kirk & Katie Mauthner in 1993 on Human Gripping Ability on Rope in Motion, were then utilized to offer broad assumptions in the EMBC report regarding capabilities of the DCTTRS system. This type of general association and over extrapolation in the 2016 EMBC Report generates some concerns with the conclusions drawn from the EMBC test series. These same concerns will surface again when we consider other system qualities.

System Strength

The concept of building a rope rescue system to specifications greatly in excess of anticipated applied forces is a widely accepted and commonly practiced risk management approach. Whether one reviews applicable OSHA regulations, ANSI Standards addressing fall protection or work positioning systems, NFPA standards addressing rope rescue, or simply reviewing any civilian SAR team SOP document for rescue/rigging, multiple references to desired *System Strength* are likely to be found. It's an engineering principle related to *Redundancy*. Recall, "**passive redundancy** uses excess capacity to reduce the impact of component failures." The terms *margin of safety* or *safety factor* are commonly used to reference degrees of capacity beyond that which is required to simply perform a specific function under given circumstances. As with many terms, such as these, specific definitions will vary from source to source. In the interest of clarity for this discussion, they will be defined here as follows:

Margin of Safety –	Difference between the breaking strength and the force applied
Safety Factor –	The ratio of the breaking strength to the force (static or dynamic) applied
System Safety Factor –	Represented by the lowest component *Safety Factor* within a given system
Static Safety Factor –	Ratio of the breaking strength to the *Static* force applied
Dynamic Safety Factor –	Ratio of the breaking strength to the *Dynamic* force applied
Static System Safety Factor –	Represented by the lowest component *Static Safety Factor* within a given system

For many teams and organizations, a 10:1 *Static System Safety Factor (SSSF)* has long been the standard to which they seek to construct their rope rescue systems. Anecdotal evidence from instructing rope rescue seminars suggests that use of a 10:1 *SSSF* is one of the more misunderstood as well as misapplied engineering concepts in the trade. Many view it as a hard and fast rule or critical boundary that somehow makes our operation *safe.* Presumably as a result of this confusion, portions of the rescue community have begun to explore other options for articulating the extra capacity to which the system is built. Terms such as Working Load Limit, Force Limiting, and Margin of Safety among others are gaining traction as engineering concepts for rope rescue systems.

Regardless of what concept the practitioner or agency chooses to find practical and useful, one must understand the underlying qualities by which the principle is associated. To illustrate this example, let's consider using a SMSB system. The Belay system has been constructed to a 10:1 *SSSF* (e.g. the weakest link is estimated to be the knotted 11mm Belay rope). During the lowering edge transition phase a 200kg mass is suddenly dropped (by virtue of a Main Line failure) about 1 meter onto 3 meters of rope. The 200kg mass statically suspended in free space will generate approximately 2kN of tension in the line, assuming no additional friction in the system. Compared to the breaking strength of the knotted 11mm Belay rope (approximately 20kN) we arrive at a *SSSF* of 10:1 (20kN:2kN) – again, under the premise that the knotted Belay rope is indeed the weakest link in the chain. Getting back to our drop (BCDTM) event, the arresting force (i.e. dynamic) will be greater than the static force. Robust pools of data from multiple sources would suggest the arresting force in this event, for devices and systems passing the BCDTM, are typically in the 9-12kN range. When compared to the breaking strength of the knotted rope, this leads us to a *Dynamic Safety Factor* of approximately 2:1 (20kN breaking strength: ≈10kN dynamic force). This is ultimately the relationship we are engineering to when originating with the 10:1 *SSSF* as our optimal *System Strength* quality.

But 10:1 *SSSF* is only part of the story. One must consider the circumstances leading us to the dynamic event. In this case it was a 200kg mass free-falling 1 meter onto 3 meters of rope. Viewed from this perspective, the BCDTM event and our 10:1 *SSSF* becomes much less of a rule and more of a decision-making strategy or template for deciding how strong the system needs to be to achieve a reasonable level of Passive Redundancy within a given system. Possessing a solid understanding of how the 10:1 SSSF provides adequate margins over and above any field-replicable system failure, allows the practitioner the flexibility to deviate from that guideline when appropriate. For example, a multi-attendant embankment rescue down a steep slope with a heavy patient in the litter can often result in upwards of 3kN of static force on the rope system. But that does not necessarily indicate that we would require a 30kN system to account for that 3kN load. Recognizing the absence of a true edge transition (and therefore little to no freefall potential) that could contribute to a large dynamic force, allows the rigging team the latitude to proceed with a SSSF well below 10:1 while still maintaining robust margins.

The dynamic force generated from a BCDTM event is comprised of:

- Mass
- Freefall distance
- Rope-in-service (and therefore combined with freefall distance – Fall Factor)
- Elongation qualities of the host rope
- Any slippage through the fall arrest device
- The presence or absence of an edge during fall arrest (Note: an edge is not present in a true BCDTM examination)

Knowing that a 10:1 SSSF accounts for these elements from an engineering standpoint provides the savvy practitioner the decision-making information to rig to the conditions. As educators and practitioners, we find the application of safety factors to be among the most useful decision-making tools we have at our disposal.

The practitioner seeking to simplify the *System Strength* decision-making process by applying a fixed kN value to the system engineering (as opposed to a safety factor, for example), may inadvertently handicap themselves by limiting their understanding of the statics and dynamics being represented. Such a philosophy will undoubtedly make the initial rigging considerations much more straightforward and streamlined. However, those are not the only factors leading to higher quality risk management. The foundation of our craft in rope rescue is to identify the most prominent hazards and associated risks. We then employ a dynamic decision-making process to maintain pace with the evolving risks throughout the mission, ultimately resulting in the application of tools and practices allowing us to return home safely after each mission.

Hands-Free Stop (aka The Whistle Test)

This is a system quality that appears to have deep roots in the rope rescue community. The very nature of the BCDTM highlights the importance of having some component in the broader system capable of arresting the falling load should other components fail. Examples of devices/systems having passed the BCDTM criteria include: Tandem Prusik Belay, MPD, 540 Rescue Belay, and VT Prusik (configured as a 6 over 1 asymmetrical Prusik), to name a few. At first glance, the hands-free stop quality appears simple to assess. The BCDTM test is conducted and the result is observed – the system either arrests the fall or it doesn't. However, upon closer examination it becomes obvious there could be significant limitations when data gathered from pure laboratory style testing (such as the BCDTM) is broadly extrapolated to form conclusions regarding reliability under normal operating conditions. As with research and data from any field, limits exist as to what can be inferred. Good examples of this include the Friction Hitch Belay (TPB) or the MPD. Both devices test well in the laboratory environment of a BCDTM examination. Data suggests both devices will reliably arrest the falling rescue load when the operator takes his/her hands off of the system (various ITRS presentations from Pendley, Gibbs, Mauthner, others). The problem arises in the fraction of a second (or more) it takes the operator to process inputs from the system/environment and then respond by letting go (or not).

Reactionary Gap is a concept that is thoroughly researched and well documented from the fields of Military & Law Enforcement. This research & testing data suggests there is a zone extending outward from the operator representing a specific distance to a potential threat (perpetrator). This distance more importantly represents *time* the Officer or Operator has to identify the threat as such, process the information, then respond accordingly. Obviously, it is advantageous for the Officer to close the gap to be as short as possible. Closing of the gap occurs by training and evaluating both ends of the continuum. Officers must practice and be evaluated on their sensory and perception skills followed by high quality psychomotor skill development and valid assessment.

There is incredible opportunity for the rope rescue community to utilize the work already being done in many other fields. Human-Machine Systems Analysis, Cognitive Task Analysis, Psychomotor Skill Development, High Risk Performance Development, Accident Analysis, & Attention Prioritization are but a few areas offering very useful information for rope rescue system development & evaluation. It is concerning that influential reports such as the EMBC Summary Report from 2016 reference and make strong recommendations regarding *Human Factors* yet provide little, if any, citation to current literature or include raw data from in-house testing.

Getting back to the topic of *Hands-Free Stop (Whistle Test)*, perhaps it is time the rope rescue community adopts terminology more accurately representative of the quality we legitimately need: self or auto actuation. In addition, there appears to be significant opportunity to adopt a more evidence-based approach to developing psychomotor skills thereby working towards more reliable human-machine systems.

The Tandem Prusik Belay offers a fine example. For many years the TPB has been called into question regarding reliability under normal operating conditions. From increased stop distance with larger amounts of rope in service (and no shared tension with the other system), to the operator minding the hitch with sub-optimal technique, to poor cordage properties for the task - the potential pitfalls are numerous. Naturally, the question arises, why even use such a system? The answer could include things like the need for lightweight, multi-purpose, & relatively inexpensive options. For many Teams, aspects of their Mission Profile might preclude their widespread and universal application of mechanical devices such as the MPD or 540 Rescue Belay. It would be a disservice to those in the Rescue Community with such Mission Profile requirements to simply disregard improvised, non-mechanical rescue safety systems. This is not meant to be a debate about which is better or preferred between mechanical devices and improvised systems, but rather, fuel for a richer discussion regarding specific system qualities such as self-actuation and the role this quality plays in critical thinking and systems analysis.

Rigging for Rescue places a very high priority on self-actuation as a system quality (i.e. *Hands-Free Stop*). This is of particular importance during the initial edge transition of a lowering operation. Neither system has been proof tested yet, rigging/inspection errors may not have been revealed, considerable coordination is required between various components, and high fall factors tend to be present.

The next time your team conducts a training exercise and live loads are being lowered, ask yourself, what might we hit while the device operator is processing the event of a system component failure? It would be beneficial if we could develop a technique whereby we closed the reactionary gap. Perhaps one day, the rope rescue community will be able to agree upon a standardized method for evaluating the efficacy of specific psychomotor skills required of operators in our systems. This sort of evolution would likely have a positive effect on operator proficiency as well as the overall safety of an operation.

Usability - Ease of Rigging, Inspecting, & Operating

From a historical perspective, this system quality appears to be one of the more subjective that we've discussed thus far. Presumably, an operator or team will find the tools and techniques with which they are most familiar to be the easiest to rig, operate, and inspect. The interesting thing about this notion is that due to the absence of valid and widely accepted assessment and evaluation methodologies, it tends to rely heavily on anecdotal evidence. The true reliability of the system is seldom addressed. This is similar in principle to early work conducted by the British Columbia Council on Technical Rescue (BCCTR) considering rescue belay systems. Initial testing to the BCDTM criteria in the 1980s revealed a wide variety of system qualities as rope systems/devices were critically examined. Observing drop test results reminds one of the non-event feedback loop concept (i.e. "We have never had a problem in 20 years using this system, etc."). For example, belaying a 200kg rescue load with a single Italian Hitch (aka Münter Hitch) might appear to be reasonable in certain situations, but prove to be unreliable in other circumstances. The adoption of the BCDTM has afforded the community a baseline for evaluating potential rescue belay systems. The prudent practitioner will exercise a high degree of suspicion when evaluating qualitative statements such as *easier, harder, simple, or complicated.*

Usability has become a quality of particular importance at Rigging for Rescue. As we review accident/incident reports and consider near misses from seminars as well as anecdotal evidence from others in the community, it becomes clear this is an aspect that needs further consideration. A quick review of the literature suggests *human error* is one of the most common contributing factors in mishaps across almost all high-risk endeavors. Many fields utilizing human-machine systems and requiring psychomotor skills to operate have invested substantial time, energy, and resources into better understanding these intricate relationships. It has long been understood that resources such as "how-to" manuals do little to communicate the principles by which a device or system functions properly. For this depth of knowledge one must dive into the textbooks of Engineering Mechanics, Newtonian Physics, Textile Fiber Properties, and Materials Science to name a few applicable to rope rescue. The 2016 EMBC Summary Report discusses *human factors* and associated impacts to rope rescue systems. But very few of the Test Series outlined in the report include human operators and there is an absence of literature review and citation regarding credible human factor research. There is information readily available from the field of Human Factor Engineering. Topics of particular relevance include, but are not limited to, Cognitive Task Analysis, Attention Prioritization, Psycho-motor Skill Development & Assessment, User Centered System Design, and Human-Machine Systems.

In an effort to more legitimately understand this system quality, Rigging for Rescue has begun to view this issue through the lens of ***Usability.*** It has become the cornerstone of our approach to developing more reliable human-machine systems. Defined by Rubin & Chisnell (2018) as "enabling users to do what they want to do, in a way they expect to be able to do it, without hindrance or question."

Nielsen (1993, 1995) has identified 5 dimensions of *Usability:*

1) Learnability – ability to begin using the system
2) Efficiency – comparative to other options
3) Memorability – ease of return to the system
4) Error resistance & remediation –
    - Fewer mistakes while learning, using, and navigating the system
    - Decreased possibility of catastrophic errors
    - Ease of fixing errors
5) User satisfaction

The dimensions of *Usability* coupled with quality assessment provide a more objective framework for understanding the user, task, and system. This concept is illustrated in research conducted by Manuel Genswein & Ragnhild Eide and presented at the International Snow Science Symposium (ISSW) 2008. The corresponding paper presented for peer review is titled "The Efficiency of Companion Rescuers with Minimal Training." One aspect of their work resulted in the development of the *Airport Approach* method of avalanche rescue for novices. The data suggests that perhaps the investment of time during the fine or bracket search phase of the companion rescue was not paying off with the expected outcome of increased precision. The ultimate goal of reducing the overall time of the rescue was not being achieved. The *Airport Approach* method requires the rescuer to progressively decrease the search speed as they approach the subject during the *Coarse Search* phase of the rescue. At three meters distance to the subject, skis are removed and the beacon orientation is no longer changed. The final rescuer path is determined at this point (i.e. the airport runway). They simply move straight ahead on this path, past the minimum distance value until the distance indicated on the search beacon begins to increase, then straight back along the path to the minimum. From here, spiral probing is conducted until a probe strike is achieved. When considered relative to Nielsen's *5 Dimensions,* it is not surprising this methodology has produced significant reductions in the time it takes novice rescuers to locate a buried avalanche victim.

The term *simplify* comes up quite frequently as the discussion turns to Human Factors in rope rescue systems. In discussions with teams who have transitioned to DCTTRS, many have stated they are addressing a human factor component by virtue of rigging both rope systems identically. They feel they are simplifying the rigging and operating requirements placed on the user; therefore they are less likely to make an error. We are not aware of data or credible literature addressing human-machine systems that supports this notion. Rigging for Rescue believes in emphasizing the importance of designing and teaching systems with human users' goals, needs, capabilities, and limitations in mind. Systematic & iterative human-machine systems should contribute to techniques and methodologies that are more functional, usable, desirable, and ultimately more effective. This is achieved through comprehensive analysis of the *User, Task,* and *System.*

In 2015, Rigging for Rescue conducted a series of human factor tests considering the reliability of friction hitch belays. Based upon extensive video analysis and interviews with human operators we were able to arrive at three factors that significantly influence the reliability of this belay system:

1. The hitch must be snug on the host rope (i.e. dressed and stressed at all times during the operation)
2. The operator's anchor side hand (holding the friction hitch) must remain perpendicular to the loading direction
3. The operator's anchor side hand (holding the friction hitch) must pull hard against the anchor (i.e. actively maintaining taut rigging)

In addition to becoming the fundamental elements of high quality psychomotor skill progressions for this technique, the list has dramatically improved peer coaching and assessment capabilities amongst team members. Certainly, this work and the associated outcomes do not represent a destination, but rather the next step in an evolution. This is not meant to be value statement in support of Friction Hitch Belay systems over mechanical (MPD or 540 Rescue Belay Device) options. It is nearly *irrefutable* that mechanical options offer the *highest degree of reliability* with the lowest probability of catastrophic outcome when used in a way whereby the operator is not defeating the fail-safe mechanism (e.g. release handle).

As a final example in this section we will return to the EMBC report statement regarding DCTTRS being a more "simple" approach due to the rigging and operating similarities between the systems. If the ultimate goal were to simply construct the system, we might tend to agree. However, this is merely a step in the progression of using the rope system to safely move the Patient and Attendant from a place of predicament to one of care and comfort. Getting back to Perrow, *the most reliable redundant systems tend to exhibit linear interactions within a given system while an independent system operates in parallel, offering a back-up to the primary system.* It is desirable for the secondary system to activate automatically upon failure in the primary system. Error detection and correction tend to be more favorable as the location of the error is obvious.

Many teams have expressed difficulty achieving 50/50 shared tension during the edge transition of a DCTTRS lowering operation. One significant reason why these operators, and many like them, tend to struggle has to do with the feedback loop they are experiencing. As they attempt to achieve a well-coordinated lower, each operator is receiving input regarding their performance. There are visual, tactile, and auditory inputs coming from the moving rope under tension, the attendant, and others on scene. The operator will process these inputs and respond accordingly with their action. As operator #1 makes their adjustment, the result flows downstream to affect the load. But it doesn't stop there. It travels upstream toward operator #2 and adds yet another input for consideration in their system. This is an example of what Perrow calls "complex system interactions." They can be described as branching paths, more open feedback loops, and/or unexpected jumps from one linear sequence to another. These complex system interactions can have a negative effect on system reliability.

Smooth, Controlled, & Predictable Movement of the Load

This system quality is closely tied to that of *Usability* as well as others such as *Independence.* Why is it important for movement to be smooth, controlled, & predictable through the edge transition? Like the other system qualities previously discussed, the presence or need exists along a continuum. The Team will prioritize this system quality much like one might adjust the Bass or Treble on the car radio. Once the load is over the edge and moving downward, both lines are under tension and supporting the majority of the mass x gravity (in high angle terrain). The Attendant has the relatively easy task of keeping the litter and Patient off of the terrain features. Any friction associated with the edge or changes of direction, such as a high directional, will offer a dampening characteristic. This tends to minimize the impacts of input changes on the operator (top) end of the system as well.

Contrast this with an edge transition scenario. As implied by the name, a *transition* needs to occur. Regardless of the rope system philosophy employed by your Team, the basic progression probably looks something like this:

- Roll call
- Edge approach
  - No or minimal tension in the operational ropes
  - Friction in the devices must be minimized to allow unencumbered movement to the true edge transition point
  - The earth is supporting most of the mass x gravity (i.e. the live load)
- Tension the system
  - Attempt to put as much tension into the system as possible, elongating the ropes as much as possible
  - Devices associated with operational ropes go to appropriate friction
  - The earth is still supporting a majority of the mass x gravity
- Edge Transition
  - Attendant leans back against the rope system
  - Pulling the load away from the terrain (if there is a litter/patient)
  - Primary support is now the tensioned operational rope(s) resisting downward movement
  - *Smooth, Controlled, & Predictable* downward movement begins via the descent control system
- Lowering phase (i.e. post edge transition)
  - Catalysts for failure have been diminished by this point (e.g. poor inspections; an attendant stumble)
  - Rigging errors would likely have been revealed during the initial edge transition (due to full system tension)
  - Significant operator modifications are complete (i.e. changing friction during edge approach, the tensioning of the system, and transitioning over the threshold – all requiring operator DCD modifications)

- Demand for highly synchronized, well-coordinated, and communicated movement is diminished
- Stopping distance due to rope elongation now becomes an increasing risk as more rope is introduced to the operation

It is during the critical *Edge Transition* phase the need for a *Smooth, Controlled, & Predictable* movement is at a premium. All system components should function concurrently and harmoniously. Subtle imperfections may get amplified and result in significant opportunity for slips, trips, stumbles, & miscommunication. The recommendations put forth in the 2016 EMBC Summary Report suggest all other issues associated with the *Edge Transition* phase are *secondary* to the risk of rope trauma due to sharpened steel, unprotected edges. The report advocates for a specific rope system management philosophy, DCTTRS, to account for this very small target on the risk management dartboard. The report also acknowledges the potential struggles that will undoubtedly be encountered when attempting to control the movement of the load with 2-rope systems simultaneously offering inputs in a non-linear, interactive fashion. The management strategy offered in the EMBC Report is more training & improved communications, under the premise that SMSB or DCTTRS will require equal amounts of training. This notion is not well supported in the Human Factor Engineering literature due to the nature of the interactions within the DCTTRS system (i.e. non-linear, complex interactions).

The literature does suggest linear interaction of the system components and more tightly confined feedback loops will offer the greatest levels of effective control and predictability. This is the same reason pilots in the cockpit do not share duties associated with operating the flight controls at the same time. There are clearly identified processes and procedures for passing control of the aircraft to the other pilot.

There are other examples of this quality in action within the field of ropework. Consider two rock climbers at a rappel station preparing to descend. Given the opportunity, most climbers are going to prefer rappelling vs. being lowered by their partner. Why? The feedback loop associated with rappelling is more closed. The system inputs and outputs exist almost entirely within the operator and the nature of the interactions of various components tends to be linear. The human-machine system is more readily responsive to change resulting in smooth and predictable descent. Certainly this is a simplification focusing on one aspect of the system. The specific situation at hand may necessitate the execution of different options to address other factors.

The initial litmus test regarding how *Smooth, Controlled, & Predictable* the movement is likely to be, will focus on a few key characteristics:

- Is the feedback loop for each operator more open or closed?
    - Example – Rappelling vs. being lowered
- What is the nature of interactions among system components - linear or complex? (i.e. branched and/or jumping from one linear system to another)
    - Example – One rope system controlling the movement of the load with the other providing an acceptably competent back-up which gets selected for

in a highly automatic fashion vs. DCTTRS whereby both rope systems are actively contributing to movement resulting in more complex (branched) component interactions

- Do the required operator outputs (device manipulation) match the design specifications of a given descent control device?
    - Example – Placing a friction hitch between the Scarab and a carabiner re-direct as prescribed in the 2016 EMBC recommendations significantly alters the range of available friction designed into the device – typically 1 or 3 horns engaged leaves significant gaps resulting in either inadequate friction or too much, depending on circumstances

In the end, *Smooth, Controlled, & Predictable* movement can likely be achieved through any number of device and system configuration options. The prevailing questions will be:

1. How much training time is it going to require to get operators and the team to a desired level of proficiency?
2. What level of flexibility will best serve the needs of your team in the environments you work?

Now that we have addressed many of the key elements by which we assess a rope rescue system, our intention is to explore how and why we differ as rope rescue practitioners and organizations. What are the primary variables that differentiate one group and its rigging philosophy from the next? And how do those differences affect risk assessment, mitigation measures, and system choices? The answers to these questions largely lie in the values we assign to the parameters we are tasked with managing.

Mission Profile

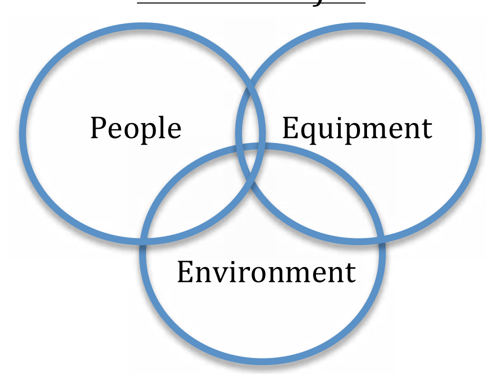
One doesn't need to wander far into the hospitality suite at a typical ITRS gathering of rescue practitioners, before realizing that the rope rescue techniques and priorities in the community run the gamut. As Tom Evans discussed at ITRS 2018, we all have a rigging philosophy that is largely based upon our values. The spectrum of values on display across the rigging community today is as diverse as the environments in which we work, the people we work with, and the equipment options readily available. Regardless of where one places more or less value, the goal must be to enhance hazard recognition, risk identification, and ultimately mitigation to an acceptable level. The motivation to adopt rigid cookie-cutter type approaches is understandable. They tend to be very efficient on the construction side, presumably simplifying some decision-making. However, this approach fails to respect the very nature of our operating environment. Naturalistic Decision Making (NDM) settings, as defined by Gary Klein, tend to exhibit challenging conditions such as:

- Time pressure
- Ill-defined goals
- High stakes
- Inaccurate or inadequate information
- Organizational constraints
- Team coordination requirements

Limitations to an extremely rigid approach rarely appear until something happens necessitating a retroactive review. In many respects, the rope rescue community appears to view the questions that arise in systems analysis as a dichotomy - this or that.

As we move forward in our *Systems Analysis,* considering various risks to be mitigated during a typical rope rescue mission, we encourage the reader to adjust the relative value of system qualities based upon the unique & dynamic relationship we call *Mission Profile.* How your Team chooses to address the dynamic relationship between the environment of operation, equipment (and systems) selected for, and the people (training, experience, and attitude) you have available will dramatically influence ability to effectively manage risk. Devices, systems, and training methods that are extremely effective for one Team may yield far less desirable outcomes for another. Just as the listener adjusts the Bass, mid-Level & Treble frequencies on their radio to achieve a desired sound, *Mission Profile* is an invisible hand guiding the adjustment of our rope system qualities with a high degree of respect for the dynamic nature of our missions.

Mission Profile



Risks to be managed

The term Mission Profile encompasses three components:

- People
- Equipment
- Environment

The components may have independence by categorization, but they are all inextricably linked to one another in any given rope rescue system. For example, a human factor (people) could play a role in the selection of a device (equipment), when that device is being utilized with icy ropes (environment). In this example, all three categories of Mission Profile contribute to the operator's ability to manage the device well given the specific conditions. The interconnectedness of People, Equipment, and Environment is a consistent theme throughout ropework and work-at-height.

From a scientific testing standpoint, it is far simpler to isolate a given variable and then test that variable against specific conditions. But when you then *apply* the newly acquired data into a complex system, the conclusions should be appropriately tempered for what is actually known about the interrelationships. Sometimes a change to a given system produces a favorable outcome in certain circumstances. But that same change may introduce risks and/or shortcomings that are not necessarily revealed at first glance.

There are costs and benefits to all of our choices. If someone sells you a benefit, assume that it has a cost. The cost may be minor or it may be major, but it exists nonetheless. So in the end, we must choose. And our choices should be predicated on our Mission Profile and how we assign value to the various elements that we are seeking to manage.

All ropework conducted at height incorporates risk. Ropes attached to anchors suspend us and devices operated by human beings control our movement. Clearly, there is risk involved. Risk is the probability that exposure to a hazard will result in a negative consequence. Risk is a potential for a loss.

Specific to comparing and contrasting DCTTRS vs. SMSB, we will focus on the following risks:

- Rope trauma due to sharp edge
- Maximum arrest force
- Stopping distance
- Operator error and usability

In our comparisons, we will endeavor to utilize *Systems Analysis* to address how the given risk affects the overall safety and efficiency of the system through the lens of Mission Profile.

<u>Risk - Rope trauma due to sharp edge during fall arrest</u>

The rope performance results from sharp edge testing conducted by Basecamp Innovations in both 2014 (Mauthner ITRS) and in 2016 (EMBC contract testing series), represent the *cornerstone* of the argument for abandoning SMSB edge transitions in favor of DCTTRS edge transitions. Other points such as reduced maximum arrest force (MAF) and shorter stopping distances are cited as additional benefits (<u>Note:</u> to be discussed in detail in subsequent sections), but the sharp edge performance is the key driver for the paradigm of advocating for both ropes being under tension for the initial edge transition in a lowering operation.

In addition to the 2014 and 2016 tests conducted by Basecamp Innovations, sharp edge testing was also conducted by Forbes (2015 ITRS), McCullar (2015 ITRS) and Gibbs (2015 ITRS). All of the researchers used exceptionally sharp edges (sharpened steel or manufactured 90° stone edge). All of the researchers employed slightly different test methods. Despite the differences in test methods and edge types, some common themes were identified:

- Tests conducted with no protective padding, 200kg test mass, and high fall factors produced failures in both DCTTRS and SMSB
- Tests conducted with adequate padding (3 layers of canvas or the equivalent), 200kg test mass, and high fall factors indicated no difference in performance between SMSB and DCTTRS. All ropes were unharmed.
- Somewhere between these two scenarios (i.e. reduced padding), differences were identified that indicated better performance results for DCTTRS.

Looking through the lens of Mission Profile, sharp edge performance is primarily an environmental factor. Certainly human factors play a role in deciding whether or not to even attempt to go over such a sharp edge and equipment factors would also play a role insofar as the edge padding, rope diameters, etc. But in the end, we are talking about an environmental factor. The overwhelming majority of credible literature addressing high-risk endeavors agrees that human factors are the most influential factors in any complex system. But the recommendation from the EMBC report is to change to a DCTTRS edge transition technique to better address an identified environmental factor (i.e. sharp edge). We respectfully agree to disagree and will explore those reasons next.

<u>Critical Analysis of Test Methods:</u>

To perform a quality test that delivers useful and realistic information, it needs to replicate a credible event and be reasonably repeatable. Additionally, conclusions drawn from a test or test series should be tempered with respect to application and/or extrapolation. The old saying, “Bread is good, God is good, therefore bread is God” comes to mind.

Edge Quality-

- All researchers used exceptionally sharp edges. The reasons presumably included repeatability of the test method as well as a more efficient pathway to identifying the marginal differences between the two systems being examined.
- For example, if the edge used was sharp - but not razor sharp - a difference may not be revealed. This might cause one to assume that the systems were equivalent.
- So in order to identify that margin, a very sharp edge has to be employed. An edge with a sharpness that would cause any practitioner to pause before considering the wisdom of going over such an edge without specific procedures and mitigation measures in place.
- It is intuitive to conclude that two ropes sharing the tension of one 200kg mass would be more resistant to abrasion/cutting versus one rope suspending a 200kg mass. They are under ½ the tension assuming equal sharing. That makes sense.
- But is a sharpened steel edge the kind of edge that gets transitioned in rope rescue responses or trainings? And if it were, risk mitigation would likely include robust padding combined with an edge transition technique that minimizes the fall factor.

3-rope System-

- The tests conducted by Mauthner (2014) and McCullar (2015) used a 3-rope system (see photo below) which skews the tests towards greater velocity than would be achieved in a real event
- The test methods were meant to replicate an attendant stumbling at the edge transition and falling on to both ropes (i.e. not a failure of a rope/anchor like in a BCDTM test).
- However, it would be a very difficult test to properly replicate with a non-live load because to do so would require the single rope (SMSB) or the two ropes (DCTTRS) to be under tension when the stumble took place {i.e. leaning back against the rope(s)}.
- The test methods utilized did not replicate that scenario. Instead there was a third rope used to temporarily suspend the test mass prior to initiating the quick release mechanism. So the ropes being examined were slack and therefore the fall distance and resultant velocity would be greater than in a real scenario
- To what degree that matters, we do not know. But the test method used to draw the conclusions in the EMBC report, is not necessarily a representative credible event
- Also, in a real edge transition without a high directional component, edge personnel are lifting to waist-high (aka vectoring) the operational lines to provide the attendant a better rope angle. This standard technique also aids the attendant in clearing the litter/bridle from edge obstacles such as the edge padding devices or the edge itself. It is not really a feasible option to transition an abrupt edge with a patient already in the litter and no high directional, lacking some aggressive edge vectoring. And so a test method to replicate an attendant stumbling at the edge as a 200kg mass without edge vectoring is a contrivance and not a replicable event in the field of use. A real event will entail edge personnel struggling to support the

operational ropes as the load is losing balance. Therefore, the velocity of those ropes settling into the terrain will be much reduced compared to the 3-rope test method employed to replicate such an event.

- In our opinion, this is a case of apples vs. oranges. The BCDTM (or similar) does not provide a clear picture with respect to examining such an event. This is a place where the rope rescue community through ASTM F32 (or something similar) should come together and devise a better test method to more properly replicate the event in question

3-rope Sharp Edge Test Method

High Fall Factor w/200 kg mass –

- A number of the examinations included high fall factors. The testing conducted by Gibbs employed a 1m drop on 3m of rope, for example.
- This is a very severe dynamic event that can only be practically replicated in the actual field of use in one of two scenarios:
    - A collapse/failure of an artificial high directional device or high directional pulley, in which case the DCTTRS may fare worse than SMSB if both ropes are directed high in the overhead pulleys
    - An edge transition with no high directional, but a horizontally-oriented patient in a 4-pt bridle system *(see photo below)* combined with the edge personnel simultaneously dropping the ropes they were vectoring

- Ultimately, a technical edge transition on a lower with a patient already in the litter is primarily an artifact of training as opposed to a real rescue scenario. We lower over edges in training with a loaded patient to practice edge transitions. But from a practical standpoint, in real calls we are more often transitioning with one-person loads and an empty basket because the patient is located below our start position.
- If the patient is on top of the cliff/building, then we can simply reduce the fall factor by employing vertical litter orientation and slide through the transition. This keeps the ropes close to the ground and essentially eliminates the possibility of missing the edge padding.

Other Factors-

- The tests conducted with fall factors assumed equal tension on the two ropes in a DCTTRS edge transition
- What about a difference in rope-in-service on DCTTRS due to:
    - Different focal point locations of the devices controlling the ropes?
    - Different rope in-feed rates of the operators controlling the devices?
- What evidence exists that suggest the marginal sharp edge performance benefits for DCTTRS vs. SMSB maintain their margins when:
    - The rope tensions are split 70% and 30%?
    - 60% and 40%?
- Anecdotally, it appears to take a while for operators to sync their lowering speeds in a DCTTRS edge transition, making it less likely the tension is split equally

during the edge transition. To assume from a testing set-up standpoint that the RIS will be equal in a DCTTRS edge transition leads to confirmation bias

- The conclusions drawn from the test results appear to focus *exclusively* on the sharp edge performance *under the conditions and test methods employed*. Other potential influencing variables that might play a role in the success/failure of a DCTTRS edge transition technique include:
    - The ability of the operators to smoothly coordinate the lower
    - The training time/effort to gain those skills
    - The defeating of the self-actuation component of the device(s)

The original inspiration-

Mauthner's 2014 ITRS presentation as well as the 2016 EMBC report, both emphasize the idea that SMSB teams have historically run a hand-tight belay at the initial edge transition for the purpose of managing sharp edge consequences. The EMBC report lists it as the first of five reasons cited for why SMSB systems became the predominant method for rope management. And that given the limited test data on sharp edge performance indicates better marginal results for DCTTRS vs. SMSB, the aforementioned premise is now refuted and therefore the technique should be abandoned.

This is a point that we would agree to disagree on insofar as the historical importance of SMSB edge transition philosophies. We believe that the primary reason for operating a hand-tight belay at the initial edge transition has been to optimize the device self-actuation – whatever the device happens to be. Ensuring reliable fall arrest of the system is predicated by operating the belay device in its most favorable self-actuation mode. Reliable fall arrest will always be most important quality in any rope system – the system has to catch (<u>Note</u>: this principle was listed as the #4/5 premise in the EMBC report). The secondary consideration is to provide a smooth and predictable in-feed of rope, so that the litter attendant is able to anticipate their next footfall and execute the transition well.

Regardless of the most important historical reasons for employing a specific belay technique, what matters is what you value in your overall system performance - today. We assign the utmost importance to reliable fall arrest; and a smooth, predictable pace of descent control as a secondary consideration. Sharp edges can be managed by other means aside from DCTTRS techniques during the initial edge transition.

<u>Sharp Edge Mitigation Measures:</u>

Despite our criticism of the sharp edge test methods utilized as well as the small sample size used to draw conclusions, sharp edge performance of ropes under certain tensions and edge qualities could very well be a real consideration to manage. We offer the following as means of mitigating the risk of very sharp edges:

- Avoid going over razor sharp edges. Find an alternative option
- Use copious amounts of edge padding and edge protection devices that are robust and well-oriented for the edge you are transitioning over

- Reduce the fall factor. Do not attempt to transition a super sharp and abrupt edge with a patient in a litter (and no high directional help) using a 4-point bridle configuration. Orient the patient vertically and slide through the edge (2-pt. bridle) keeping the ropes proximal to the ground
- Use parapet wall techniques such as lowering the patient into place over the edge with lifting straps controlled by four edge personnel (no attendant). And then have the attendant scramble down into position and orient themselves for attending duties

In the end, your choice to subscribe to a DCTTRS edge transition or a SMSB style edge transition is a *value decision*. If you value the sharp edge performance data and ascribe a tremendous amount of importance to that parameter, then your choice may trend towards DCTTRS. But if your value system favors not defeating the self-actuation feature of a device and maintaining a predictable pace of descent control, then your choice will likely trend towards maintaining the system you are already trained in – an SMSB edge transition.

In order to receive the marginal performance benefit cited as a result of the testing conducted on sharp edges, you would have to have the following parameters in place:

- 200kg mass and a high fall factor
- An exceptionally sharp edge
- Minimal padding and/or really poor rope alignment to that edge causing a pendulum of the load (Note: it is hard to align poorly to a manmade wall)
- A 4-pt bridle orientation on a litter with no high directional in place

The switch to DCTTRS edge transition technique is not a cost-free endeavor. You can train to it, but it will take some time and effort. That same time and effort could instead be used for polishing your command and control systems (human factor), system inspection methods (human factor), or scene size-up and rope alignment skills (human factor). Training time has to be spent thoughtfully and prescriptively for maximum benefit to your team.

Anecdotally, in online searches of incidents and accidents in rope rescue, results tied to poor inspections, poor rigging, loss of control of the running end of the rope, poor command & communication, and other forms of human error appear to significantly outweigh those associated with rope trauma due to sharp edges.

Risk - Stopping distance during fall arrest

Stopping distance is a very important risk management consideration for rope rescue systems. There are hazardous obstructions that a live load could strike on a cliff face or manmade structure such as ledges, vegetation, I-beams, or the ground itself. A well designed and operated two-rope rescue system is one that arrests a fall reliably, while keeping stopping distance within commonly accepted limits (i.e. BCDTM criteria for the edge transition).

We will consider two variables that influence stopping distance in fall arrest:

- Elongation
    - Rope stretch
    - Device stretch (e.g. Prusiks)
- Rope slippage through the device
    - Device behavior given rope qualities & applied force
    - Operator action as well as reaction time

Certainly mass and freefall distance are factors as well, but they end up being reflected in the elongation and slippage values. Additionally, momentum would be a variable as well, but we will assume that teams are generally conducting their lowering operations at similar speeds.

The BCCTR Belay Competence Drop Test Method parameters include a stopping distance limit of ≤1m. Given only 3m of RIS to begin the test, commonly used rescue belay systems combined with typical rescue rope make/models pass the criteria, easily. There are plenty of testing data in the rope rescue community to support this notion.

However, another consideration is when faced with increased RIS on a longer lowering operation. Rope that stretches 10% with 3m RIS will extend 30cm. However, that same elongation will result in 3m of stretch with 30m RIS. This relationship seems to be well understood in the rescue community and has been addressed in previously cited presentations by Mauthner (IKAR 2005) and Gibbs (ITRS 2007). Over the past 10+ years, members of the rope rescue community operating SMSB systems have trended towards adoption of a DCD on their belay line to mitigate the stopping distance risk with increased RIS.

In the 2016 EMBC report, the Series 3 test results conducted with 30m RIS comparing DCTTRS to DMDB resulted in an almost 4-fold stopping distance difference. The report states,"…it is clear that a DMDB presents a considerably higher risk to the rescuers and patient of striking an obstruction during fall arrest. The testing series clearly shows that rescue belaying using TTRS has distinct advantages over DMDB systems with un-tensioned belay lines."

However, the 2016 EMBC report also states: "A common practice among many rope rescue teams is to convert the un-tensioned belay line into a TTRS once the rescue load is below the lip of the edge and the attendant has good control of the load. This practice addresses both the maximum arrest force (MAF) and excessive stopping distances mentioned above."

This is a *very important* distinction to recognize when reading the 2016 EMBC report. According to the report, the risk differences as they pertain to stopping distance between DMDB and DCTTRS only applies when operating an *un-tensioned belay line*. And the report highlights that difference in testing with 30m RIS – not with a short amount of RIS such as during the initial edge transition.

To compare stopping distance risks between DCTTRS and SMSB, we will focus on two fall arrest events:

- During the initial edge transition
- After the initial edge transition

<u>During the edge transition:</u>

- **Elongation of rope/device**
    - The true BCDTM test method is **<u>not applicable</u>** to DCTTRS rope systems; it is only applicable to SMSB systems, for which it was designed
    - It would be difficult to introduce a 1m drop on 3m of rope, while simultaneously having the remaining rope already tensioned. The intent of the BCDTM and historic body of data reflects a situation whereby the only influence acting upon the mass during the falling event is gravity. Comparing Mauthner's TTRS data from 2014 & 2016 to historic BCDTM drops with SMSB could likely result in biased conclusions due to significant differences in actual test methodology
    - However, given the short amount of RIS at the *start* of a rope rescue operation, the differences in rope elongation between DCTTRS and SMSB would be a matter of centimeters, not meters
    - The robust data from SMSB testing to the BCDTM indicate favorable elongation numbers well within acceptable performance limits (≤1m)

- **Rope slippage through the device**
    - Likely more favorable for SMSB. Why? The operational technique does not involve defeating the self-actuation mode of the belay device. Therefore, the reactionary gap is more closed compared to DCTTRS
    - The final stop distance values while defeating the self-actuation mode of a device are highly dependent on human factors
    - While DCTTRS might produce the shortest stop distance numbers in the data set produced by EMBC test methods, it also opens the door for catastrophic failure by virtue of the operator defeating the

self-actuation mechanism. This is also reflected in testing data from Gibbs (ITRS 2015) and unpublished data collected by Tom Pendley also in 2015.

<u>After the edge transition:</u>

- No differences between SMSB and DCTTRS due to **elongation of rope/device** or **rope slippage through the device**. This is assuming that the SMSB system follows the same principles of DCTTRS insofar as incorporating descent control and self-actuation on both rope systems (i.e. post edge transition) and those same applied principles produce similar results
- Certainly, there may be system configuration differences between SMSB and DCTTRS post-edge that affect the stopping distance values between the two systems. For example, the inclusion/exclusion of the extra friction post on an MPD device, or the operator's grip orientation on the release handle of the MPD

<u>2016 EMBC Report regarding stop distance:</u>

- 2016 EMBC report Series 3 test data summary results and discussion states, "In some cases, the stopping distances with DMDB systems were 8-10 times greater than what occurred with TTRS." This stated ratio is derived from the table on page 44 of the report. The tests conducted to produce that ratio of "8-10 times greater" were 3m RIS and a snug top-rope (i.e. zero fall factor test).
- In the 2016 EMBC test summary for the above test method, the stopping distances were approximately 50cm for DMDB and 5-7cm for TTRS. Hence the statement, "…8-10 times greater…" Given those test conditions, the resulting stop distance for DMDB was approximately 40cm greater.
- Typically, 3m RIS is reserved for a *dynamic* fall arrest event such as a BCDTM test. Not a snug top-rope test. Regardless of the peculiar amount of RIS for this test method, the DMDB extension value of 50cm was ½ of the BCDTM acceptable threshold of 100cm.
- The Series 3 testing that utilized 30m RIS indicated a 4-5 times greater stopping distance for DMDB depending on rope type. The actual stop distance differences between DMDB and DCTTRS amount to a range of around 115-230cm depending on rope types. However, that is with a hand-tight belay, which is not recommended for operations of 30m RIS
- The 30m RIS stop distance values in the EMBC Series 3 testing were on par with the same results Rigging for Rescue demonstrated in 2007 at ITRS in Mike Gibbs' presentation *Rescue Belay Long Lowers*. The notion of a hand-tight belay rope (i.e. DMDB per 2016 EMBC Series 3 test method) with increased RIS

(>30m RIS) is an outmoded rope rescue technique that was long ago debunked as being a sound practice.

At Rigging for Rescue, we strongly advocate for morphing the SMSB system into a TTRS once we have achieved predictable and consistent rope tension. That is typically – but not always - after the initial edge transition. At that point in the operation, we are willing to trade the benefit of reduced stopping distance due to rope elongation for the increased risk of defeating the self-actuation mode of the backup device. The risk is justified by the fact that the primary catalysts for system failure no longer present as significant a risk as at the initiation of the operation (i.e. rigging or inspection error, attendant stumble).

Proponents of DCTTRS edge transitions have acknowledged that defeating the self-actuation mode of the device(s) incorporates human factor risks that may contribute to longer stopping distances. To mitigate that risk, their recommended remedy is to utilize backup belayers called *rope tailers*.

The use of rope tailers raises some questions:

- What if you do not have the available personnel to tail the ropes? Is the technique still safe? Less safe?
- What about the efficacy of rope tailing? Does it decrease stop distance? What testing evidence exists using human operators combined with rope tailers that validate the technique? We are not aware of such testing outside of our own 'quick look' examinations.

In 2015, Rigging for Rescue conducted MPD drop tests utilizing human operators (Gibbs, ITRS 2015). The operators defeated the release mechanisms on the two MPDs while conducting a DCTTRS lower of a 200kg mass. One rope was cut away mid-lower. The stop distance results were highly variable.

To be fair, rope tailing might likely contribute to keeping the load from achieving inertial runaway. However, one must question just how effective rope tailing is in reducing stop distance. To tail the ropes, the rope tailer(s) must control the running ends of one or more ropes without interfering with the device operator's ability to operate their device. To not handicap/frustrate the device operator, there will inevitably be some slack between the rope tailer and the operator's brake hand.

To recap the risk associated with stop distance while comparing DCTTRS and SMSB, consider the following:

- There is no difference (in principle) once both systems are operated in the same/similar fashion. Typically, after the initial edge transition.
- There is an unknown difference in elongation of the host rope during the initial edge transition. But the difference would be negligible given the short RIS and the existing data demonstrating acceptable stop distance values for SMSB systems to the BCDTM criteria.

- There is a potentially significant difference in slippage through the device – favoring SMSB over DCTTRS – during the initial edge transition due to human factors associated with the defeating of the device self-actuation mode. We are unaware of a ***single data point*** exceeding widely accepted performance limits when the MPD or 540 are operated as an un-tensioned system. Otherwise stated, when the release handle is not being used the Belay is unquestionably reliable. Data suggests the same cannot be said about DCTTRS during the edge transition.

Risk - Maximum Arrest Force (MAF) during fall arrest

The MAF produced in a fall arrest event is affected by:

- The size of the mass
- The length of the freefall
- The elongation qualities of the system arresting the fall
- Any slippage (or lack thereof) of rope through the device
- The rigidity of the mass (i.e. human being or steel plates)

The BCDTM parameters include a MAF limit of ≤15kN. Recently, the EMBC reduced the acceptable threshold value to ≤12kN. In our experience conducting drop tests to the BCDTM parameters, typical MAF values range from around 9-12 kN. In the USA, OSHA allows for up to 8kN arrest force for a single person in a full body harness. CE regulations allow for 6kN. Because the BCDTM/ASTM F2436 test replicates a two-person load plus equipment (e.g. litter/rigging), a MAF value of 12kN would be compliant with OSHA and CE allowable deceleration values.

To compare DCTTRS to SMSB for MAF values, we will follow a similar approach to how we compared stopping distance values – during the edge transition and after the edge transition. During the edge transition will be further broken down into two parts:

1. One rope failing (e.g. rigging error) when first tensioning the system at the edge (i.e. BCDTM drop)
2. Both ropes intact and the fall at the edge replicating a litter attendant stumble as opposed to a rope/anchor failure

<u>During the edge transition:</u>

- **MAF w/one rope/anchor failing**
    - SMSB data for MAF during the edge transition is robust. Typically 9-12kN with a rigid test mass and no edge friction. Within acceptable limits per BCDTM and OSHA/CE
    - DCTTRS data for this scenario is ***<u>unknown</u>***. As previously discussed in the Stop Distance analysis, a BCDTM test method for a DCTTRS edge transition is very difficult to achieve with only two ropes in the vertical plane. Both are under tension supporting the load, therefore it is impossible to have one meter of true freefall with only gravity acting on the load

- **MAF w/both ropes intact**
    - SMSB and DCTTRS data for this event is likely limited to the sharp edge tests conducted by several different groups. However, those sharp edge tests do not properly replicate the scenario involving an attendant stumble at the edge (i.e. 3-rope test set-up)
    - As previously discussed in the Sharp Edge analysis, the test method for a stumble at the edge with both ropes intact is essentially impossible to properly replicate without a live load as

your test subject leaning back hard on the rope(s). The EMBC test method does not account for edge vectoring, further biasing the examination towards higher fall arrest velocities

- However, despite absence of high validity test data accurately replicating this event, we suspect there would be a difference. The difference could likely be moot as both SMSB and DCTTRS would produce MAF within acceptable limits per the BCDTM criteria, given the rough similarities to a BCDTM examination

<u>After the edge transition:</u>

MAF w/one rope failing
No differences between SMSB and DCTTRS. This is assuming that the SMSB system follows the same principles of DCTTRS insofar as incorporating descent control and self-actuation on both rope systems (i.e. post edge transition) and that those same applied principles produce similar results. The 2016 EMBC report states, “The typical peak forces of DMDB systems are about 50% higher than what DCTTRS peak forces are.” However, once again it is important to read the report carefully. The 50% higher MAF value is derived from top-rope, zero-fall-factor testing of DCTTRS vs. DMDB with a hand-tight belay rope. So the MAF difference is only applicable if your team maintains a hand-tight belay throughout the operation. Again, this is an outmoded technique and should only be considered for smaller amounts of RIS (i.e. edge transitions) or smaller loads (i.e. one-person load in a pickoff).

In the end, MAF values for both SMSB and DCTTRS are well within acceptable levels based on rope rescue standards and governmental regulatory agencies. Differences may indeed exist in specific circumstances, but those margins would not adversely affect the human beings associated with the fall arrest event due to deceleration values. In principle, this is no different than the previous stop distance risk discussion. As a community, we should adhere to acceptable performance limits. The objective is to prevent performance decline from exceeding specified limits. To go beyond that for a marginal gain, one has to critically consider the associated costs.

Risk – Usability and User Error

The risks associated with system Usability as well as human error represent some of the most important qualities for rescue teams to proactively manage. A variety of tools are at the disposal of the practitioner such as device familiarity, inspection criteria, system simplicity, checklists, and proper engineering to name a few. The safest systems tend to be those exhibiting a high degree of Usability.

As discussed earlier, DCTTRS tends to involve more complex interactions and therefore less linear interactions. Linear interactions are inherently more reliable. DCTTRS edge transitions also tend to include less reliable error detection, less streamlined error correction, and a steeper learning curve. We are not suggesting that people cannot be trained to safely conduct DCTTRS edge transitions. They will simply spend more time getting to a given level of proficiency to better read the various inputs as they relate to the observable outputs (i.e. the feedback loop). As a result, the team or practitioner needs to highly prioritize the marginal benefits of sharp edge performance, because it will cost them some valuable training time to gain the requisite proficiency.

The EMBC report states on page 15 in the section on *Controlling the Load*, "that the greatest gains to attaining good control of the load are in the process of training, and equally important - if not more so – a revision to current EMBC Command & Control processes." We agree that training and improved communications can make significant differences in rope rescue proficiency. The report continues by saying, "As such, good control of the load – particularly with edge transitions – can be accomplished with either TTRS or DMDB techniques, and load control cannot therefore be used as an argument in favour of DMDB systems."

This is a logical fallacy. In our opinion, the statement implies the choice is equivalent to a coin toss (i.e. they both require training, therefore they are equal). However, if a team is already trained in SMSB edge transitions, it costs very little to maintain the status quo. It is adoption of the new technique whereby the team incurs significant cost. The cost typically occurs at the expense of something else. That is not free, nor is it equal. The exchange of a finite resource (training time) for a perceived gain does not address the differences in investment required to reach a similar level of proficiency. One is not as easy as the other; therefore a greater investment will be required.

Edge transitions require smooth, controlled, and predictable movement of the live load.

- Timing and coordination are paramount during high risk, difficult edge transitions
- Each station must be able to anticipate what is coming next, efficiently process the inputs (e.g. the feel of the running end of the rope, hearing commands, observing what is transpiring) and deliver a predictable response
- The literature suggests teams should seek a very linear relationship between what the operator feels, hears, or sees (input side) versus what they are able to do to achieve controlled movement of the load (output side)

A SMSB lowering-based edge transition provides for 100% load control by the Mainline operator. A change in the in-feed angle to the device and rope begins to flow. As an operator one can see and feel how subtle inputs affect the output. The practitioner can be very precise in their ability to control the movement of that live load through varying terrain and changing tension. The feedback loop provides the operator a clear and familiar picture. The literature associated with human-machine system interactions supports this notion.

Varying terrain and changing tension during abrupt edge transitions makes DCTTRS a potentially challenging system to manage well. As the attendant crests over the edge from flat ground to steep ground, their mass times gravity increases rope tension. The two tensioned lines are being managed in a dynamic relationship toggling between a 60/40 to 50/50 to 30/70 split in load ownership. Neither system truly owns the load; therefore, the complex and non-linear qualities of the technique tend to provide an unclear feedback loop.

Despite the challenges, DCTTRS edge transitions are certainly achievable. Teams are operating them every day. They just take practice. We have observed, however, that there are conditions that contribute to smoother DCTTRS edge transitions:

- Both lines suspended through a high directional pulley – either a tree, I-beam, or Lazy Leg A-frame device
    - You essentially are starting the operation on top-rope and the changes in rope tension (i.e. from flat ground to steep ground) are reduced and therefore more manageable in DCTTRS
- Co-located device focal points
    - Operators working side-by-side can better coordinate lowering pace to stay in sync
- A rolling, gradual edge transition, like on a lot of embankment rescue scenarios
    - Again, the change in rope tension is more gradual than in an abrupt transition
    - And the consequences of an inconsistent in-feed of rope are reduced because the attendant(s) does not require as precise of rope tension to anticipate their next footfall
- A true 2kN load (i.e. 2-person)
    - The load input imparts enough force to cause rope to travel through two devices - each of which are constructed with adequate friction for 2+kN

But this list of variables is not always in place. For example, what if:

- There is no artificial high point?
- The team cannot co-locate the focal points due to inadequacy of independent anchor systems at that common location?
- The terrain includes a very abrupt 90-degree edge transition?
- The operation is a 1-person load for a pickoff?

What then? Use the same technique? Does the team have an alternative solution that is well practiced?

Since the original 2014 sharp edge presentation at ITRS and the subsequent recommendations from the 2016 EMBC report, we have experienced more and more clients trying DCTTRS at the edge. When the conditions are favorable, success can be recognized. When certain conditions are unfavorable, the results tend to be mixed. The most common scenario we observe occurs when the operators have too much friction for the load in question (i.e. 1-person load; likely, the most common on a real rescue operation involving a lower). Seemingly insignificant, this often results in safety issues due to highly variable practitioner responses as a result of the more complex feedback loop that is created. The operational techniques in this scenario seem to be universal: the operators attempt to push rope into their devices. Yikes! We take this very seriously at Rigging for Rescue trainings. It is not OK to push rope into a DCD – ever. There must be enough standing part tension to cause rope to flow through the DCD.

The math breaks down as follows:

- Each device is built for a rescue sized load (approximately 2+kN tension) – this is a key rigging principle of DCTTRS
- Both ropes are being tensioned simultaneously at the start of the operation
- The live load is commonly a 1-person load or approximately 1kN
- The devices each built for 2+kN are then splitting a 1kN load in half
- Therefore, the system is overbuilt with approximately 4-5 times the friction needed to effectively control the lower
- Inevitably, the operators push rope into the variable friction DCD or they come off of the extra friction post on the MPD losing the recommended S-bend orientation. This should not be considered sound practice.

There are numerous other scenarios that commonly occur in rope rescue that include existing standard procedures in a SMSB system. But equivalent operational solutions are more elusive when following strict adherence to DCTTRS. There appears to be a significant gap in operational recommendations from the EMBC report when faced with typical, but unfavorable DCTTRS edge transition conditions. Some examples include:

1. **An operation requiring a 90-degree change of direction (COD) on the descent control system.** Such a rigging configuration allows the operation to be run parallel to the road or cliff edge. This is a typical set-up for motor vehicle accidents down an embankment, for example. This commonly utilized approach provides valuable workspace for both the lowering and raising phases of the operation.

    i. Will this require independent and redundant COD systems in order to co-locate the focal points for DCTTRS? This would entail rigging four anchors in total in order to maintain full system redundancy (i.e. two for the operational ropes and two independent CODs)

ii. Or are both lines run through one COD, therefore losing some valuable *Independence* between systems? A potentially risky choice with catastrophic consequences on acute angle CODs.

2. **A scenario that includes a scarcity of anchoring options at a given focal point location (i.e. not able to rig two 20kN independent/redundant systems side-by-side).**

   i. How well will operators be able to synchronize lowering speed when focal points are not co-located and include dissimilar RIS?

   ii. Will there be a difference in sharp edge performance now given different amounts of RIS? Is that a safety issue?

3. **What about constructing an artificial high directional (AHD) device such as an Arizona Vortex?**

   i. Consideration must be given to the availability and complexity of rigging side anchors for guying it securely in place. Toppling the AHD is a legitimate risk.

   ii. Should teams be concerned about both ropes being rigged high given the toppling risk?

   iii. But separate heights will result in different amounts of RIS. Does that negate the marginal benefit of sharp edge performance?

Because DCTTRS edge transitions are a relatively new technique in North American rescue circles, answers to these various questions are likely still being considered. Teams using DCTTRS edge transitions will simply have to learn through experience and assess for themselves how to manage the risks presented.

DCTTRS edge transitions - per the EMBC 2016 report and recommendations - encourage a very rigid approach to decision making. Judgment is presumably suppressed in the spirit of simplification and standardization. SOPs and SOGs exist for justifiable reasons. But a strict DCTTRS edge transition approach closes more doors than it opens.

A tremendous amount of emphasis is placed on an incredibly low frequency event, supported by limited and flawed test methods, to advocate for an approach that requires numerous training hours to achieve proficiency.

Conclusion and Recommendations

It is not without a healthy dose of irony that we recognize it has required around 50 pages of content and untold hours of writing and research, to address a topic with a sub-title of *Much Ado About 4 Meters.* Clearly, there must be much ado about 4 meters. By now the reader may have gathered that we are skeptical of rigid rigging philosophies such as DCTTRS as recommended in the 2016 EMBC Summary Report. Difficult edge transitions present teams with very dynamic situations to be actively managed. We subscribe to a different default position. One based upon actively ascribing value to various system qualities as viewed through the lens of Mission Profile.

For several years, we have consulted numerous teams and practitioners regarding the salient points between DCTTRS and SMSB edge transitions. The primary points that we tend to gravitate towards are:

- The debate is largely about 4 meters of linear distance. That distance being from the completion of the *edge approach phase* to the completion of the *edge transition phase* (i.e. ropes are settled on to the edge padding and the attendant is below the lip)
- System qualities of significant importance to be actively managed include:
    - *Not defeating* the self-actuation mode on our backup system until we have achieved a proof test on our primary system, particularly with high reliability devices such as the MPD & 540 Rescue Belay
    - Providing a smooth and predictable pace of descent control to the attendant being lowered
    - Usability - Systems that are simple, reliable, and minimize human error while maintaining maximum flexibility for the dynamic environment in which they are utilized (i.e. favoring linear systems and avoiding techniques that handicap operations)
- Question the extremely strong emphasis of an environmental factor (i.e. sharp edge) as a catalyst for system change based on:
    - Test methodology as it pertains to replicating a credible event
        - The BCDTM (or similar) was never intended for evaluation of Two Tensioned Rope Systems. Also, the use of a 3-rope

test method does not replicate edge transition rope tension for either DCTTRS or SMSB

- The acknowledged marginal differences in sharp edge performance between the two systems (based on test data)
- Absence of citations involving accidents and incidents highlighting sharp edge rope trauma as the difference-maker in system reliability
- The allocation of training time required for achieving a given level of proficiency in DCTTRS edge transitions
- The absence of operational guidelines for troubleshooting scenarios that do not cleanly fit into the rigid DCTTRS recommendations

A key benefit of the SMSB system for rope management is that it is linear. Linear systems are inherently more reliable than systems with complex interactions. The SMSB system is going to morph into a DCTTRS once consistent and predictable rope tension is achieved (e.g. after the edge transition). Certain situations will justify an earlier transition to DCTTRS. Using the SMSB algorithm offered below, the transition is simply a step ahead in the normal operating progression. This maintains the linear nature of interactions in the system. Additionally, if the practitioner fails to recognize the situational difference justifying an early transition to DCTTRS, the team will simply operate well within acceptable performance guidelines while maintaining SMSB.

DCTTRS - Lowering edge transition

It has been observed that strict adherence to DCTTRS with one-person loads (i.e. lowering the Attendant to the Subject for a pick-off) during a lowering edge transition can introduce additional difficulties in achieving a desirable outcome. The cited benefits of DCTTRS per the EMBC report yield even less influence in legitimately managing risk by virtue of the lighter load. For example, risks associated with maximum arrest force and stop distance due to rope stretch are further diminished beyond what are *already acceptable* performance limits given two-person loads. Additionally, rope trauma due to sharp edges becomes less of a potential risk. Unfortunately, the costs associated with adoption of DCTTRS edge transitions are still present and more exacerbated. For example, it is very difficult to avoid *pushing rope* into the two DCDs when attempting to manage 0.5kN of applied tension on devices rigged to each manage tension in excess of 2kN. That is a 4-fold gap in performance capability. Anecdotally, it is quite common to see some combination of the following occur in such scenarios:

- The Attendant grabbing the ropes and dynamically yanking against the tension (i.e. towards the edge) in order to get rope to flow through the DCDs

- The device Operators *pushing rope* into their DCDs to reduce friction

- Operators of MPDs coming off of the additional friction post and negatively affecting the S-Bend configuration of the rope through the MPD

- Operators of ATC or Scarab systems utilizing Prusik backups *rigged anchor-side of the DCD*, changing their gripping location to *load-side* of the Prusik in order to reduce the in-feed angle. Now the hands-free-stop device (i.e. Prusik) is compromised given the location of the Operator's closed hand.

All of these techniques are *reactions* to having excessive friction relative to the live load input tension. These reactions can create frustration, confusion, and ultimately safety issues during the critical edge transition phase of the operation. We have observed *every single one* of the above reactions on multiple occasions as teams experiment with DCTTRS edge transitions – particularly with one-person loads, which are arguably more common on lowers than two-person edge transitions.

The presence of two or more of the following conditions appear to positively contribute to achieving smoother, more consistent, & predictable movement of the live load while utilizing a DCTTRS edge transition for a lowering operation. Teams with an exceptional amount of training and/or operational time could certainly improve outcomes with fewer favorable conditions present:

1. Both ropes equally elevated through a High Directional system or under tension from above (e.g. operating from a floor or platform above the live load edge transition)
2. Ambulatory Patient and Attendant able to walk back through a gentle edge transition
3. System Focal Points in close proximity to one another (i.e. co-located)

If two or more of the conditions are NOT present, Teams should recognize & accept certain realities including, but not limited to:

• Absence of system self-actuation due to overriding the hands-free-stop mechanism of the device(s)

• Potentially increased stopping distance due to human reaction time/action (<u>Note:</u> even with Rope Tailers)

• Increased probability of an Attendant stumble at the edge transition due to inconsistent in-feed from the operational ropes

• Increased complexity with rigging an artificial high directional (AHD) device due to equally elevating both ropes. The potential for toppling the AHD represents an unacceptable risk in our opinion, and mitigation measures involve the added task of securing the device with laterally anchored guy lines.

Recognizing unfavorable conditions, Teams operating with strict DCTTRS adherence should consider deviating from their default position to something more like the legacy system of SMSB. However, it is unlikely that Teams focusing on DCTTRS will also practice the device manipulations and operational techniques associated with SMSB methods.

The complexities associated with deviating to a system of lesser familiarity/proficiency would arguably increase Rescuer exposure to risk due to:

- Device mastery deficiencies

- Command and control differences

There are numerous scenarios in which DCTTRS lowering-based edge transitions are not well suited. How will Teams address system deviation methods if the conditions present are not optimized for operating DCTTRS? With the emphasis on *simplicity* associated with DCTTRS, will practitioners be proficient in recognizing situational differences and required mitigation measures? When unfavorable DCTTRS conditions are present, what are the costs for failing to recognize the situational complexities and deviating to an alternative method?

SMSB - Lowering edge transition:

- Teams can approach all high angle, lowering operation, edge transitions without caveat and expect acceptable MAF, stopping distance (due to system elongation & human reaction time/action), as well as self-actuation to the greatest extent possible. This assertion is supported by > 35 years of testing, critical system analysis, and extensive review of literature addressing Bimanual Coordination, Dual-Task Interference, Attention Prioritization, Open / Closed Human-Machine Systems, and Linear vs. Complex Component Interaction.

- If the unique situation at hand suggests the consequence of increased stopping distance due to human reaction is acceptable **AND**:

    - There is a high directional through which both ropes can be routed (appropriate consideration must be given to the choice of rigging both high or Main high and Belay lower, at live load tie-in height), **OR**,

    - The rope system is operated from above the live load starting location (i.e. no edge transition in the BCDTM sense) **OR**,

    - An ambulatory Attendant and/or Patient will transition a rounded edge with excellent footing,

THEN the Team could consider progressing ahead in the SMSB system algorithm to the DCTTRS phase of lowering. It is important to note, if the Team chooses not to make the early transition to DCTTRS, *no additional risk* is incurred above what the Team (and the greater rope rescue community) has already deemed acceptable by existing standards.

The transition to DCTTRS is already a normal and well-practiced phase of the lowering operation. Post edge transition, when the Team deems the risk of increased stopping distance due to rope stretch to be *greater* than the risk of increased stopping distance due to human reaction, friction will be added to the Belay. Now a hands-free-stop combined with DCD will be present on both Main/Belay. The system is now being operated as a DCTTRS.

It should also be noted, if the situation presents a sharpened steel edge over which the live load must travel, extreme caution should be exercised in an effort to protect the operational ropes. Reasonable mitigation efforts could include:

• Generously and liberally padding the edge with robust material (e.g. 3+ layers of canvas or equivalent)

• Utilizing a vertically-oriented litter allowing the Team to slide through the edge transition thereby minimizing the potential for a sudden and uncontrolled drop of the ropes onto unprotected edges (i.e. approaching a zero fall factor)

• Prioritizing the value of excellent rope alignment to the edge transition during all training and operational sessions. This will significantly reduce the probability of a pendulum of the load during the edge transition phase of the lowering operation

• or, **change the entire rigging and operational philosophy that has served the rope rescue community well for the past several decades to address a problem that has a low frequency of occurrence, employing a technique that results in a number of usability and safety concerns, and supported by testing evidence that does not replicate a credible event**

SMSB
(Lowering Edge Transition)

Standardized scene size-up
& system configuration

Edge Approach

Belay - fully functioning, optimized for self-actuation

Main – little to no friction, optimized for freedom of movement of the load to the edge transition point

IF
Two or more
are present:

- Elevated Ropes
- Ambulatory Patient & Attendant
- Rounded edge transition

THEN

Edge Transition

Belay - hand tight, optimized for self-actuation
(Note: MAF & stop distance due to elongation *well within* commonly accepted performance limits)

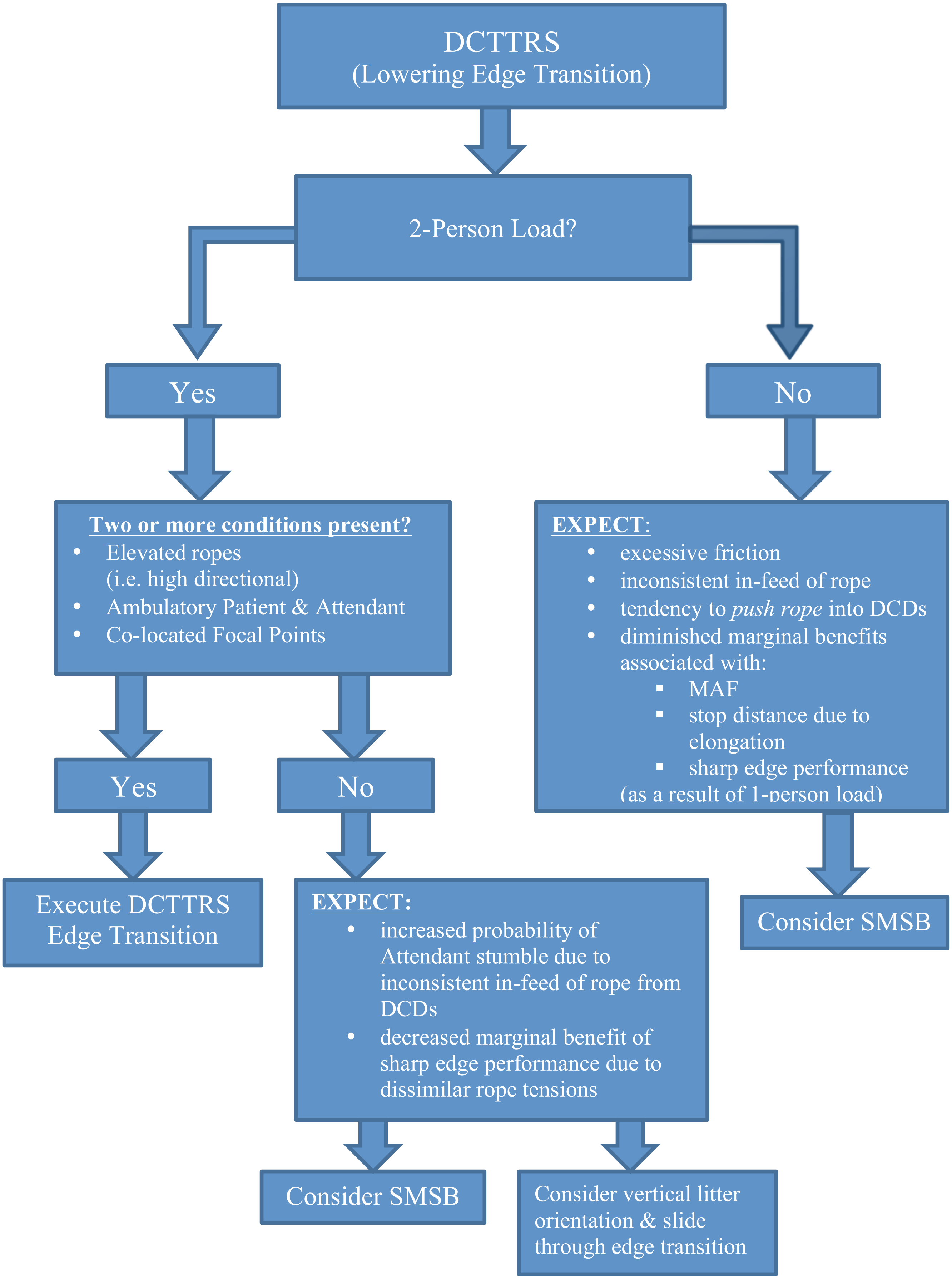
Main – full friction, reduced gradually until load begins to move; hands-free-stop placed standing side of DCD to optimize Usability

Post Edge Transition*

Belay - DCD with hands-free-stop on standing side, optimized for Usability

Main – DCD with hands-free-stop on standing side, optimized for Usability

*MPD and 540° users will operate as TTRS


DCTTRS
(Lowering Edge Transition)
2-Person Load?
Yes
No
Two or more conditions present?
• Elevated ropes (i.e. high directional)
• Ambulatory Patient & Attendant
• Co-located Focal Points
Yes
No
Execute DCTTRS Edge Transition
EXPECT:
• increased probability of Attendant stumble due to inconsistent in-feed of rope from DCDs
• decreased marginal benefit of sharp edge performance due to dissimilar rope tensions
Consider SMSB
Consider vertical litter orientation & slide through edge transition
EXPECT:
• excessive friction
• inconsistent in-feed of rope
• tendency to push rope into DCDs
• diminished marginal benefits associated with:
▪ MAF
▪ stop distance due to elongation
▪ sharp edge performance
(as a result of 1-person load)
Consider SMSB

If you currently operate a sound SMSB edge transition system, we would encourage you to maintain the status quo. However, if you also maintain a hand-tight belay throughout your entire operation, we would recommend adopting DCTTRS rope management techniques once consistent rope tension is achieved.

At ITRS 2017, Tom Evans offered robust meta-analysis of historic friction hitch testing. The term "convenience sampling" was used once again (also Evans, Truebe ITRS 2016) to suggest "researchers use a convenient number of samples based on ease and availability rather than on how many samples would be needed to address a particular research question." The sharp edge testing and other Series from the 2016 EMBC Summary Report appear to fall into this category of examinations.

Perhaps there is more to it than just a sharp edge? In Russell McCullar's 2015 ITRS paper, he refers to difficulties associated with operating an un-tensioned MPD or Petzl I'D. It is well understood among trainers that the MPD and similar devices (e.g. 540) can present challenges during development of psychomotor skills required to operate a given device in a hand-tight manner. There is little doubt it produced a level of relief amongst some when a respected researcher suggested we should abandon hand-tight belaying in favor of two tensioned ropes throughout the entire operation. A DCTTRS edge transition does make the inadvertent lockup of the MPD go away, but it overrides the fail-safe mechanism of the device. We believe it to be one of the most beneficial design features of the device ensuring against catastrophic system failure.

One key benefit to the ongoing debate is teams that previously operated hand-tight belays for too many meters of descent are gaining awareness of the risk associated with this practice. In 2007, Mike Gibbs presented to the ITRS community about tensioning the Belay with a DCD, adding a hands-free-stop component to the Main, and ensuring these changes don't negatively impact system performance. The SMSB system is now morphed into a DCTTRS, at an operational time such that the benefits of DCTTRS outweigh the risks. To this day, we believe this progression constitutes current best practices for rope rescue operations. It is all about managing the right risk at the right time.

Incidents and accidents involving catastrophic engineering failures do not appear to be particularly frequent in rope rescue. The culprit more often involves human interface. Improper inspections, miscommunication, flawed rope alignment, and other human-driven errors tend to populate the list of contributing factors in accident and near miss reports. To effectively mitigate those risks, Rigging for Rescue's rope rescue value system ascribes a high degree of importance to **reliable fall arrest** and system **usability.**

In closing, we sincerely hope that you have discovered some useful information in this comparative analysis of SMSB and DCTTRS. We strive every day to be well-informed educators in rope rescue. It is our craft and we are privileged and fortunate to be able to work with such high quality teams and individuals. It is important to be rigorous in questioning one's own practices, seeking out quality information guiding us in the ongoing evolution of better techniques. As the late, great John Evans was fond of saying, "Always maintain a rigid state of flexibility."

Thought for the Day

Science is facts;
just as houses
are made of stone,
so is science
made of facts;
but a pile of stones
is not a house,
and a collection of facts
is not necessarily
science.

Jules Henri Poincaré (1854-1912)
French mathematician

Table 1

Author(s)	Title	Published	Year
Johnston, Paris, Smith	Toward Assessing the Impact of TADMUS Decision Support System and Training on Team Decision Making	Command & Control Research & Technology Symposium	1999
Albert, Weigelt, Hazeltine, Ivry	Target Selection During Bimanual Reaching to Direct Cues Is Unaffected by the Perceptual Similarity of the Targets	Journal of Experimental Psychology - Vol. 33 No. 5	2007
Chiou, Chang	Bimanual Coordination Learning with Different Augmented Feedback Modalities and Information Types	www.doi.org,10.1371/journal.pone.0149221	2016
Timber-Rosenau, Marios	Central attention is serial, but midlevel and peripheral attention are parallel - A hypothesis	The Psychonomic Society, Inc. - online publication	2016
Banister	Developing Objectives & Relating them to Assessment	The Center for Teaching & Learning	2002
Winfred, Winston, Edens, Bell	Effectiveness of Training in Organizations: A Meta-Analysis of Design and Evaluation Features	Journal of Applied Psychology - Vol. 88 No. 2	2003
Cacciabue	Guide to Applying Human Factors Methods	Springer	2004
Simons, Chabris	Gorillas in our midst: sustained inattentional blindness for dynamic events	Perception - Vol. 28	1999
Gorman, Cooke, Winner	Measuring team situation awareness in decentralized command & control environments	Ergonomics	
Hazeltine, Weinstein, Ivry	Parallel Response Selection after Callostomy	Journal of Cognitive Neuroscience Vol. 20 No. 3	
Hazeltine	Response - response compatibility during bimanual movements: Evidence for the conceptual coding of action	Psychonomic Bulletin & Review Vol. 12 No. 4	2005
Kennerley, Diedichsen, Hazeltine, Semjen, Ivry	Callostomy patients exhibit temporal uncoupling during continuous bimanual movements	Nature Publishing Group - www.neurosci.nature.com	2002
Klein	Naturalistic Decision Making	Human Factors - Vol. 50 No. 3	2008
Cooke, Salas, Cannon-Bowers, Stout	Measuring Team Knowledge	Human Factors - Vol. 42	2000
Cooke, Kiekel, Helm	Measuring Team Knowledge During Skill Acquisition of a Complex Task	AFOSR Grant No. F49620-1-0287	
Gorman, Cooke, Winner	Measuring team situation awareness in decentralised command and control environments	Ergonomics	
Schvaneveldt, Durso, Goldsmith, Breen, Cooke, Tucker, De Maio	Measuring the structure of expertise	International Journal of Man-Machine Studies - Vol. 23	1985
Mortimer, Mortimer	Biological Limitations on Human Thinking Processes in Search and Rescue	ITRS Proceedings	2016
Diedrichsen, Hazeltine, Kennerley, Ivry	Moving To Directly Cued Locations Abolishes Spatial Interference During Bimanual Actions	Psychology Science - Vol. 12 No. 6	2001
Pashler, Johnston	Chapter Four - Attentional Limitations in Dual-task Performance	Dual-task Performance -	
Wickens	Processing Resources in Attention, Dual Task Performance, and Workload Assessment	Office of Naval Research Engineering Psychology Program - Contract No. N-000-14-79-C-0658	1981
Cratty, Noble	Psychomotor Learning	Encyclopedia Britannica - britannica.com	
Unknown	Psychomotor Skills	Unknown	
Ruthruff, Van Selst, Johnston, Remington	How doers practice reduce dual-task interference: Integration, automatization, or just stage-shortening?	Springer-Verlag	2004
Austin	Task analysis: Teaching multistep skills made easy	www.ttacnews.vcu.edu/	2012
Edwards	Teaching Psychomotor Skills in the Fire Service		
Sauer, Burkolter, Kluge,Ritzman, Schuler	The effects of heuristic rule training on operator performance in a simulated process control environment	Ergonomics - Vol. 51 No. 7	2008
Schneider, Detweiler	The role of practice in dual-task performance: toward a workload modelling in a connectionist/ control architecture	DARPA Contract Number N00014-86-K-0678	1987
Chijioke	Appraisal of theoretical models of psychomotor skills and applications to technical and vocational systems in Nigeria	Journal of Research and Development - Vol. 1 No. 6	2013
Fadde	Training complex psychomotor performance skills: A part-task approach (Handbook of training and improving workplace performance. Volume 1: Instructional design and training delivery)	Pfeiffer of Wiley & Sons	
Suksudaj	What factors influence learning of psychomotor skills by dental students	Submitted as a requirement for the degree of Doctor of Philosophy in Dentistry - University of Adelaide	2010
Perrow	Normal Accidents: Living with High Risk Technologies	Princeton University Press - ISBN 0-691-00412-9	1999
Reason	The Human Contribution - Unsafe Acts, Accidents, & Heroic Recoveries	Ashgate Publishing Company - ISBN 978-0-7546-7402-3 - www.ashgate.com	2008
Mauthner	Moving Beyond 10:1 SSSF: Introducing Force Limiting Systems and Managing the Right Risk at the Right Time	2014 ITRS Proceedings - Denver, CO	2014
Mauthner	Two-Tensioned Rope Rescue Systems: MPD Current Best Practices	Unpublished White Paper - Basecamp Innovations Ltd.	May, 2015
Mauthner	Dual Capability Two Tensioned Rope Systems (DC TTRS)	2016 ITRS Proceedings - Albuquerque, NM	2016
Mauthner	EMBC Rope Rescue NIF Equipment Testing Summary Report 2016	Contract No. CS 4912 - File No. 1070-20	2016
Genswein, Eide	The Efficiency of Companion Rescuers with Minimal Training	2008 ISSW Proceedings - Whistler, BC	2008
Rubin, Chisnell	Handbook of Usability Testing, Second Edition	Wiley Publishing	2008
Nielsen	Usability Engineering	Cambridge, MA Academic Press	1993
Nielsen	10 Usability Heuristics for User Interface Design	www.nngroup.com/articles/ten-usability-heuristics/	1995
Roscoe, Craig, Douglas	End-User Considerations in Educational Technology Design	www.igi-global.com	2018
Evans, Truebe	A Review of Knot Strength Testing	2016 ITRS Proceedings - Albuquerque, NM	2016
Evans	A Review of Friction Hitch Testing	2017 ITRS Proceedings - Denver, CO	2017

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