Mirrored Systems-

Reflections from the Edge

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Transporting a patient utilizing a rope rescue system is a balancing act that requires careful consideration of many competing variables. Some of these variables are independent of each other, such as the selection of a particular device (i.e. generic Device A versus Device B; they both perform similar functions). The choice between Device A and Device B creates negligible differences, whereas other choices introduce dependence on different elements of the overall system, creating a more tightly coupled, complex system.[1] For example, the choice of a specific technique would fall under this latter category. The technique likely requires specific equipment, personnel, proficiency, etc. that makes it dependent on certain elements being either present or absent in order to make it a safe and effective choice.

Rope rescue is nothing more than an access and transportation tool. Regardless of the system, technique, or combination of devices in play, the objective is the same for all teams – get access to the patient and move them out of harm's way. There are lighter systems and heavier systems, simpler and more complex systems, ones that incorporate specific devices and others that involve improvisation. There is no right answer as to which system is the "best" because the nature of the choices involved is too dependent on specific elements of a team's *mission profile.* However, the adoption of a new system involving specific technique modifications should be carefully and rigorously examined because of the tightly coupled, complex nature of rope rescue systems. The high-consequence elements make it important to assess the system qualities and performance in order to ensure that we are not operating with false assumptions in place.

It is in this spirit of discovery that we sought to examine Mirrored Systems under certain operational conditions using drop test methods. A Mirrored System is a rope rescue system in which each rope serves simultaneously as a lowering/raising line as well as a competent back-up to the other line.[2] While the generic definition of a

[1] Perrow, Charles. "Living with High-Risk Technologies. "*Normal Accidents*. New York: Basic Books, 1984. Print

[2] Mauthner, Kirk. "Moving Beyond 10:1 SSSF." *Introduction force Limiting Systems and Managing the Right Risk at the Right Time* (2014):1 Print.

Mirrored System could apply to a number of different device combinations, it seems in practice that the term is reserved for a two-rope system incorporating the use of MPDs on each of the operational ropes. Mirrored Systems is a specific subset of Two Tensioned Rope Lowers (TTRL).[3] Other TTRL systems such as two generic descent control devices each incorporating a hands-free backup device (e.g. Prusik) could potentially qualify as Mirrored Systems by the above definition, but in practice they seem to be more commonly referred to as "shared tension" or "twin tension" methods. The agreed-upon terminology on this topic appears to be in flux within the rescue community. For the purpose of this study, we limited our drop testing assessment of Mirrored Systems to a two MPD device system.

The MPD and Mirrored Systems

The MPD has been on the market for several years now. The device has a number of qualities that can be assessed objectively and others that require a more subjective approach.

MPD Qualities

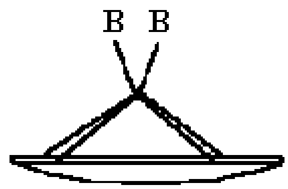
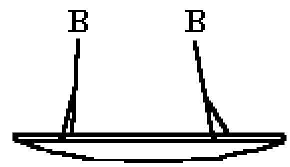
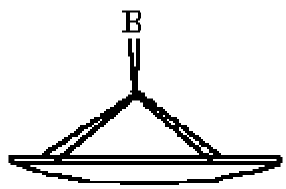
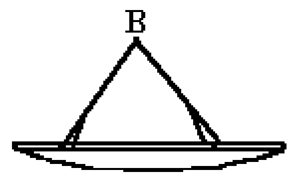
Description	Assessment	Other comments
Rated MBS	✓	44 kN; robust construction
3rd party certifications	✓	UL, NFPA 1983
Grip required	✓	Minimal tail tension
Weight	**?**	Who's carrying?
Cost	**?**	Who's paying?
Ease of inspection	✓	Icons well displayed
Ease of use/training	✓	Intuitive mechanics
Other human factors	**?**	Ease of misuse?
Reliable fall arrest	**?**	In which mode of operation?

It is the last two qualities on the list ("other human factors" and "reliable fall arrest") that we sought to gain greater insight into during the drop test examination.

TTRL systems are not new to rope rescue. They have been utilized for a very long time, and they come in many different forms. Some TTRL methods utilize a two-bridle system. Others incorporate the use of only one descent control device (DCD) that accommodates both ropes simultaneously.

[3] Ibid. 2

Two-Tensioned Rope Lower Methods

	1 Point of Attachment (Typically 1 Attendant)	**2 Points of Attachment** (Typically 2 Attendants)
TWO BRAKES ON TOP	 **TWO ROPE**	 **DUAL ROPE**
ONE BRAKE ON TOP	 **TWIN ROPE**	 **DOUBLE ROPE**

What is common with all TTRL methods is that both of the operational ropes are typically under tension throughout the entire operation. Operationally, this differs from the Single Main, Separate Belay (SMSB) style of rope management. In a SMSB system, one rope is under tension and the other rope acts as a competent backup to the tensioned line. One of the long-recognized pitfalls of a SMSB system is that the backup line loses a lot of its "competence" with increased rope-in-service, due to excessive rope elongation, should the hand-tight backup rope have to come into service (i.e. during a Mainline failure, for example). However, this system quality can be mitigated by incorporating a DCD on the backup line at a point in the operation where increased rope-in-service presents risk to the operation. In 2007, Rigging for Rescue conducted a study addressing this specific system modification. The findings were presented at ITRS 2007 as Rescue Belays Long Lowers.

In Rescue Belays Long Lowers, two questions were posed in advance of conducting the drop tests:

1. How much will added friction on the belay affect overall stopping distance?

And more importantly…

2. Does the added friction compromise the reliability of the rescue belay device?

It is this second question that is *critical* to any system modification, whether that change involves a specific device or a given mode of operation. In an attempt to solve one perceived problem, you may unintentionally introduce new risks to the operation.

The MPD has essentially two different operational modes for a lowering evolution – one is as a DCD requiring the operator to manipulate the release mechanism, and the other is as a hand-tight backup device requiring a semi-slack line through the device mechanism (in order to prevent inadvertent lock-up). If you were to operate a Mirrored System with each MPD being managed in its two respective lowering modes, then you would essentially be operating a SMSB system. It is only when both MPDs are in DCD mode that the system morphs into a TTRL. Because a Mirrored System with MPDs is generally operated as a TTRL system and because it typically does not incorporate other devices to safeguard the MPD (i.e. Prusiks; another DCD), an additional systems analysis question needs to be answered:

Can a stand-alone DCD simultaneously provide reliable fall arrest?

So what constitutes reliability? Specific to fall arrest, does it mean that the device/system is automatic? Self-actuating? A search of the term "reliability" reveals a whole host of definitions depending on the specific context. For example, something is said to have a high reliability if it produces similar results under consistent conditions.[4] Reliability is theoretically defined as the probability of success (Reliability = 1-probability of failure).[5] Perhaps a more intuitive approach to defining reliability as it applies to ropework fall arrest would be:
you can depend on it.

Drop Testing

The genesis of this test series on MPDs was born out of curiosity. We have been using the devices for a number of years now in our rope rescue training seminars at Rigging for Rescue. Many of the individual practitioners that we train are from organizations that have recently adopted both the MPD and Mirrored Systems. Naturally, we field a large variety of questions on both the device and the system. It became imperative that we increase our own understanding of the nuances of both the device and the system by conducting a drop test series. Coincidentally, a fire department client of ours was strongly considering adopting the MPD and they had already begun conducting some "quick look" tests. We decided to collaborate on the drop test series.

[4] Institute of Electrical and Electronics Engineers (1990) IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. New York, NY, 1990. ISBN 1-55937-079-3. Print

[5] "Reliability Engineering." Wikipedia, 2015. Web

The drop tests were conducted over two consecutive days in May, 2015 at a fire department training tower. The key parameters included:

- Human operators on the two MPD devices
  (trained fire department personnel)
- 200kg test mass (steel plates)
- zero freefall (snug toprope)
- both ropes were directed through an artificial high directional device in order to eliminate edge friction and prevent the test mass from scraping down the wall of the test tower
- ≈1375cm initial rope length, prior to lowering
- a coordinated shared-tension lowering of the test mass for a few meters, followed by the intentional failure of one of the two rope systems using a pre-rigged quick release mechanism
  (at the test mass connection point – out of view of the device operators)
- ≈1700cm rope-in-service at the time of the designed failure
- device operators were not informed as to which rope system would be "failed"

A total of 51 drop tests were conducted. The first 3 tests were not included in the data summary. The research team conducted those tests in order to work out the kinks in the test set-up. The following 48 tests included 48 fire department personnel, all with varying levels of training on the MPD device. Every drop test participant had some previous department training on the MPD. The 48 individuals were paired up, and each pair conducted two consecutive drop tests.

On the first day, 32 drop tests were conducted (tests #4-35). The device operators were instructed to initiate a coordinated shared-tension lower and to reach a representative operational lowering pace as soon as possible. They were also instructed to operate the MPDs as per their previous training and experience.

On the second day, 16 drop tests were conducted (tests #36-51). The operators were given different instructions than the Day 1 test participants. For their first test, they were instructed to open the release mechanism to its maximum open setting (rotate orange release handle "wide open") and to then manage the descent control through the use of some combination of:

- the friction post
- in-feed angle of the rope to the device
- their grip on the running end of the rope

For their second test, they were instructed to use "Teacup Technique" to manipulate the release handle. Teacup Technique involves opening the release mechanism 100% and then using only counter-rotational force with the thumb and index finger to prevent the release mechanism from actuating. When the MPD release handle is held in this position, it appears similar to how one would hold a cup of tea. The idea behind the technique is to not have as aggressive of a grip on the release handle, thereby increasing the likelihood that the device would actuate during fall arrest. The other descent control instructions remained the same.

Testing Highlights

The most compelling takeaway from the test series was that the MPD did not self-actuate when a line failure occurred. This was evident over the course of numerous drop tests. In order for fall arrest to occur, it required an action on behalf of the device operator as well as reaction time.

- Of the 48 tests, 17 had stop distances that were deemed to be "long" (≥170 cm). 170cm represented 10% of total rope-in-service. In 2007 Rescue Belays Long Lowers testing, it was observed that a typical pre-tensioned line would result in around 5% elongation during fall arrest. A result of 10% indicates something else is going on. In this case, it is the delay in device actuation.

- Three of the tests resulted in the test mass going to the ground; albeit two of those three were in a controlled manner.

- Running end control appears to be a critical component to a shorter stop. "Letting go" does not appear to be the best course of action for reliable fall arrest.

- Two tests resulted in the operator's hand being trapped in the space between the release mechanism and the aluminum side plates of the device. Both of these tests resulted in longer stop distances.

- Shorter stopping distances were observed with some combination of:
    - Use of the device friction post
    - Maintaining control of the running end of the rope
    - Use of "Teacup Technique"

Original research question:
Can a stand-alone DCD simultaneously provide reliable fall arrest?
No. Currently, I think it requires a combination of devices to achieve that objective.

Examples would include:

- A DCD in combination with Prusiks (e.g. Scarab and Tandem Prusiks)
- A 540 Rescue Belay with a DCD on the standing part of the rope
- Parallel Plaquettes
- An MPD with a DCD on the standing part of the rope

Moving forward with Mirrored Systems

So how do we proceed with this information? For starters, this is not meant to be an endorsement of the previously cited systems nor an indictment of the MPD. Rather it is a critical analysis as to what the device is and is not able to accomplish – DCD and auto-stop at the same time are incompatible qualities. Currently, no device provides for both simultaneously. We simply need to temper our expectations and manage the risks accordingly. With the MPD, both of those qualities are available, just not at the same time. The device has to be operated in a specific mode in order to function as a DCD or, alternatively, in a different mode as a reliable fall arrest device.

Was it a surprise that the MPD did not self-actuate in release mode? No, quite the opposite - it would have been puzzling had it self-actuated. The device has a handle that is stamped "Release." It comes as no surprise that rope travels through the device with that handle engaged, regardless of the circumstances. This phenomenon was well documented by Billy Masterson's presentation at ITRS in 2011. Many practitioners may have similar suspicions regarding the MPD in the release mode, but prefer Mirrored Systems and the MPDs, in particular, for their numerous other good qualities. And I would concur with such a sentiment, after the initial edge transition has been completed.

So why post edge transition? Prior to completing the edge transition, you are faced with a number of unknowns. And you are contending with a high-risk phase of the overall operation. Edge transitions can be difficult. Post edge transition, your primary (aka Mainline) system has been "proof tested" (if it is the only system bearing weight during the transition). Many of the operational risks and unknowns go away after the initial edge transition has been executed. The risk of the attendant slipping and tumbling at the edge has come and gone after the edge transition has been completed. Rigging and inspection errors would likely have been revealed upon the initial tensioning of the primary system. Post edge transition, the risk of a system failure is reduced.

There are a number of key elements that we are managing in an edge transition:

- Good communication
- Sound technique
- Proper rope alignment

All of these items are very important factors to executing an edge transition well.

However, there are two conditions that must be present and a number of other items that are tertiary to the discussion:

- We must have reliable fall arrest.
- And we need to give the attendant a smooth, predictable pace of descent control.

Do we have reliable fall arrest in place with two tensioned lines at the edge transition? The testing of Mirrored MPDs tells me that no, we do not have reliable fall arrest with both devices engaging the release handle. Fall arrest relies on an action and reaction time – aka the Reactionary Gap.[6]

Experts in defensive tactics talk a lot about the Reactionary Gap. Police are schooled in it. The Reactionary Gap is the time you have between identifying a threat and reacting to it.[7]

There is a 4-stage process to the Reactionary Gap:

- **Steady state**: Walking down the street, blissfully enjoying the stroll
- **Identifying**: Wait--that guy's holding something shiny in his hand...
- **Thinking**: He's coming at me. Quick, think! What should I do?
- **Reacting**: Stop walking forward. Move to his non-knife side. Prepare for his attack. Respond with force.[8]

An example from a ropework scenario might unfold as follows:

- **Steady state**: Lowering a live load with a DCD, watching the tracer patterns on the rope flow through the device.
- **Identifying**: Wait - something has changed – the tracers are accelerating.
- **Thinking**: This is abnormal. Quick, think! What should I do?
- **Reacting**: Increase your grip on the running end of the rope. Match your other hand on to the rope.

This sequence of events takes time. And perhaps even more importantly, the exact reaction is uncertain. Obviously, training is very important to increasing the likelihood of a favorable reaction. But the drop tests we conducted on the MPD and Mirrored Systems indicated that the reactions are highly variable. This should not come as a surprise, as human beings are highly variable and often unpredictable in their actions.

What about the second critical item to a successful edge transition? Do we provide the attendant a smooth ride and a predictable pace of descent control with two tensioned lines being operated by two operators managing separate devices? Anecdotally, I have yet to see it be done very well. And I have seen it botched numerous times in training scenarios. The ropes are rarely splitting the load in a 50/50 manner, and there is some inevitable passing of the tension back and forth between the two devices. This causes a "choppy" feed for the attendant and makes it challenging for them to anticipate their next step. Add to the mix a loaded litter -

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[6] Hom, James. "Distance Learning: The Concept of *Maai*." *Martialarts.jameshom.com*.2010.Web.2015

[7] Ibid. 6

[8] Ibid. 6 & 7

and the myriad of challenges that this presents under the best of circumstances – and you are set up for a poor edge transition.

There seems to be two conditions that can ameliorate some of the choppiness of a TTRL method at the initial edge transition:

1. If the ropes are directed up high through some sort of artificial high directional. This gives the attendant a nice high top-rope at the start of the operation and they can better tolerate some oscillation in rope tensions.
2. If the two device operators are proximal to each other and can watch the pace of the tracer patterns on the rope pass through the other operator's device. This provides the operators an opportunity to synchronize descent pace.

But are those conditions always present for your edge transitions? And if not, how many edge transition techniques do you want to be well trained in? What benefits are you getting out of your TTRL edge transition method? Are those benefits worth the tradeoff for a choppy feed or possibly compromising your fall arrest reliability?

Sharp edge considerations

So is there a compelling reason to consider transitioning technical edges in a rope rescue scenario using TTRL? At ITRS 2014 in Golden, Colorado, Kirk Mauthner presented "Moving Beyond 10:1 SSSF", and in that talk he shared drop testing videos that compared sharp edge performance of a SMSB system versus a TTRL system. The test results seemed to indicate that there was a performance benefit to having two ropes splitting the tension of the falling load in a sharp edge scenario as opposed to the traditional dedicated Mainline and hand-tight Belay line (i.e. TTRL outperforming SMSB).

We decided to do our own short drop test series on this same topic to see if we could either validate or contra-indicate Kirk's results. Our intent was not to duplicate Kirk's test set-up, but rather to add to the pool of collective data by modifying the parameters. Key differences included:

- a 1m drop on 3m of rope with a 200 kg mass (i.e. BCCTR belay test)
- a sharp rock edge (as opposed to a steel edge)
- a pre-tensioned Main for SMSB and two pre-tensioned lines for TTRL tests (as opposed to slack lines)

It was very much a "quick look" test series much like Kirk's own "quick look" from 2014. We conducted seven drop tests. Our limited pool of data indicated little performance difference between SMSB and TTRL over a sharp rock edge. When the edge was unprotected (i.e. no padding in place) both the SMSB and TTRL systems had catastrophic failures of both ropes. When the edge was appropriately padded (canvas and fire hose), both the SMSB and TTRL systems showed little to no performance difference, and the ropes appeared to be unharmed.

Sharp edge takeaways and considerations:

- If it is sharp, pad it – there seems to be little performance difference with proper padding in place.
- If it is sharp and you miss the padding, you might be in trouble regardless of your technique.
- A performance difference may exist, but it involves margins; requiring a specific edge quality, padding quality, and velocity combination to identify those margins.
- In a TTRL edge transition, it is false to assume that the rope tensions will be equal throughout the entire transition. With a hypothetical sharp edge performance difference, you may not benefit from it based on the varying amounts of rope tension between the lines in use.

More importantly, there are other ways to manage a difficult, sharp edge aside from a given rope tension technique. If it is sharp and difficult (i.e. no artificial high directional), use vertical litter orientation and shuffle through the transition. Don't risk the tumble with horizontal orientation. Keep the fall factor low and the patient package close to the terrain. Vertical litter orientation for high angle rescue operations seems to be highly underutilized by rescue teams and it offers numerous benefits:

- An easier and less physical edge transition.
- A lower-risk edge transition by keeping the lines and the litter close to the ground reducing the severity of a slip or tumble.
- The patient does not experience the tilting of the litter at the edge like they do in horizontal configuration (spilling to the inside rail).
- The patient is less exposed to overhead hazard (e.g. rock fall) after the edge transition versus a traditional horizontal orientation.

There are certainly patient injuries/conditions that do not lend themselves to a vertical litter orientation – a broken pelvis, for example – but barring those scenarios, the vertical litter is a viable option that offers excellent patient care for difficult terrain.

My perspective of this information

At the end of the day, it all boils down to risk management and decision-making. When I consider all of the factors in play at the edge, I distill it by order of importance:

1. Reliable fall arrest. Your device/system must catch the falling load. Quickly.
2. A smooth transition for the attendant, thereby reducing the risk of a slip or tumble at the edge (i.e. consistent and predictable pace of descent control).
3. Everything else, in whatever order you wish to assign, based on your own assessment of the risks and cost/benefit relationships.

Currently, I find myself skeptical of TTRL edge transitions. Anecdotally, they seem to present challenges for the device operators to synchronize lowering pace in a manner that provides a predictable pace of descent control. Additionally, a TTRL system that defeats the system/device self-actuation mode or one that relies on human reaction time, incorporates risks that would be best avoided.

With approximately 3-5m of rope-in-service at the edge transition, stop distance due to elongation is negligible regardless of whether or not you are sharing tension or using a hand-tight belay. There is only so much rope available to stretch. You are not traveling far either way, assuming a self-actuating device. But stop distance due to lack of self-actuation could be to the ground. Once the edge is executed and your system is now "proof tested", go ahead and go to a TTRL; ideally with auto-stop on both systems. Elongation is now mitigated with the shared tension approach and the probability of a system failure is greatly reduced post edge transition. Therefore, the risk associated with the lack of self-actuation is also greatly reduced.

The MPD and recommendations

The late, great Mark Miller had it right when he said, "currently, the best belay system going is a 540 Rescue Belay for the lower and an MPD for the raise." Well said. The irony is that you have a 540 mode on the MPD – you just have to use it. It was designed that way. It is in the instructional manual.

On the switchover to raise, the MPD cannot be trumped. An untrained bystander could safely run it. On the raise, there is currently not a more reliable belay device in rope rescue than the MPD. It is the release handle on the lower that introduces questions regarding reliability. The MPD is a fine device, complete with a well-designed mechanical fail-safe. However, like all devices, it requires the operator to be well trained in its operational nuances. Essentially, it is a DCD with a one-way rope trap that can be defeated by the operator. Monitoring how and when the release mechanism is operated, should be appropriately considered.

MPD operational recommendations:

1. Don't train to "just let go." Letting go of one thing (i.e. the release handle) while holding onto something else (i.e. the rope) does not appear to lend itself to consistent results.
2. Emphasize control of the running end – *never* let go of the rope while moving a live load. Ideally, train to match hands on the running end during an atypical event (e.g. rope accelerating).
3. Use the friction post, when possible. At least have the rope reeved over the friction post even if the operator is not actively engaging the post for additional friction.
4. Use a less aggressive "grab" of the release handle, ideally. The Teacup Technique likely has some limiting factors such as thumb/finger fatigue. However, there are similar methods that involve using the palm of your hand in counter-rotational force that are less fatiguing and still meet the concept of a less aggressive grab of the handle.
5. Add more hands to the running end of the rope, when possible. This requires the human resources, but if you have them at your disposal then by all means have additional hands on the running end feeding rope towards the device operator.
6. Execute edge transitions with one MPD operated in self-actuation mode - similar to a 540 Rescue Belay – and the other MPD in descent control mode. This ensures that the Reactionary Gap does not adversely affect your reliable fall arrest during the critical initial edge transition should the primary descent control system fail.

In conclusion

Everything has an Achilles Heel. Some shortcomings are relatively benign. Others are not. As rescuers, it is our job to identify those potential pitfalls and manage them well.

In a two-rope system, we absolutely should be sharing the load in more or less a 50/50 fashion - ideally, with self-actuation on both devices. This should occur after the initial edge transition has been executed and it should continue all the way to the finish of the operation.

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