West Coast Lifelines

Vulnerability and Interdependency Assessment

Supplement 1: Resilience

West Coast Civil Defence Emergency Management Group

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IMPORTANT NOTES

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Cover Photo: Cobweb in South Westland. Photo by David Elms

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Resilience

1 INTRODUCTION

Resilience is not an easy concept to pin down – one report referred to a claim that "well over 100 unique definitions of resilience have appeared" (SEBoK 2017) – but it is central to West Coast lifeline vulnerability. It is therefore appropriate to survey its meaning, how it fits in to disaster response and recovery (concentration is on the latter), how it can be measured and assessed, and what are some general strategies for attaining and enhancing it. Most will be well known, but some could be unexpected.

The West Coast in its entirety, its geography, geology, communities, economy and all its lifelines can be thought of as an immensely complex system with all its components interacting dynamically with one another. It is a system-of-systems (Bodeau et al. 2013), in some ways similar to military or aerospace SoSs but in other ways very different even to the extent of being significantly more complex. Yet complex systems can be made to seem simple when looked at aright (Kluger 2007), and the lens of a resilience approach is a great aid in doing so.

To make sense of lifelines, they have to be seen in the context of the whole. The nature and effects of natural disasters need to be understood so that lifeline vulnerabilities can be explored and assessed, but then to be able to prioritise recommendations for improvements, both the cost of these improvements and their beneficial effects on communities, businesses and the economy must be understood. At first sight the task might seem dauntingly large. However, the patchiness of available information, the deep complexity of the whole and the insensitivity of the results to fine detail mean that no bravura mathematical analysis would make sense. Numerical intricacy is unnecessary. What *is* needed, though, is a close attention to logic and to a balanced view that checks out with practical reality.

A further point is that resilience is a relatively new concept, at least as applied to civil engineering and related problems. Ten years ago the word was hardly known. The emphasis at that time tended to be on risk. Resilience does relate to risk, but in reality it is a very different beast. The relation between the two is discussed in the context of ideas on the nature of resilience explored in the next section.

2 WHAT IS RESILIENCE?

The Oxford English Dictionary gives as one of its definitions of resilience: "The quality or fact of being able to recover quickly or easily from, or resist being affected by, a misfortune, shock, illness, etc.; robustness; adaptability." This is a useful definition as, unlike many others, it centres around two issues: recovery and resistance. Another definition is given in the Collins English Dictionary, where in the context of ecology, resilience is "The ability of an ecosystem to return to its original state after being disturbed." It is useful to think of an ecosystem as an analogy to the human-related systems of the West Coast. Both are living, dynamically changing systems with a capacity to resist adversity or adapt to it either directly or by evolution. However, in both cases if the adversity is too great, a tipping point may be reached beyond which the system is unable to recover. More on this later.

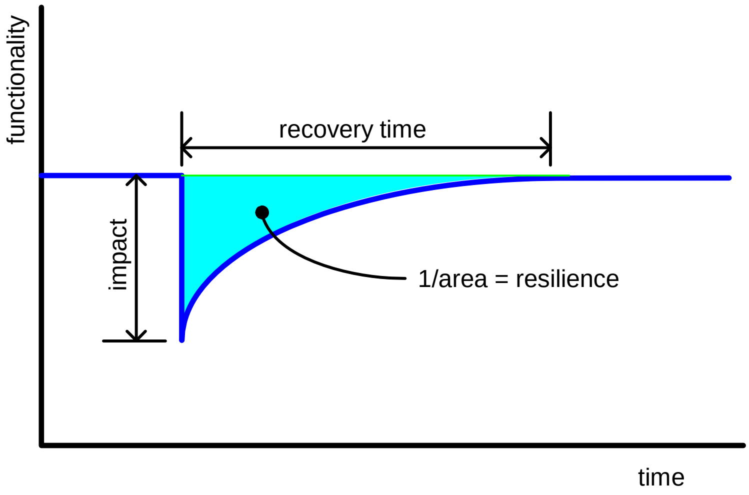

Figure 2.1: Basic Resilience Concepts

Figure 2.1 shows some of the basic concepts of resilience. A system, say a community, has a stable level of functionality. At some point in time it is hit by a disaster and there is an immediate impact on its functionality, which drops to a lower level, perhaps zero. There is then a time of recovery until normal functionality is restored. One possible measure of the system's – the community's – resilience is the shaded area in the diagram, or rather, its inverse. The smaller the area, the better the resilience. The area relates to the magnitude of the initial impact, the length of the recovery time and the shape of the recovery curve.

Although Figure 2.1 gives some basic ideas, it must be borne in mind that it is a great simplification of the issue in reality. Its vertical axis shows only one variable, "functionality", where in practice there would be many where larger systems are considered: different parts of the Coast's road system could have many different impacts, for instance, and different paths to recovery, and though Figure 2.1 might apply to a single section of road, the road system as a whole is more complex by far. In any case, the shape of the recovery curve for a road is more likely to be that shown in Figure 2.2. The initial impact on the road of a slip, washout or whatever is to close the road, which then has zero functionality. After a while and a good deal of effort the road is partially opened, say as a single lane, or to 4WD vehicles. Only after more time (and effort) is the road fully open again.

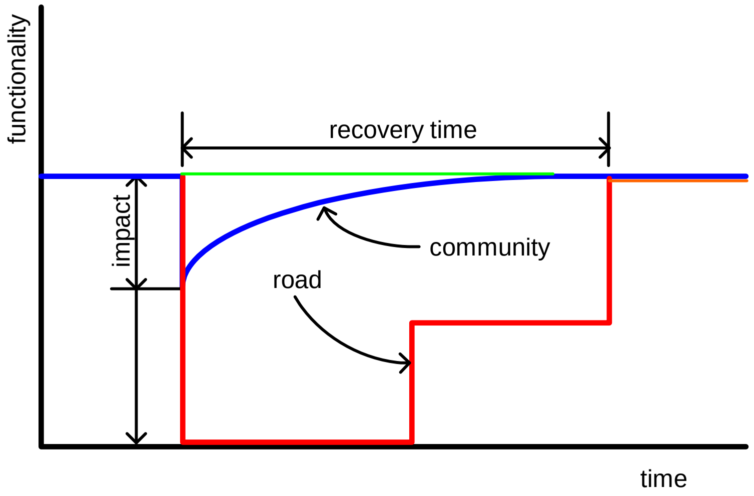

Figure 2.2: Recovery Paths for Community and Road

A further point is that the stable final recovery state is not always a return to the original. Figure 2.3 shows that as well as returning to is original state, the system might be permanently impaired and only return to a lower level of functionality (curve c). There could also be cases, rare but real, where the final result is better than before due to newer equipment, better design and suchlike. More importantly, there will also be situations where the impact is so great that the system will never recover and functionality will sink to zero (curve d), as was the case with the fire at the Waiuta Mine pithead. If the impact is too great, a *tipping point* is reached and recovery is impossible. The possibility must always be borne in mind when designing or managing for system resilience. Some situations, processes, companies or industries are sensitive. They have little latitude and a minor impact could push them over the edge with serious consequences for the wider community.

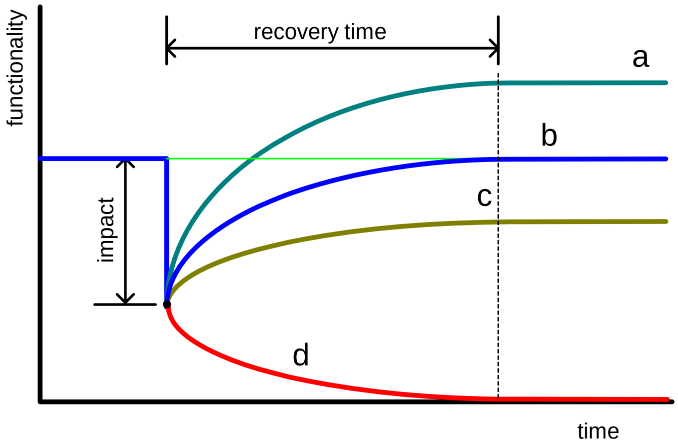

Figure 2.3: Different Recovery Levels. *For curve d the system has passed its tipping point***.**

Finally, regarding recovery path, Figure 2.4 shows that the recovery curve could have many shapes. There might, for instance, be an initial delay before recovery could start. Figure 2.4 also shows the effect of one of the strategies for improving resilience: buffering. Both the initial impact and the recovery path and time can be improved by introducing a buffer, which typically could be the availability of supplies when their normal source is cut off. A reservoir can provide water while a water source or treatment plant is out of action, and any household on the Coast would be wise to have at least a week's emergency supply of food. A buffer acts to delay the immediate effect of an impact.

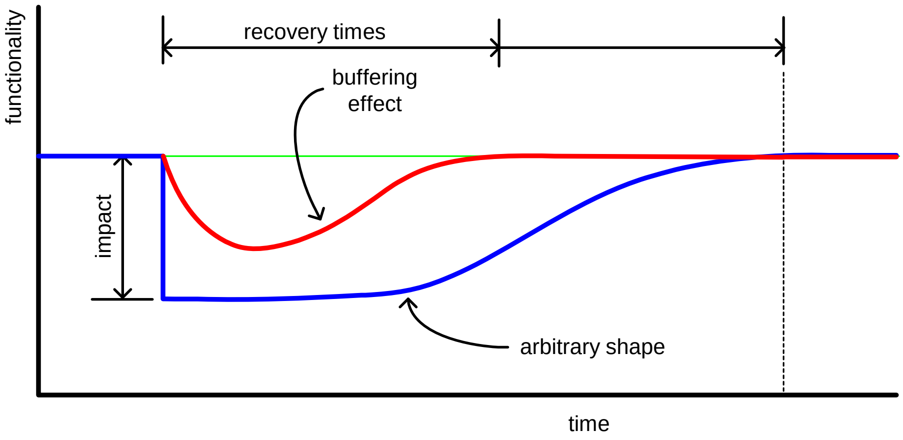

Figure 2.4: Recovery Curves can have Many Shapes. *Buffering reduces and delays the effect of an initial impact.*

It is useful to consider how resilience differs from risk. The two are very different.

Risk is to do with the likelihood of and consequences of some future anticipated perturbation of the system. We estimate risk so that we can if necessary do something to change a system's response. Insofar as we have to decide what is to be done, risk and decision are intimately related. And because every decision results in future consequences, then every decision has risk associated with it.

It follows that it is helpful, when estimating risk, to be clear as to the associated decision.

A difficulty with risk is that it is necessarily associated with a specified perturbation. What, then, if we cannot be sure what that perturbation might be? In such a case, we would design for resilience. This is the stance taken throughout this report: we do not know what might actually happen, other than that it is likely to be something unexpected. Although elsewhere we have looked at the consequences of major earthquakes, storms and tsunamis, the scenarios are not at all predictions of what will actually happen. Rather, they are simply means of probing the West Coast systems, particularly the lifeline systems, to identify vulnerabilities – to see what would break, as it were. The importance of expecting the unexpected is dealt with persuasively by Taleb in his book *The Black Swan* (Taleb 2010). It is recommended reading for all lifeline engineers.

Risk ideas and approaches are widely used by engineers, and so they should be. They are important ways of dealing with the inevitable uncertainties that go with engineering. Nevertheless they have many limitations and traps. A number of criticisms are dealt with in a recent survey (Carmichael, 2016), which could be read together with subsequent discussions of it (Blockley, 2017; Elms, 2017).

A final point about resilience is how it could be measured; its metrics. One was mentioned earlier as the inverse of the area above the recovery curve (Figure 2.1). Others that have been suggested are (SEBoK 2017)

1. Time duration of failure or outage
2. Time duration of recovery
3. Ratio of performance recovery to performance loss
4. A function of speed of recovery
5. Performance before and after the disruption and recovery actions
6. System importance measures
7. Maximum outage depth
8. Expected value of capability (i.e. the probability-weighted average of capability delivered)
9. Threat resiliency (i.e. the time-integrated ratio of capability divided by the minimum required capability – essentially that shown in Figure 2.1)
10. Expected availability of required capability (the likelihood that for a given adverse environment the required capability will be available)
11. Resilience levels (the ability to provide required capability in a hierarchy of increasingly difficult adversity)
12. Resource resiliency (the degradation of capability that occurs as successive contributing assets are lost)

The reference suggests that the most important, if any one had to be chosen, would be item 9: threat resiliency. The variety of possible measures reflects the different contexts in which resilience occurs. Some of the measures, for instance, would apply to, say, power supply, which is an important lifeline. Nevertheless, in most situations where resilience is used in this report, quantitative measures are not relevant. Resilience is more a way of looking at the situation and seeing how things could be done better in broad terms. A detailed numerical analysis would not be appropriate because of the uncertainty and quality-limitations of much of the information to hand as well as the limitations imposed by simplifications and assumptions. As far as we are concerned, it is the logic implied by a resilience approach that is important, not fine detail. In other words, it is the ideas that count – and they are powerful – and not the numbers. In the end it is perhaps no more than, and certainly no less than, inspired common sense.

3 STRATEGIES FOR IMPROVING RESILIENCE

To improve resilience, it is helpful to understand that a resilient system possesses four attributes: capacity, flexibility, tolerance and cohesion (SEBoK, 2017). To expand on these in turn:

Capacity is "the attribute of a system that allows it to withstand a threat"; that is, to minimise the initial impact of an adverse event. This can be achieved in several ways:

- *Absorption.* This is simple and obvious: just make something strong enough that there is no damage, or impact in the sense of Figure 2.1. Absorb the blow. Or at least, ensure that if there is damage, it does not impair the functionality of the system. It used to be fashionable to design structures such that beam-column joints might yield and absorb energy while still not allowing the structure to collapse in an earthquake. People would be safe. Unfortunately the safety-above-all approach perhaps looked at too limited a system, and the economic cost of an earthquake proved far too high. Lesson: choose your system carefully.
- *Redundancy.* We are concerned with the capacity of the system as a whole. If a road is closed by slips the problem is far less serious if alternative routes are available. In structures, multiple load paths help maintain functionality. Note that this idea is as applicable to management as it is to physical situations: a strictly hierarchical management system is vulnerable. Another area is data: redundancy of backup is a good idea. The underlying point is that these strategies of redundancy, layered defence and so on are very widely applicable and are not at all restricted to physical systems such as lifelines.
- *Layered defence.* If one defence is overwhelmed, it helps if there is another. Christchurch, for example, is protected from the Waimakariri by stopbanks. If they should be breached, there are secondary stopbanks. This especially makes sense if the issue is important.

Flexibility is the "attribute of a system that allows it to restructure itself in the face of a threat." We've said above that the West Coast can be thought of a dynamic system-of-systems, constantly changing and adapting. Flexibility can be achieved by:

- *Reorganisation* (or system architecture – adaptability). For instance, suppose Lake Kaniere were afflicted by an algal bloom. The lake is the primary source of water for both Hokitika and Westland Milk Products. What would be needed, and quickly, would be an alternative source of water.
- *Complexity avoidance.* Complexity, in our vocabulary, refers to how difficult it is to describe what the word refers to. In other words, the more complex a system, the more difficult it is to understand it and know exactly what is going on. In structural engineering, it is easier to have a single dominant and predictable mode of failure than to be unsure of exactly what is going to happen. What one is after, then, is predictability. See comments on loose coupling, below.
- *Backup availability*. Various examples come to mind: the availability of gensets, for example, or temporary bridging. The latter strikes us as being important in that if all temporary bridging

sits in Christchurch, it might not be possible to get any over to the Coast for some time in the event of a major earthquake. The Greymouth New World supermarket has a backup system in place allowing it to operate even if Internet connection were lost.

Tolerance is the "attribute of a system that allows it to degrade gracefully following an encounter with a threat." That is, it should provide time for response to start before full loss of capability. It is the opposite of brittleness. Tolerance can be provided by:

- *Localised capacity.* The functionality should be concentrated in individual nodes with the ability to operate independently. For instance, in a major earthquake, telephone connection outside the Coast might be lost, but it would be helpful if telephones within the area could still make contact with each other.
- *Loose coupling*. This is an idea brought out by Perrow (1984) in his investigation of major disasters. He noted that many resulted from what he called tight-coupled systems, where everything was interconnected with everything else. Failure of one part led to failure of the whole. For example, if everything were dependent on electric power from the grid, loss of power would mean the functional failure of everything. On the West Coast there is considerable interdependence between systems. A wind storm, for example, could block roads, delaying restoration of damaged power or telecommunications lines. Loose coupling would also minimise cascading failures as well as the spread of failures.
- *Reparability.* That is to say, fixability. This should be looked at in a broad frame, including access, availability of spares (especially in emergency situations), ability to locate and identify damage, technical capability and so on.
- *Buffering.* We have discussed this above (Figure 2.4). The West Coast is sustained by flows of many sorts: traffic, tourists, milk, coal, water, money, information and so on. Buffers will reduce the immediate impact of a disaster on these essential and interacting flows.

Cohesion is the "attribute of a system that allows it to operate before, during and after a threat." This is as much as anything an issue of different organisations working together with positive cooperation.

- System nodes (elements) need to be capable of communicating, cooperating and collaborating with each other. A recent example is the way in which different and competing telecoms companies cooperated in setting up communications links with Kaikoura following the earthquake there. It is an attitude and expectation that needs to be part of the culture, rather than something that suddenly appears when there is a need.

An interestingly different set of strategies can be found in the report by Bodeau et al (2017). The systems discussed there could hardly be more different from the West Coast lifelines: they are concerned with cyber resilience and security, particularly in a military context. However, it is precisely because the contexts are so different that it is worthwhile looking at what they have to say. Not everything is applicable by any means, but quite a few of the ideas, suitably translated into our own language, can have a powerful resonance. Besides, looking at what other people do, for better or for worse, can be fun.

4 ATTITUDE

Working with resilience in mind requires more than knowledge and a set of techniques. It also requires a particular attitude, a mind-set, rather different from most people's normal way of going about things. Resilience means being prepared for anything – being prepared for the unexpected – and this has two implications. The first is a need for awareness, for expecting the unexpected and therefore looking for it. There is a creative element to it: we could call it "creative awareness". The second implication is that there will be a need to move quickly to deal with whatever is the problem. One needs fleetness of foot.

These two ideas can be used to underpin and suggest practical engineering approaches. For instance, the need to be aware of what is going on can lead to monitoring regimes, perhaps making creative use of new technology such as using drones to check out hidden gorges for slips. As for moving rapidly to deal with the unexpected, there may be strategies that could help such as having a supply of spares ready to hand.

5 SUMMARY

This supplement presents a number of resilience ideas as a toolbox for practical use.

It discusses the nature of resilience – its relation to risk and how it is principally concerned with anticipating the unexpected; with meeting black swans head on, as it were.

It presents a number of general strategies for improving, ensuring and enhancing resilience. The list is intended to be useful rather than exhaustive.

The life of the West Coast is a complex system-of-systems, living and evolving dynamically as a whole. For this reason, what has been discussed here is intended to be applicable to every aspect, as much directed at community and economic resilience as it is at the immediate technical issues of lifeline systems.

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