An Information Sharing Framework for Roading Emergency Response and Recovery

André Dantas*
Dharmista Gohil
Erica Seville

Abstract
Roading organizations are involved in a wide range of emergency response and recovery activities that requires information sharing. This paper presents an information sharing framework for roading organizations. The framework is applied to a desktop case study in the South Island of New Zealand to establish the approximate magnitude of potential benefits. Results show that a potential reduction in time and cost of emergency response activities could be reached if the conceptual framework was implemented through reduced response times, fast access to relevant information and therefore enhanced decision making.

1. Introduction

Information sharing is a critical element in deploying roading organisation resources during emergency response and recovery activities. Without collecting, collating and communicating data and information among multiple organizations, damage may not be properly assessed and resources may not be adequately deployed, which may cause inefficient coordination and decision-making (Britton, 2004; CAE, 1997). According to the efficiency levels of information sharing, even a small event such as a car crash may either result in a short or long road closure. On the other hand, an earthquake event, for example, requires intensive exchange of damage and resource deployment information that may save lives and reduce disruption. These complexities emphasise the need to develop robust yet simple frameworks for sharing information and communicating decisions within and between organizations involved in response and recovery activities.

Although it is acknowledged the importance of information sharing during emergency events, current practices and techniques present considerable limitations in providing tools that fulfil the needs of emergency management practitioners. Technological advances in information management of spatial-temporal data such as Geographical Information Systems (GIS) have been made in recent years (Birking, 1996; Kwan and Lee, 2003; Schwarz, 1989; Lanza and Siccardi, 1995; Hazelton, 1991). Nevertheless, after studying various implementations of GIS in emergencies, Zerger and Smith (2003) concludes that most case studies do not have a real-time capability and require events to be pre-modeled.

This paper takes an end-user centric approach rather than a platform centric approach in the design of an information sharing framework for New Zealand roading organizations. The framework is the result of conducting comprehensive analyses of the nature and background of involved organizations; the characteristics of their involvement; their data/information needs; their data/information sharing needs; and how organizations could/should share data and information. After this introduction, the emergency management context in New Zealand is described. The third section summarizes the role of roading organizations during emergency events. The information sharing framework is introduced in the fourth section. The framework is applied to a desktop case study in the South Island of New Zealand. Finally the sixth section discusses the main findings of this research, as well as recommendations for further studies.

* University of Canterbury, Private Bag 4800, Department of Civil Engineering, Resilient Organisations Research Programme, Christchurch, New Zealand. Tel +64-3642238 email:,andre.dantas@canterbury.ac.nz,

This paper takes an end-user centric approach rather than a platform centric approach in the design of an information sharing framework for New Zealand roading organizations.The framework is the result of conducting comprehensive analyses of the nature and background of involved organizations; the characteristics of their involvement; their data/information needs; their data/information sharing needs; and how organizations could/should share data and information. After this brief introduction, the emergency management context in New Zealand is described. The third section summarizes the role of roading organizations during emergency events. The information sharing framework comprising a series of steps for information acquisition, storage and sharing during emergency events is introduced in the fourth section. The framework is applied to a desktop case study in the South Island of New Zealand. Finally the sixth section discusses the main findings of this research.

2. Emergency management in New Zealand

In New Zealand, the Ministry of Civil Defence and Emergency Management (MCDEM) is a semi-autonomous body within the Department of Internal Affairs. MCDEM has over-arching responsibility for developing and maintaining the preparedness of the New Zealand community for any natural and technological hazards or disasters (Britton and Clark, 2000). The CDEM Act (2002) requires every local authority to plan and provide for Civil Defence and Emergency Management (CDEM) within its district, and to ensure that it is able to function to the fullest possible extent, even though this may be at a reduced level, during and after an emergency. One of the features of the Act is that this requirement also applies to lifeline utilities and central government departments. MCDEM works in coordination with local and regional governments, utilities and the emergency services involved in CDEM. MCDEM's Director acts as Chief Executive of the Ministry in its day-to-day operations. In cases of national emergencies, the Director has special powers defined in the legislation. In the event of a Civil Defence Emergency declaration, the CDEM Group (or local) Civil Defence Controller co-ordinates the response and makes decisions about key response actions after communication and consultation with the emergency services, health agencies and key lifeline organizations. The regional and national CDEM Emergency Operations Centres (EOCs) interact with these organizations to facilitate and support decisions on prioritization of response activities. Relevant data/information from all the above organizations is expected to be shared with CDEM agencies to facilitate decision making.

3. Roading organizations and emergency response in New Zealand

Typically, Transit NZ appoints Consultants to undertake technical services to determine work requirements according to Transit NZ Regional office's directives, and Contractors for carrying out the physical works. The State Highway network is divided into seven regions, each with their own Consultant and Contractor arrangements.

This structure provides the State Highway network with some resilience during emergencies in that many of these Consultants and Contractors are national or sometimes even international organizations. This means that resources can be brought in from other areas to boost resources available to an affected region during the crisis. However this structure also adds complexity that needs to be recognised and managed. As the number of organizations involved in effecting response and recovery increases, particularly if an emergency spans more than one region, communication and sharing of information within and between organizations becomes more complex to manage.

The Transit NZ emergency response process can be divided into 6 core elements, these are: (1) **event warning**; (2) **event observation**; (3) **event assessment**; (4) **organisation action**; (5) **organisation reporting**; (6) **organisation re-evaluation**. During re-evaluation (6), the outcomes are used to decide whether the response is considered over or should be continued from event assessment (3). The dynamic nature of emergency response is such that many elements of the response process are conducted simultaneously and as the event develops, the appropriateness of different response strategies needs to be constantly re-evaluated.

In each stage of the response process, different organisations are involved. In the event warning phase, external organisations such as research institutes, meteorological services, regional and local councils etc provide initial warnings and updates of potential events. During or after the event (event observation phase), the Contractor along with external organisations and the public verify initial damage caused to the transportation system (pavement and bridge collapses, obstruction of lanes, etc.). Depending on the extent of damage, these conditions are reported to the Consultant, Transit NZ, Local Road Controlling Authorities, the emergency services and other lifeline organisations, or if a Civil Defence Emergency has been declared, the regional or national CDEM EOC. In the subsequent phase (event assessment), again depending on the type of the emergency, all the above organisations except external organisations and the public are involved. Organisation action involves the same organisations deploying their physical and personnel resources according to their response responsibilities. Most of the field operation is conducted by the Contractors in small and medium events.

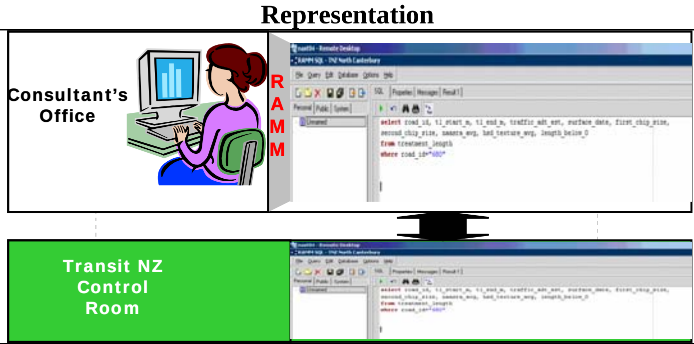
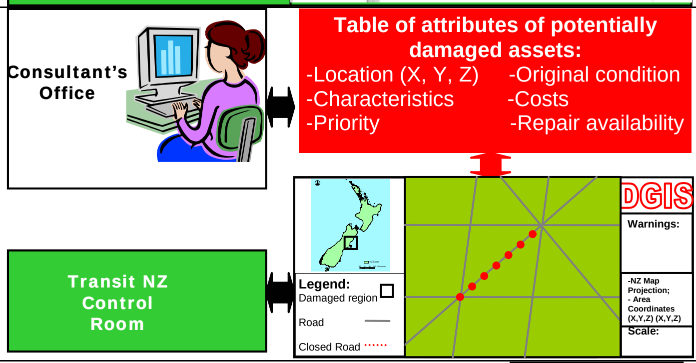
In large events the CDEM Controller, lifeline organisations and Local/Regional Authorities are also involved. These actions are supervised by the Consultant and Transit NZ. As part of organisation reporting, the Contractor, CDEM, Local/Regional Authorities and lifeline organisations describe current road conditions after the initial round of measures and any further development of the original event (better information about damage, more events, etc.). These reports are then taken into consideration during organisation re-evaluation, in which the organisation evaluates the measures taken and their efficiency. Finally, decisions are made as to whether to continue or stop response activities depending on the efficiency assessment. If a decision is made to continue, the process restarts again from event assessment.

Emergency situations are classified by Transit NZ into 3 levels according to the time required for road reopening: small (a specific part/segment of the State Highway network is affected for an approximate duration less than 6 hours), medium (multiple parts/segments of the State Highway network are affected for up to a day) and large events (severe damage to the State Highway Network, other lifeline infrastructure systems and life threatening situations are observed, prompting Civil Defence to dictate response and recovery priorities) [13].
Organizations involved in response and recovery activities need a large variety of information. In order to act in a coordinated and effective way organizations require access to data and information characterizing the disaster's intensity, location and related damage, as well as the availability of human and physical resources. Organizations will have their own particular information needs, which may be different for each level in the organisation. For example, Transit NZ Headquarters' personnel in Wellington will need general road closure information such as summary of damage, expected opening, forecasted recovery cost, etc. On the other hand, the Transit NZ network engineer will need access to much more specific information about damage, work progress, costs and resources availability.

4. An emergency response information sharing framework for New Zealand roading organizations

This framework was developed following the concepts of knowledge and information management (Choo, 2002). The first step in the process was to identify the information needs of the organizations involved in response. This was done by examining Transit NZ's emergency procedures and reports and translating these using the Integrated DEFination (IDEF0) modeling language (semantics and syntax) (FIPS, 1993), into a summary of information needs and sources during each phase of the response and recovery effort (Table 1).

These information needs were then considered in the conception of the data/information sharing framework. The framework utilizes Transit NZ's current inventory database to generate a Dynamic Geographic Information System (DGIS) for emergency response. Transit NZ's inventory database (RAMM), comprises historic data on roading assets and their condition over time. In an emergency response event, the framework proposes that data from RAMM is dynamically retrieved, organized and distributed amongst Consultants, Contractors and Transit NZ using the DGIS. The data/information framework establishes the linkages, templates and sharing standards to enable the conversion of RAMM into information required during emergency response activities (*DGIS*). For example, during an emergency event with warning (e.g. flooding), the framework (see Figure 1) is applied following the steps and the representation below.

<table>
<tr><th>Step</th><th>Representation</th></tr>
<tr><td>1- Preliminary information on the potentially damaged region and assets is used by Transit NZ, Consultants and Contractors in generating data/information related to the potential emergency using RAMM and emergency response resources are placed on alert;</td><td>
</td></tr>
<tr><td>2- Relevant information is then extracted from RAMM by the Consultant and linked to maps using DGIS;</td><td>
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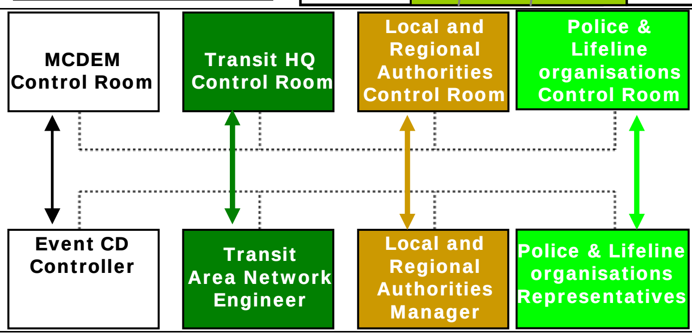
<tr><td>3- The Consultant alerts other possibly involved parties (MCDEM, Local and Regional Authorities, other lifeline organisations) and Transit NZ regional and national HQ offices;</td><td>
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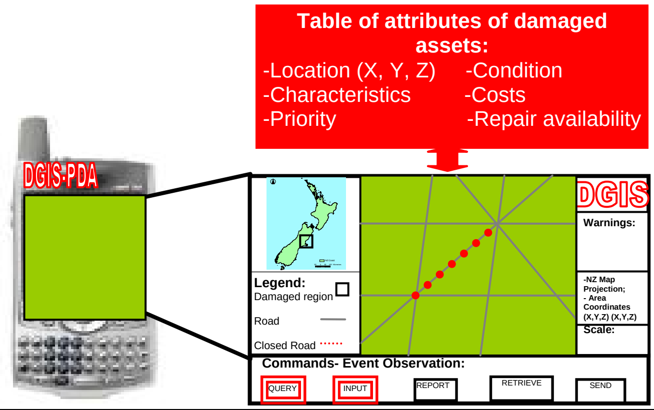
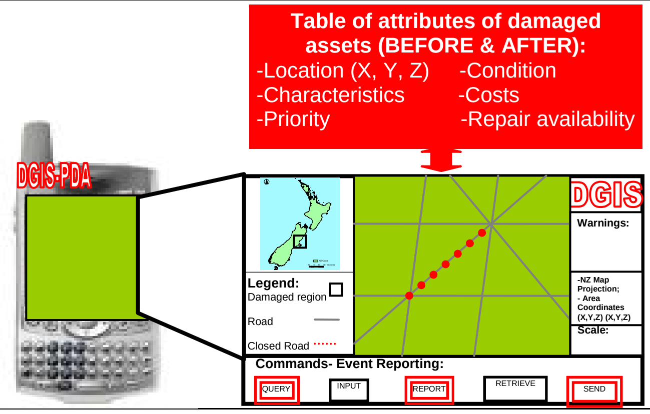
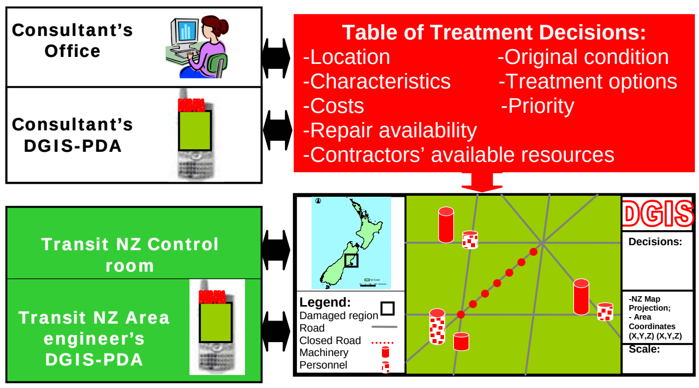
4- The Contractor reaches the damaged road. Using DGIS-PDA*, the contractor records the observed conditions of the damaged assets;



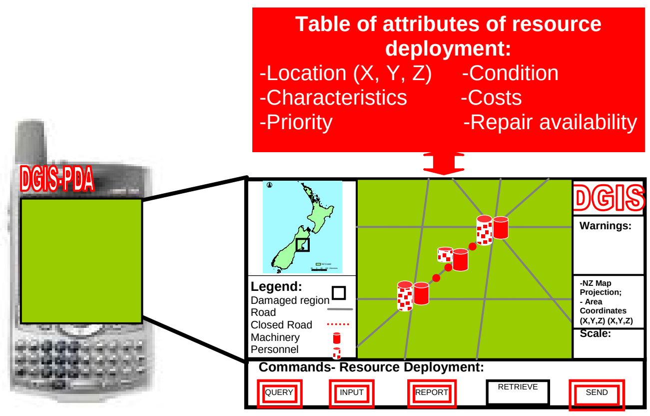
5- The observed conditions are summarized and **Reported** back to the Consultant via the DGIS database;



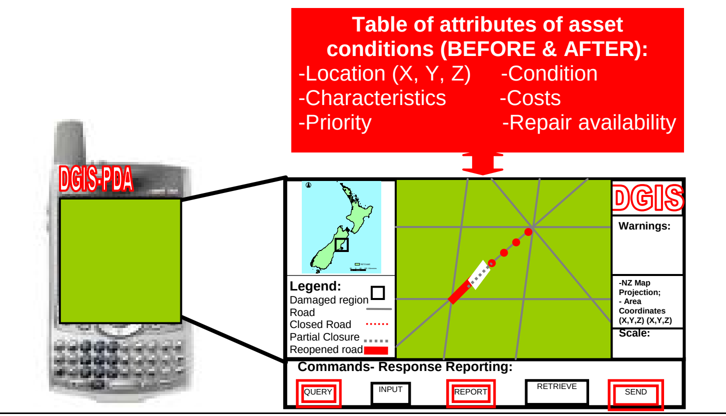
6- Considering available resources recorded in the *DGIS* database, Consultant and contractors make **Treatment Decision**, which is shared with among them and with Transit NZ HQ;



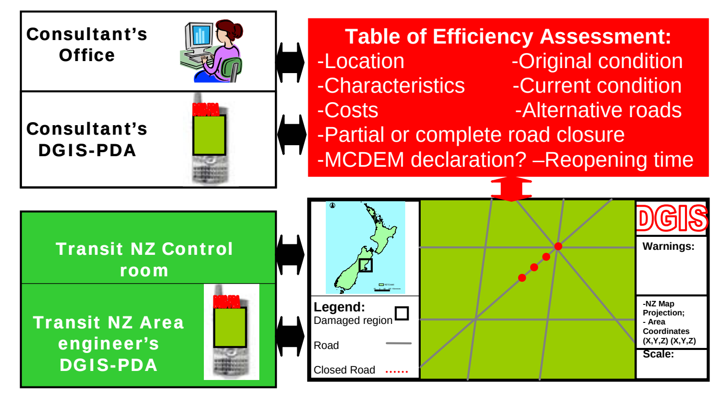
7- The Contractor ***Deploys Resources*** to implement the treatment; actual resource deployment is recorded into the *DGIS-PDA*;



8- After the completion of the work, the Contractor compares before/after event conditions and conducts a ***Results Reporting***, which is subsequently recorded into *DGIS-PDA*;



9- The Consultant retrieves data and conducts an ***Efficiency Assessment*** in which either the response is finalized (road opening) or continued; and



10- If the response is continued, the Consultant re-starts the process from the ***Treatment Decision*** phase. Otherwise, the road segment is reopened to users. Contractors, Consultants, Transit NZ and other involved parties are informed of road reopening.

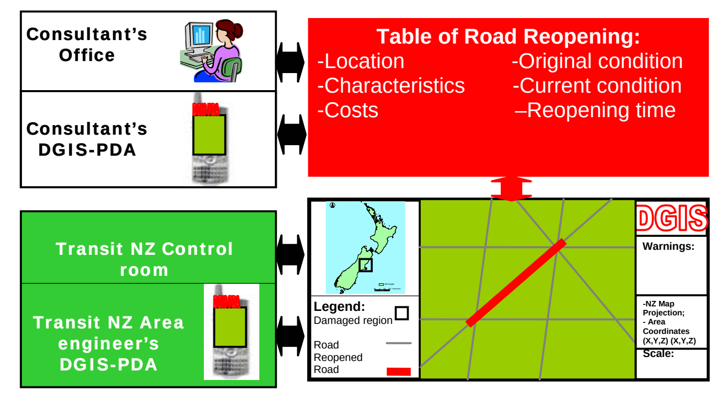


Figure 1 – An example of response steps and their representation

5. Case study

This proposed information sharing framework was applied in a desktop case study in the South Island of New Zealand to establish the approximate magnitude of potential benefits. This section describes the implementation issues and a comprehensive analysis in terms of cost (NZ$) and time (minutes) of response activities with and without the data/information framework.

This case study is divided into 4 sub-sections. The first sub-section introduces the study area and the data sources and types used for the case study. In the second sub-section, the information sharing framework is applied to a road closure example. The third sub-section presents the estimation and analysis of time and cost for road closure reopening, for current practices (without data-information framework) and with the proposed framework.

5.1 Study area and data sources

The case study comprises of road closures in the South Island of New Zealand. South Island is divided into six regions namely North Canterbury, South Canterbury, West Coast, Coastal

Otago, Central Otago and Southland. Each region has a contractor and a consultant for the construction and maintenance of the State Highways on contractual bases. During the duration of the case study, Opus International Limited (Opus) had the contract for consultation with Transit NZ for all these regions except Coastal Otago.

The road closure data used for applying the data/information framework is obtained from Opus International Limited’s office in Greymouth where all the road closures in the South Island of New Zealand are stored. The database comprises information such as closure date, closure time, open date, open time, State Highway (SH), Route Station (RS), Route Position (RP), Location, closure type, closure reason, comments, region, road closed by, etc. The total road closures recorded during the 1 year period (April 2004 to March 2005) are 113. Figure 2 shows a GIS map (*GeoMedia Professional*) with the road closures categorized as per the road closure type.

5.2 Information sharing framework is applied to a road closure example

The information sharing framework is applied to a road closure that occurred on Saturday, 8th January 2005 at 5.00 am. The road between Tapanui and Gore (Pomehaka Bridge) was closed by the contractor due to flooding. The road was reopened after 37 hours, 40 minutes, on 9th January 2005 at 18:40:00 hours. Each of the response phases using the data/information framework is explained below:

- Using warning from MetService, RAMM database and *DGIS* maps are selected for the potentially damaged areas;
- The consultants retrieve the data from RAMM and export it to *DGIS*. The map showing the roads likely to be damaged and other features on the road like, signs, bridges, etc., and their exact location is displayed on the map along with their attributes like signpost ID, type of signpost, foundation, bridge name, length, etc;
- When the disaster occurs, the contractors go on site while the consultants fill in the details in emergency response form. This data is then shared with the other roading organizations and Civil Defence. The contractor accesses this information using a PDA or cell phone with mapping facilities;
- Once the contractor reaches the road closure site, the actual damage on the site is examined and then updated in the *DGIS* and shared with the consultants and other roading organizations;
- The consultants then assess the damaged condition based on the data/information provided by the contractor in DGIS and make decisions about the treatment to be given and prioritization of the work. The decision is made and shared in *DGIS* by the consultants. The contractors do the repair as per the instructions given by the consultants or the Civil Defence;
- After the repair is conducted, the contractor reports back to the consultants the condition of the road after repair. The condition of the bridge and the reinstallation of the signpost are reported back on *DGIS*; and
- The consultants then decide if the repair is done or the work is to be continued. After all the repair work is conducted, the road is reopened to traffic.

5.3 Assessment of time and cost saving using data/information framework

To estimate the amount of time and cost saved using the data/information framework, the time and cost of disaster response using current practice and using data/information framework is calculated. As only the total time for disaster response is available from the road closure data, it is subdivided into time periods for each phase using a set of assumptions. Also, the road closure costs are assessed based upon road traffic and time of closure (AM or PM).

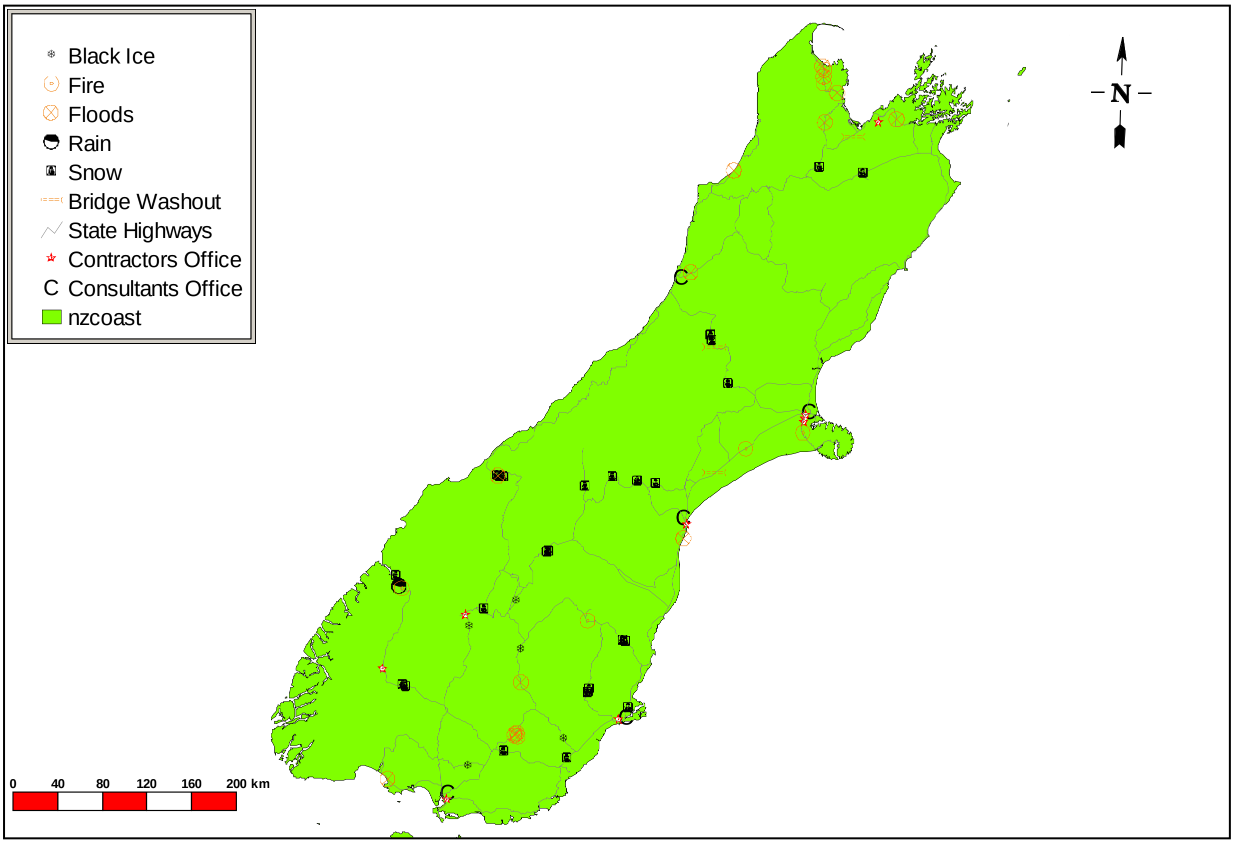


Figure 2 –Road closures categorized as per the road closure type.

A road closure event *e* that had a Response Time (RT_e) and is classified according to its type (*Y*) and emergency level (*EL*). Each event is also associated with a set of response phases *p* where, external agency or police contact consultants (*p=1*); consultants contact contractors (*p=2*); contractors reach the disaster affected site (*p=3*); contractors inform consultants of actual site condition (*p=4*); decision made on the treatment by contractors and consultants (*p=5*); Wait till condition suitable for repair or to get orders from MCDEM (*p=6*); repair done (*p=7*); and report to consultants (*p=8*). Combining all the data, each event (*e)* has been described as in Equations 1, 2, 3 and 4.

$$e = \{Y; EL; \text{and}\, t^{p}_{EL;y}\} \qquad \text{(eq. 1)}$$

$$EL = \begin{cases} 1; & if\,(RT_e < 6 \quad hours) \\ 2; & if\,(6 \le RT_e < 24 \quad hours) \\ 3; & if\,(RT_e \ge 24 \quad hours) \end{cases} \qquad \text{(eq.2)}$$

$$ART_e[EL;Y] = \sum_{p=1}^{8} AT^{p}[EL;Y] \qquad \text{(eq. 3)}$$

$$AT^{p}[EL;Y] = \frac{\sum_{e=1}^{n} t^{p}[EL;Y]}{n[EL;Y]} \qquad \text{(eq. 4)}$$

Where,

$ART_e[EL;Y]$= Average time for road reopening for an event *e*, level *EL* and type *Y;*

AT^p [*EL*; *Y*] = Average time for each phase *p* and emergency level *EL* and type *Y*.

t^p= time for each phase *p* for each event *e*;

n= number of event of same type *Y* and same emergency level *EL*.

In order to partially assess the efficiency of the information sharing framework, the travel delay costs to road users are estimated. The Average Cost of the road closure *(AC)* is dependent on the type of road closure, the level of emergency and the response phase duration. The total cost of a road closure is the summation of all costs for each phase, which is given in Equation 5.

$$CP_e^{p} = t^{p}_{(EL;Y)} \times \frac{AC^{e}}{ART_e} \qquad \text{(eq. 5)}$$

Where,

AC^e= Average cost of road closure for total time of road closure to the user; and

ART_e =Average road reopening time for a road closure event *e* for an emergency level *EL* and type *Y*.

$CP^p{}_e$=Cost per phase *p* for an event *e;*

$t^{p}_{(EL;Y)}$ =time for phase *p* for an emergency level *EL* and type *Y*; and

The implementation and operation of the data/information framework is expected to reduce the response duration for some of the phases. There may not be any change in time for some phases; however the overall time is very likely to be reduced. For each phase, potential reduction can be achieved by adopting the following measures:

- Phase 3 (time taken for contractor to reach the site): This time can be reduced if the contractor has a GIS map showing the exact location of the road closure site. The amount by which this time is reduced may be assumed to be between 1 to 5 % of the original time;
- Phase 4 (contractor informs the consultant the actual site condition): This time can also be reduced using the information framework by 1 to 5% because the contractor has the details of the road site in DGIS;
- Phase 5 (decision making stage on the treatment to be given): time can be reduced by 10 to 15%, since all the data/information is available for the decision to be made quickly;
- Phase 6 (waiting time for the orders from Civil Defence in case of large events): time for this phase can be assumed to be reduced by 10 to 15%, since the Civil Defence will have the GIS maps and the required information based on which the decision may be made faster then current practice;
- Phase 7 (the time taken to do the repair work): time may be reduced by 1 to 5% if the contractor has the map of the existing road features, etc before the road closures; and
- Phase 8 (consultants can report back to the Civil Defence and the contractors of the condition after the repair): it can be reduced by 1 to 5% with the use of the framework.

Based on these assumptions, 3 scenarios are created as summarized in Table 2. For scenario 1, the durations of 1 and 2 are not reduced but 3, 4, 7 and 8 are reduced by 2.5% and phases 5 and 6 are reduced by 12.5%. For scenario 2 (best case scenario) the durations for phase 1 and 2 are not reduced, but phases 3, 4, 7 and 8 are reduced by 5% and phases 5 and 6 are reduced by 15%. Finally, for scenario 3, (worst case scenario) the durations for phase 1 and 2 are not reduced. The durations for phase 3, 4, 7 and 8 are reduced by 1% and for phase 5 and 6 are reduced by 10%. The percentage reduction in time is applied to all the phases for the three scenarios to calculate the reduction in time. The cost for the 3 scenarios is found by calculating the proportional cost for the reduced time as compared to the original time. The results of the average time and cost for all scenarios are in Table 2.

The total cost of road closures per year is estimated to be approximately 3 million dollars. By using the data/information framework, the cost of road closures can be reduced up to 2.7 million dollars. The best case scenario (scenario 2) would generate 5.53% (NZ$ 162,342) reduction while the worst case scenario (scenario 3) would generate a reduction of 1.70% (NZ$ 49,952).

The analysis of road closures reveals that slip events cause the highest costs (NZ$181,849) for the current practice (business as usual). With the use of data/information framework, cost reduction could range between 5.89% and 2%. The annual cost of road closure due to flooding, snow and accidents is also high and considerable reduction in the cost of these road closures may be achieved in Scenario 2. For small emergencies, the maximum cost of road closures is due to accidents. On one hand, this may be because from the 113 road closures recorded for 1 year (from April 2004 to March 2005), 29 road closures are due to small accidents. On the other hand, it could also be because all the road closures due to accidents that do not have an initial warning which means that the consultants and contractors may not be well prepared for the response and the accidents mostly occur on roads with high traffic flow thus causing delay to more users.

Table 2 – Case study scenarios and their respective annual costs

		Percentage of time reduced for each phase (%)								**Annual Cost (NZ$)**	**Reduction (NZ$)**	**Reduction (%)**
		p=1	*p*=2	*p*=3	*p*=4	*p*=5	*p*=6	*p*=7	*p*=8			
Scenarios	Business as usual	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2933331	0	0
	1	0.0	0.0	2.5	2.5	12.5	12.5	2.5	2.5	2839672	93659	3.19
	2	0.0	0.0	5.0	5.0	15.0	15.0	5.0	5.0	2770989	162342	5.53
	3	0.0	0.0	1.0	1.0	10.0	10.0	1.0	1.0	2883379	49952	1.7

6 Conclusions

This paper has shown the potential in adopting an information sharing framework to improve emergency response. Due to its simplicity and adequacy to current practices and procedures, it is very likely that the data/information framework could be applied to all the emergency types and emergency levels for response action by the roading organizations in New Zealand. Furthermore, the framework could also be applied to other countries considering their legal and institutional framework of the roading organizations.

Two main limitations can be identified in this research work. Firstly, the information sharing framework and the DGIS software have not been implemented and applied yet. Another limitation is quality and availability of road closure information. This has affected accuracy of the time and cost reductions after the implementation of the DGIS. Nevertheless, these limitations do not affect the validity of our findings, because an initial research effort has been made to demonstrate the potential of conceiving a customized tool for data/information sharing during emergency events.

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Table 1. Transit NZ and response partners' information needs in response activities

	Regional Consultant info needs	Regional Contractor info needs	Transit NZ Regional Office info needs	CDEM Group info needs
Event Occurrence		-Potential damaged area/region -Type of event -Intensity and expected duration -Available resources		
Event Observation	-Damaged area/region -Type of event -Damaged asset type -Partial or complete road closure -Alternative roads -Traffic flow composition -Contractors' resources -CD emergency declaration?	-Damaged area/region -Type of event -Attributes of potentially damaged assets (location; original condition; characteristics; costs; priority repair availability).	-Damaged area/region and event type -Damaged asset type; -Partial or complete road closure -Alternative roads -Traffic flow composition -Contractors/Consultants' available resources -Initial road closure time/ costs estimation -MCDEM emergency declaration?	
Event Assessment	Comparison before and after / damaged asset Location Original condition Characteristics Treatment options Costs Priority Repair availability -Contractors' available resources		-Report on before and after / damaged asset -Summary of damaged assets per type -Summary of treatment options -Summary of Costs/Priorities Repair availability -Consultants and contractors available resources -Initial road closure time estimation -Initial cost estimation -MCDEM emergency declaration?	-Report on road closures (Location; Partial/complete; Expected road opening -Consultants and contractors available resources -Initial cost estimation
Resources Deployment	-Location of Contractors' equipment and personnel -Deployment times -Allocation plan of resources and personnel per damaged asset (location; original condition; characteristics; treatment; priority; effectiveness) -Traffic management plan MCDEM emergency declaration?	-Allocation plan of resources and personnel per damaged asset (location; original condition; characteristics; treatment; priority; effectiveness) -Deployment times -Traffic management plan -MCDEM emergency declaration?		
Event Reporting	Damaged area/region -Attributes of damaged assets: (location; original/current conditions; characteristics; treatment; costs; priorities; repair availability)	Damaged asset type Attributes of damaged assets: (location; original/current conditions; characteristics; treatment; costs; priorities; repair availability) -Partial or complete road closure -Alternative roads -Traffic flow composition -Contractors' available resources	-Damaged asset type -Partial or complete road closure -Alternative roads -Traffic flow composition -Contractors/Consultants' available resources -Road closure time/costs estimation -MCDEM emergency declaration?	
Event Re-assessment	-Comparison before and after / damaged asset (location; original condition; characteristics; treatment options; costs; priority; repair availability) -Contractors' available resources Stop response/Initiate Recovery mode/Continue Response?		-Report on before and after / damaged asset -Summary of damaged assets per type, treatment options, Costs and Priorities -Repair availability -Consultants and contractors available resources -Initial road closure time cost estimation -Stop response/Initiate Recovery mode/Continue Response? -MCDEM emergency declaration?	-Report on road closures (Location; Partial/complete; Expected road opening -Consultants and contractors available resources -Initial cost estimation