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A decision support system for improving the management of traffic networks during disasters

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Abstract

Natural disasters such as bushfires and floods arising from climate change are becoming more frequent and intense, posing serious threats to the safety and security of road users. There is a need for improved decision support tools for more effectively managing road networks during natural disasters.

The Intelligent Disaster Decision Support System (IDDSS) was recently developed to provide a platform for integrating a vast range of road network, traffic, geographic, economic and meteorological data as well as dynamic disaster and transport models. It has numerous features for supporting homogenous data aggregation, manipulation and visualisation that can be used to investigate a wide range of disaster management issues. An application of the IDDSS involving the management of road networks during bushfire and floods events is presented to illustrate some of its capabilities.

Traffic Management Points (TMP) are locations where road blocks are established by police during emergencies to stop traffic entering areas that are considered dangerous. An optimisation model within the IDDSS has been developed to determine the best location of TMP's in the event of a bushfire.

Fire progression is simulated using the GRASS model. Short and medium term forecasts of the damaged areas are then made. Buffer zones outside the predicted damaged region are determined. Intersections near edge of the buffer zones outside the predicted damaged areas are then considered sites for TMP. These candidate sites are evaluated using a genetic algorithm to determine the best location of TMP considering available police resources, risks to road users as well as traffic disruption. Origin and destination matrices are estimated from traffic counts to determine appropriate intersections for TMP as well as to estimate the disruption costs.

1. Introduction

More frequent extreme weather events from climate change presents a major threat to the reliability of traffic networks, creating the need for improved tools for decision support for traffic management in emergencies (Arkell & Darch 2006; IPCC 2014:8:23). Recently there has been an increase in the prevalence and severity of natural disasters such as floods, cyclones, and fires in Australia. Floods in Queensland and Victoria as well as fires in Victoria and New South Wales in the past five years have led to extensive disruption to traffic networks as well as massive road infrastructure reconstruction programs. In Queensland over 9000 km (27%) of the state's roads were affected during the floods in the 2010-2011 wet season. In early 2011, 100% of the state was declared a disaster with approximately 20 610 km of roads closed.

During and following a disaster event, failure to effectively manage traffic on road networks has led to a major disruptions as well as security issues. As a result, emergency service organisations frequently deploy Traffic Management Points (TMP) or road blocks as part of a broader traffic management plan during a disaster. Despite the good intention, these road blocks are often a source of significant conflict among local communities and others with a pecuniary interest in the affected area.

General warnings and alerts are typically not effective for motorists. Flash floods and bushfires can suddenly create hazards. Drivers often have limited knowledge of threats from disasters and the options available to avoid them, such as knowledge of alternative routes. Emergency services in disaster situations typically have to create a number of road blocks and develop diversion plans.

Decision Support Systems (DSS) are widely used in emergency management to solve a range of complex disaster related tasks. They can provide a representation of disaster scenarios to assess vulnerability, damage cost and emergency response policies in disaster mitigation, preparedness, response and recovery phrases. Usually DSS for emergency management are designed to cope with a specific type of disaster, such as floods (Todini, 1999), earthquakes (Eguchi et al. 1997) and hurricanes (Tufekci 1995). However very few existing DSS can provide decision support for multi hazards and guidance for drivers. Hazus (FEMA 2014) can provide decision support for disasters such as earthquakes, hurricanes and floods. Hazus includes models for predicting potential losses from natural disasters and utilises Geographic Information Systems (GIS) to visualise high-risk locations and infrastructure. It is however limited to estimating losses and developing mitigation approaches as well as supporting disaster response. It cannot provide information for managing traffic networks following disasters.

Currently, there are no systems for supporting emergency managers and drivers in responding to hazardous conditions during or immediately following a disaster. There is a need for improved decision support to reduce the disruption costs for drivers as well as enhance their level of security in emergency situations. Recent developments in sensor networks, spatial data analysis procedures and traffic models provide an opportunity for improving the management of traffic during disaster events. This paper describes a range of advanced technologies that have been integrated to create a unified platform for reducing the disruption costs to road users in emergencies.

2. The Intelligent Disaster Decision Support System (IDDSS)

The Intelligent Disaster Decision Support System (IDDSS) developed within the Centre for Disaster Management and Public Safety at The University of Melbourne provides a platform for integrating a vast range of road network, traffic, geographic, economic and meteorological data as well as dynamic disaster and transport models (CDMPS 2014; Rajabifard et al. 2015). It has numerous features for supporting homogenous data aggregation, manipulation and visualisation that can be used to investigate a wide range of disaster management issues.

The IDDSS is designed to provide decision support for a wide range of natural disasters including bushfires and floods. It aims to facilitate decision making processes in natural disasters such as floods and bushfires by integrating disaster modelling, spatial data analysis, visualisation and optimisation technologies. The IDDSS system is a data-driven system, which needs to access and manage homogenous geospatial data from distributed sources as well as the validated Volunteered Geographic Information (VGI) from crowd-sourced platforms, dynamic feeds from social media channels (e.g. Twitter) and live data from sensor networks (e.g. VicRoads and the Australian Bureau of Meteorology). It can also be treated as a model-driven system since all the modules and functionalities are designed to integrate and extend various existing disaster models.

The spatially enabled platform incorporates both spatial and non-spatial information from a variety of sources as well as authoritative information and also other relevant data and crowd-sourced geospatial data. Transport authorities and state decision-makers are authoritative stakeholders whose roles are directed by polices, regulations, and laws. Authoritative stakeholders may guide the overall response and recovery and provide initial resources to mitigate damage in extreme events, but social stakeholders, such as private industry and communities, will participate in the process as well.

The IDDSS generates decision-relevant information using spatial data integration relating to the status of the transport network and the surrounding environment permitting a deeper understanding of the interactions between risks, decisions and the performance of transport networks to be gained. The IDDSS also provides a spatial enabled information platform for integrating the datasets required for simulation and optimisation modelling.

This trans-disciplinary perspective examines the interplay and dynamics across all pieces and focuses on developments that can produce major improvements in coordination, synchronization, resilience, and preservation of critical transport infrastructure over space and time during the stages of disaster response and recovery to extreme events. Similar approaches have been used by governments across Asia-Pacific influencing how they build, use and administer their spatial information infrastructure with a focus on sustainable development and disaster management (Holguin-Veras, et al., 2012; Rajabifard, 2007; Mansourian et al. 2006).

The system architecture identifies a range of services that directly or indirectly work with aggregated geospatial data. It is crucial to construct an integral data management solution for the IDDSS. Two open-sourced projects Postgres (with PostGIS plug-in) and GeoServer are employed for this purpose. The combination provides a foundation for the IDDSS data management including data storage, query, analysis, conversion and publishing and remarkably improves the flexibility and scalability of data sources configuration for the IDDSS. IDDSS embraces open-source frameworks and open standards (CDMPS 2014).

Disaster modelling and related spatial analysis is another key feature of the IDDSS. GRASS (Geographic Resources Analysis Support System), R and GeoTools libraries are incorporated in the system for this purpose. These libraries are widely accepted and their consolidation provides the IDDSS with sophisticated flood and bushfire models as well as advanced spatial data processing capabilities. The IDDSS focuses on utilizing existing disaster models rather than developing new models which allows the system to be used on a broad range of disasters and analysis of their impacts (such as risk areas, transportation networks and local economics) across heterogeneous data sources.

The IDDSS provides a platform for integrating spatial data (including infrastructure and terrain) as well as models (including disaster and traffic simulation) that can be used to investigate a wide range of disaster management issues. The IDDSS has numerous features and widgets to support homogenous data aggregation, manipulation and visualisation. This broad range of functionalities improves useability and makes it easier to extend and apply in different scenarios. The data layers, modelling and simulation analysis processes can be accessed via a web interface that gives complete flexibility to the users to select data layers and run simulations.

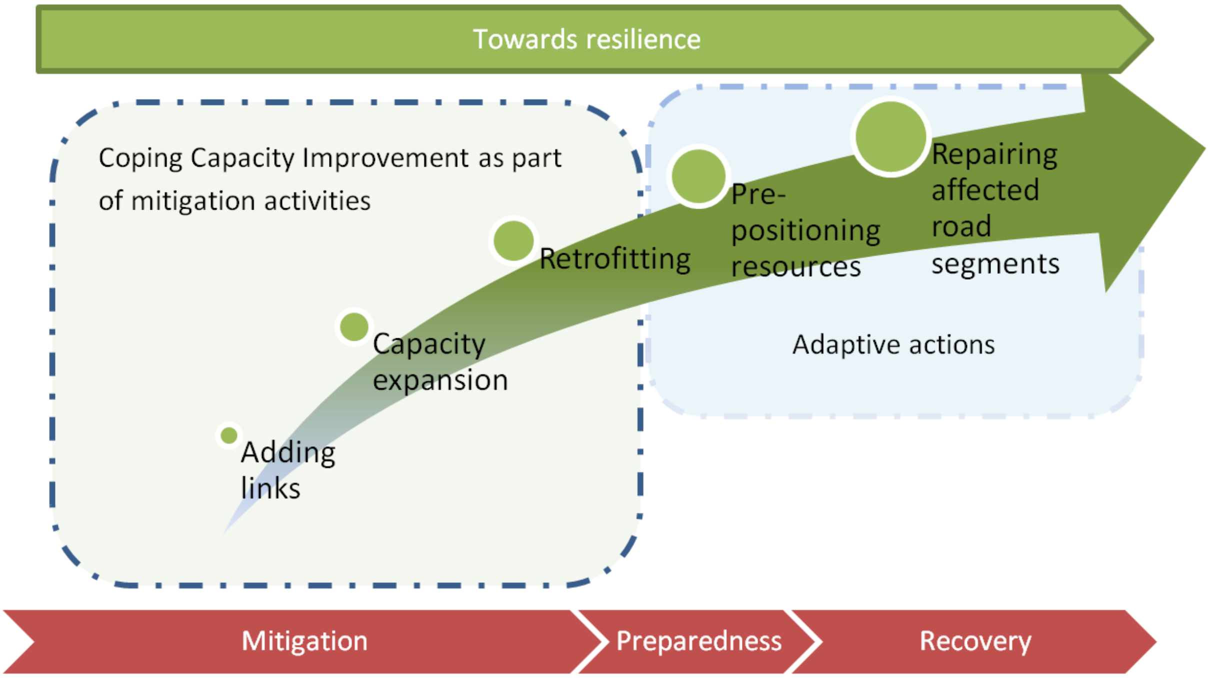
Simulation modelling is used to represent disaster events and their impacts as they develop. A scenario based approach is used to characterise the nature of disasters. This includes the scale, intensity and timing of extreme events. Estimates of the damage to transport infrastructure networks are then made. Changes to the transport demand based on the residual capacity of the network can subsequently be determined.

3. Road Network Resilience and TMP Planning

Although there is a degree of uncertainty around the definition of road network resilience, Murray-Tuite (2006) defines it as a system's performance under disruptive conditions and gives a quantitative measure for network resilience as performance of the network in terms of traffic flow in an unusual circumstance. Miller-Hooks et al (2012) postulates two aspects for road network resilience which were originally suggested by Rose (2004). One aspect is the inherent quality of a network through its topological and operational attributes to cope with a disruptive condition, that is called “coping capacity” by Faturechi & Miller-Hooks (2014).

The other aspect is a set of adaptive actions that could be taken into account to make the network more resilient. These actions may be either pre-incident or post-incident. In other words, not only should a road network be designed in a way to be more resilient but also activities that are performed during the aftermath of a disaster play an important role in its resilience. Based on this definition of resilience, several studies have been conducted so far to both assess a network’s performance measure like resilience and optimise pre-disaster and post-disaster activities so that the chosen measure of resilience is kept to the highest level (R. Faturechi & Miller-Hooks 2014; Zhang & Miller-Hooks 2014; Miller-Hooks et al 2012; Chen & Miller-Hooks 2012). Likewise, for pre-disaster or post-disaster activities, the aim is to make an optimal investment decision in order to keep the resilience of the network at highest level. Figure 1 demonstrates this concept for road network resilience.

Figure 1: Inherent and adaptive aspects of road network resilience



According to the abovementioned conceptualisation for road network resilience, during the mitigation phase in the disaster management cycle, some activities such as adding links, capacity expansion and retrofitting can be taken into account to improve the resilience of a network. Moreover, adaptive actions during the preparedness and recovery phases, such as pre-positioning resources or repairing road segments during the aftermath of a disaster affect the resilience of a road network.

One important aspect in adaptive actions that affects the resilience of a road network is managing traffic flow through Traffic Management Points (TMP) and road closures in aftermath of a disruptive event. The significance of planning TMP has two major aspects. One aspect is more user-centric when operation authorities want to keep system-wide performance of the network to the highest possible level. For example, the interest here is to minimise the increase of total travel time in a network after a disruptive event while road closure is inevitable to keep drivers outside the impacted areas. Hence, road closures should be planned in an optimum way so that drivers are less affected by the incident and their exposure to disruption is minimised.

The other major aspect is more operation manager-centric where system managers and authorities are more interested in facilitating evacuation and logistics operations and protecting the community and its safety. Murray-Tuite (2006) highlights safety as one dimension that affects resilience. Furthermore, transportation networks play a critical role in natural and human-caused disasters as an underlying means for evacuation, rescue operations and mobilising essential resources for increasing the safety of those in the vicinity of the impacted areas. In an emergency, while the need for movement increases drastically, the availability of transportation infrastructure often deteriorates. In other words, the demand for transportation escalates while supply shrinks in the wake of a disruptive event such as a bushfire or flood. Therefore, in this situation, road closures should be managed in an efficient way that not only supports the safety of drivers but also be optimised from the perspective of both normal users and system managers (e.g. incident controller) who want to support logistics and evacuation operations as well. Huibregtse et al (2012) also illustrates the positive impact of road closures in the evacuation process that adds another angle to the importance of efficient TMP planning.

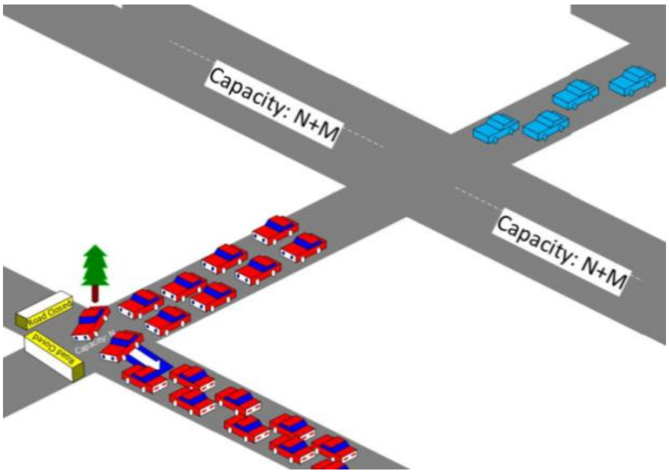
3.1 Traffic Management Point Planning

According to Guidelines for the operation of Traffic Management Points during class 1 emergencies, the purpose of TMP is to control the traffic flow where an emergency happens or has the potential to happen. These emergencies include natural disasters such as bushfires and floods or any type of damage to road network components that makes it unusable or dangerous to use. TMP may have different access levels depending on the incident. Furthermore, incident controllers establishes and manages TMP in consultation with persons from the emergency services and people who know the area. After the decision is made by an incident controller, the police force is usually responsible for managing road closures or they may delegate it to personnel from other emergency organisations such as firefighters. This practice of decision making may fail to look at the system-wide performance of the road network as well as potential logistics and operation activities because it is undertaken by persons who lack detailed knowledge of these factors.

One reason that decisions may not be optimum is because the decision maker does not necessarily have perfect knowledge about the affected road network whereas having thorough knowledge of the road network is essential for efficient planning (Zimmerman 2010). To illustrate its importance, consider the scenario represented in Figure 2 as an example. Knowing that left and right turns at the first crossroad on the right of the image has more capacity than the second one, if incident controller decides to divert the traffic in the second crossroad, it may lead to more congestion compared to the first crossroad. Additionally, if drivers who have not yet entered into the congested road (blue vehicles) are informed about the road closure ahead, they may decide to reroute at the first crossroad. Since drivers typically do not have any knowledge about the incident and the road closure, they will continue until they encounter the congestion. In this scenario, if the road closed at the first crossroad on the right in Figure 2, its adverse impacts on traffic flow would be lower.

As discussed above, since the current practice of managing TMP suffer from the lack of complete knowledge of the affected road network, decisions are not guaranteed to be optimised. Thus, DSS, can provide a tool for integrating required geospatial and traffic data, optimisation and simulation could be helpful in making optimal decisions. Such DSS may involve utilising two approaches. The first approach is more optimisation-based where a simulated incident is given to an optimisation problem to find the optimal locations for TMP. In this approach, the objective is to make decisions which maximise a preferred performance measure for the road network. This performance measure, which is chosen by incident controller, could be various measures of effectiveness such as travel time, distance, flow and capacity (throughput) or accessibility. The second approach to support the process of decision making using DSS is more simulation-based. The main goal in this approach is to simulate the impact of potential decisions made by incident controller on the road network prior to implementing TMP in the real world.

Figure 2: A scenario where road closure caused congestion



Moreover, the other way to deal with the adverse impacts of road closure is by communicating information about road closures ahead to drivers through in-vehicle guidance systems and variable message signs (VMS). In-vehicle guidance systems have been shown to have a great impact on mitigating congestion in urban road networks (Dong 2011). In fact, in-vehicle guidance systems can be considered a type of an Intelligent Transportation System (ITS) that aims to make transportation systems more efficient by providing a platform for decision making. Recently, dynamic route guidance systems (DRMS) allow drivers to decide on their trips based on dynamic travel time and real-time congestion instead of traditional shortest paths that only consider off-line, static or time-dependant travel times of the road network segments. In other words, DRMS consider the uncertainty and dynamic aspects of transport systems and communicate information about delays that may happen because of potential uncertainties in supply and demand or natural and human-made incidents on roads. In addition to in-vehicle guidance systems, the role of VMS has been studied by Erke et al. (2007). Results show that drivers have a high level compliance with information presented on VMS particularly when road closure details are displayed.

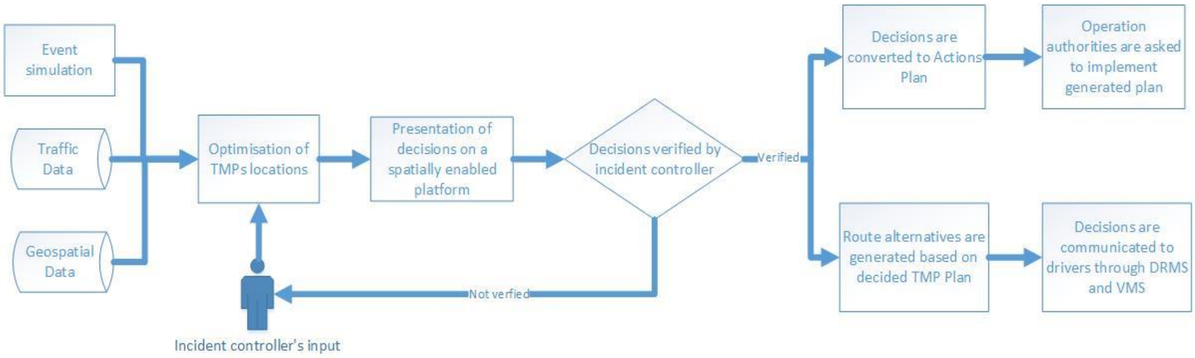
Integrating an optimisation-based approach with DRMS and VMS as two methods of communication to drivers, a decision support system may be utilised to optimise TMP planning in the first step. Then, road users could be informed about the possible congestion that can be created by road closures. This information can be also supplemented by alternative routes as well. Figure 3, illustrates this approach.

Taking the approach illustrated in Figure 3, in order to optimise the process of decision making for TMP, the IDDSS is a suitable platform to be utilised. One reason is because of its disaster simulation engine which is needed for the TMP optimisation. Currently, bushfires and floods can be simulated in the IDDSS. Moreover, the visualisation power of IDDSS helps present spatiotemporal information in a spatially enabled platform. Importantly, IDDSS has data integration features which facilitate providing heterogeneous spatial and non-spatial data for optimisation. Figure 8 shows a simulated bushfire in IDDSS along with its impacted road network and risk area. The following section elaborates on TMP planning optimisation as an element of decision making flowchart presented in Figure 3.

3.2 TMP Planning Optimisation: Conceptual Framework and Formulation

A conceptual framework for optimising TMP planning (TMPP) as part of a DSS-module which is being built within the IDDSS is shown in Figure 4. This framework consists of three layers including disaster simulation, traffic simulation and optimisation. In the disaster simulation layer, a scenario-based technique is used. This involves a hypothetical disaster scenario being created while the probability of the scenarios is not considered. A scenario is created by the IDDSS disaster simulator. After simulating the disaster, impacted road networks are analysed and used for optimisation. However, impacted road network elements could be chosen by an incident controller as an external input as well. Furthermore, a risk assessment layer is required to identify risk level in the vicinity of the simulated disaster. This analysis is necessary to estimate a buffer zone that is considered as safety margin around impacted areas. For this purpose, the incident controller would determine a desired risk level to construct the buffer zone. The buffer zone includes all areas that have a higher risk than the chosen risk level. In other words, higher than a certain risk level should be preserved as buffer zone so that if the incident spreads then response organisations will have enough time to react accordingly.

Figure 3: Flowchart of DSS-intervened decision making



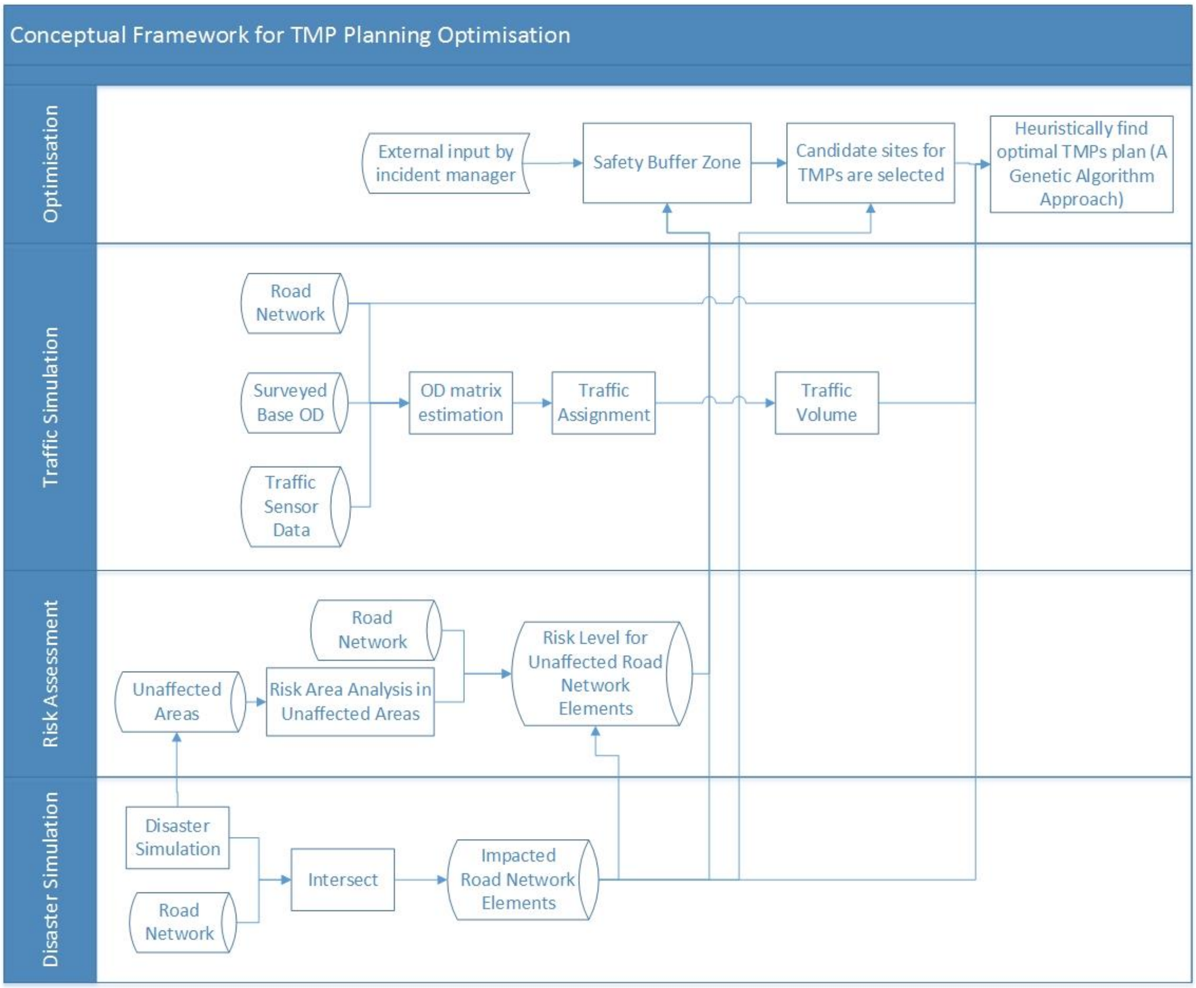
In the traffic simulation layer, the demand is first calculated through solving an Origin-Destination (OD) demand estimation problem. This problem aims to find a feasible OD matrix by using traffic flow sensors. OD demand estimation problem is formulated as an optimisation problem where it is desired to minimise the difference between the estimated OD matrix and target OD matrix as well as minimising the difference between observed link flows and estimated ones. The approach used in this study is based on the method proposed by Spiess (1990). This method involves a base OD matrix being adjusted by observed traffic counts. The base OD matrix can be built upon survey data and a trip distribution model although this approach works without having a base OD as well. Here the observed traffic counts are retrieved from traffic sensor datasets.

Using the output of OD demand estimation, a traffic assignment problem is solved to calculate the traffic volumes on each link. Traffic assignment, route assignment or route choice is concerned with behaviour of users in the selection of available paths. One model for traffic assignment is User Equilibrium assignment (UE) which is developed based on Wardrop’s equilibrium condition (Patriksson, 1994). However, a multiclass traffic network equilibrium model may be more suitable since not all vehicles will be able to use all links. In multiclass traffic network equilibrium, the class of vehicle types such as trucks versus cars are taken into account.

Finally in the optimisation layer prior to actual optimisation process, a set of intersections are selected as candidate sites for TMP. This selection leads to lower disruption costs because, at a TMP, vehicles do not need to do a U-turn and go back using the same road. Therefore, a set of candidate sites consists of all intersections within an area around the buffer.

After constructing the set of candidate sites, the actual process of optimisation starts. Inspired by Network Design Problem (NDP), we formulate TMPP problem using a bi-level optimisation approach. NDP deals with making optimal decisions about the expansion of road network infrastructure. Yang & Bell (1998) proposed two forms of NDPs. One is a discreet form which involves adding new road segments (links) to existing infrastructure. The other form is continuous which deals with optimal capacity expansion of existing road segments. With either addition or expansion, the NDP is interested in optimizing an investment decision that maximises or minimises a network performance measure (e.g. total travel cost or throughput) while considering the effect of decisions on route choice behaviour of the users. However, in the TMPP problem, we are interested in knowing what the optimum decisions are for closing network links so that those decisions, as opposed to other non-optimal ones, minimise travel time within the disrupted road network. In other words, the goal is to know what set of TMP will result in higher travel time reliability. Travel time reliability as a critical network performance metric has attracted considerable attention of researchers (Faturechi & Miller-Hooks 2014). As discussed earlier, the reason behind identifying optimum solution for TMPP is that this can be used to develop an efficient plan to reduce congestion that happens due to drivers' lack of knowledge about road closures. Hence, TMP planning is defined as an NDP which can be formulated in a bi-level optimisation framework.

Figure 4: Conceptual Framework for TMP optimisation



In bi-level framework for NDP, a game theoretic approach called Stackelberg leader-follower competition is utilised. In this approach, upper-level, decisions are made by system manager to optimise a system-wide performance measure and in the lower level, drivers use the system for their own benefit in a way to minimize their travel costs. In this framework decisions that are made in upper level affect route choice decisions in the lower level, although upper level decisions do not determine the exact user's behaviour. The optimal solution is reached when above Stackelberg competition reaches an equilibrium when neither leaders nor followers can improve their benefit (Gibbons 1992).

Following above definition, Yang & Bell (1998) formulate the network design problem as Eq. (1) to (4).

$$Minimize\ F\big(u, v(u)\big) \qquad (1)$$

$$Subject\ to\ G\big(u, v(u)\big) \leq 0 \qquad (2)$$

Where *v(u)* is defined by:

$$minimize\ f(u, v) \qquad (3)$$

$$subject\ to\ g(u, v) \leq 0 \qquad (4)$$

Where *F* is the objective function of the upper-level decision-maker and *u* is the decision vector (design decisions). Moreover, the objective function at lower-level is defined by *f* along with its decision variables *v*. In addition, *G* and *g* are the constraint sets of upper-level and lower-level decision makers, respectively.

By formulating the TMPP as a NDP in a bi-level framework, we seek to make decisions which minimise the total travel time of the whole network with disrupted links. In the upper level, the objective function is to minimise total network-wide travel time subject to relevant design constraints. The decision vector consists of decisions relating to choosing the roads that should be closed. Accordingly, *v(u)* is herein defined as the network equilibrium flow which is considered as a response of lower-level problem to the decisions at the upper-level. Hence, the abovementioned user equilibrium assignment is used to model the behaviour of drivers taking advantage of the new designed network.

Since a bi-level structure with a non-linear traffic assignment in the lower level is an NP-hard problem (Mesbah et al 2012), a heuristic solution method is appropriate for solving it. Thus, a hybrid genetic algorithm is exploited to solve the TMPP problem where each chromosome represents a set of decision variables for TMP. That is, each chromosome represents a solution of which links in the road network are blocked. In order to comply with the set of candidate sites as design decisions, each solution represents a combination of links whose start or end nodes are among the set of candidate sites. Moreover, special crossover and mutation techniques need to be designed so that the population of chromosomes is constrained to assure the disaster-impacted area is unreachable. The fitness value for each solution is a function of solution’s disruption cost. The disruption cost is calculated by Eq. (5).

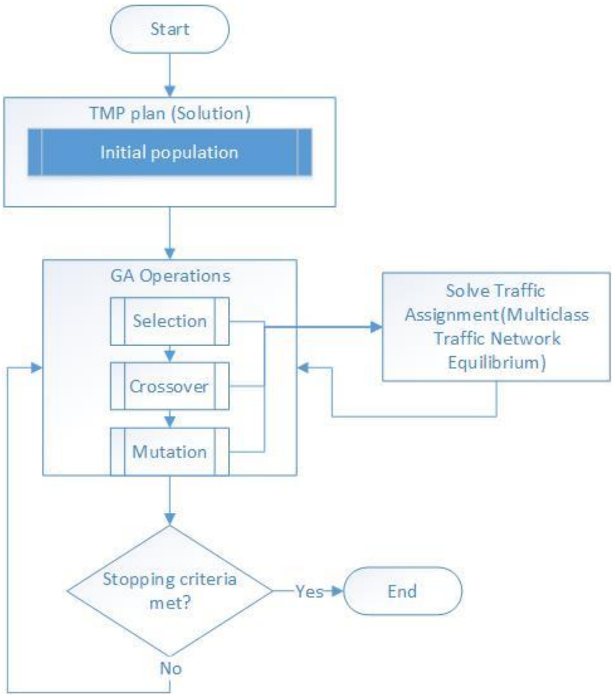
$$C = \frac{T_d}{T_o} \qquad , \ T_d > T_o \qquad (5)$$

Where *C* is the disruption cost, T_o is original travel time of the network before the incident and $T_d$is the network’s travel time with the impact of disruption. Having this disruption cost, the fitness value for each chromosome can be normalised by $\frac{1}{C}$ which means that a fitness value is higher with a lower disruption cost. To calculate the travel time of disruption, a user equilibrium assignment is performed to compute the total travel time in the network for solutions of the GA. Figure 5 presents an overview of the hybrid GA which is adapted from Zhang & Miller-Hooks (2014).

3.3 Scenario Analysis for Urban Flood

This section illustrates how the TMPP module of IDDSS can be applied to urban flooding. The Maribyrnong river region located in Melbourne’s inner western suburbs is used to illustrate the flood modelling capabilities within the IDDSS. This area has a mix of residential and commercial properties that have been severely affected by floods several times in the past. This is particularly due to low elevation, which is surrounded by hills that increases the risk of floods and their potential impacts as the majority of this area can be inundated by major floods (e.g. event with 100-year return period).

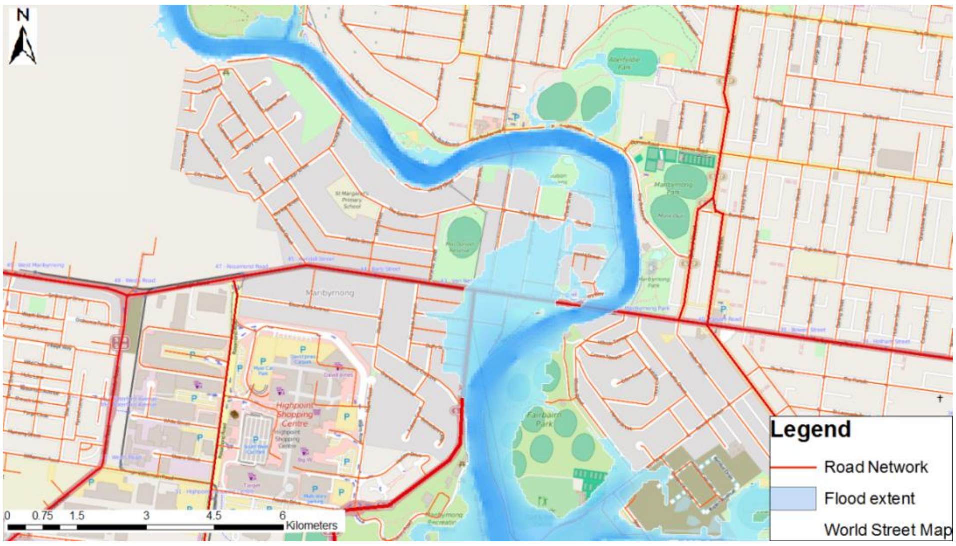
Figure 5: The overview of the GA for solving TMPP



In 2014, over 371 residential and non-residential buildings were located in this area that could be potentially affected by floods. Over two-thirds of the buildings are one-storey residential houses and they can be highly impacted. Raleigh road, which is the extension of the Maribyrnong road, serves as the major road connecting the township and the city. This critical road can be highly affected by floods since it is partially built over the river through a bridge. Other streets and roads in the area can be blocked as the result of a flood and traffic can be completely disrupted by moderate and major floods.

The IDDSS provides several analysis methods to help gain a clear view of the situation and facilitate decision making processes. The hydrologic model “r.lake” from the GRASS library (GRASS 2014a) can be used to simulate the progression and growth of flooding (CDMPS 2014). Outputs include a range of flood maps as well as damaged road network elements (Figure 6).

Figure 6: Model outputs: flood map (blue polygons)



Having the features of a simulated flood, it is important to find out what segments of the road network are affected by flood and accordingly the extent of safety buffer zone gained through spatial analysis. The TMPP module is then applied to investigate possible users' behaviour on the newly shaped road network and optimise the location of TMP based on the method described above. Since this process involves an iterative process including OD matrix estimation and traffic assignment plus calculation of fitness for each solution in upper level function, it is substantially computational intensive. Consequently, it may take enough time to make running this process in the background a necessity. Figure 7 shows the proposed locations for TMP that are visualised after the optimisation process finishes.

Figure 7: Proposed locations for TMP on the road network (roads in red are disrupted)

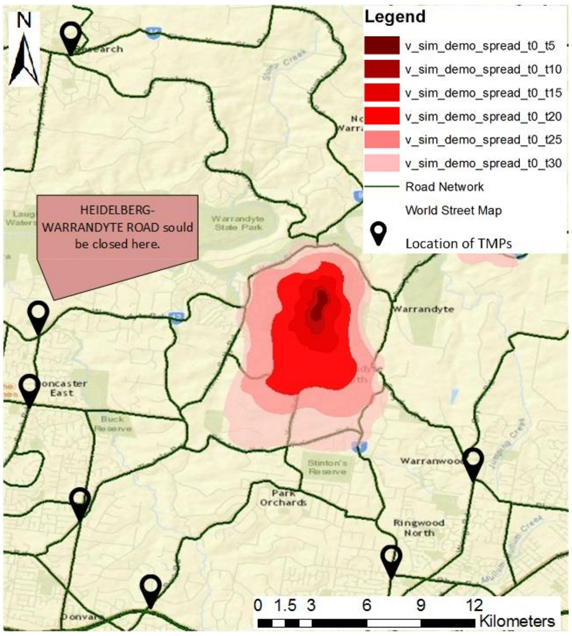
3.4 Scenario Analysis for Bushfires

Similarly, this section illustrates how the TMPP module of the IDDSS can be applied to bushfires. Warrandyte, a north-eastern suburb in Melbourne (24km from the CBD) was chosen as the study area for the IDDSS bushfire simulation. It was at the centre of the "Black Friday" bushfires that occurred in January 1939, in which 71 people died, 1300 homes were burnt and a total of 3700 buildings were destroyed. Other major bushfires swept through Warrandyte in 1851 and 1962.

The majority of the area is classified as a bushfire prone area due to its location, being situated in, "a meandering gorge along the Yarra River and surrounded by forest parks and hilly bushy areas. The extreme bushfire risk comes from the combination of high fuel loads in the surrounding forest parks, homes nestled into bushland, the hilly terrain and a lack of accessibility with few major roads and narrow unmade local roads" (MFB 2012).

The IDDSS can provide information for planning road closures. Using the bushfire model "r.spread" (GRASS 2014b) from the GRASS library and starting the simulation with validated VGI bushfire reports (ignition points), the system can provide an animation showing how the bushfire spreads over time. In addition, the simulation shows the elapsed spread time, wind speed and direction, as well as the number of persons, properties and land size are that under risk. During setting up a scenario to run, various settings such as wind speed, wind direction and ignition points are chosen and the model simulates the bushfire accordingly. Figure 8 illustrates a bushfire scenario with one ignition point as well as the result of optimisation performed by the TMMP module in the IDDSS to propose the best location for TMP. This optimal solution considers the topological and operational attributes of the network from both a supply and demand perspective.

Figure 8: Visualisation of the bushfire spreading and proposed locations for TMP on the road network



4. Conclusions

Extreme weather events arising from climate change are posing serious threats to the reliability of transport systems, creating the need for improved tools for decision support for more effectively managing disasters.

The IDDSS provides a platform for integrating a vast range of road network, traffic, geographic, economic and meteorological data, enabling plug-in components with innovative models and algorithms to be implemented in a systematic means. Dynamic and flexible models can be used for managing road transport systems allowing evaluation of disasters scenarios. The paper illustrates how the damage to traffic networks from floods and fires can be estimated and visualised. This information can be used for models to determine the location of Traffic Management Points that minimise the disruption to road users. In doing so, an optimisation framework has been developed to plan the optimal location of Traffic Management Points based on the residual capacity of road network and estimated demand levels.

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