Using GoldSim for joint probability assessment of closure times on linear infrastructure

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ABSTRACT

Flooding of major regional roads and rail corridors severely disrupts transport operations including the export of mined minerals from central and north Queensland which contribute heavily to the Australian economy. It is important for proponents developing new infrastructure and operators of existing infrastructure to understand annual closure times resulting from flooding.

Long linkages of road or rail that cross a number of catchment basins and a large number of drainage lines can be difficult to assess due to spatial variation, moving storms and concurrent storms. The objective of this paper is to create a simple methodology, using joint probability, to quantitatively assess the closure time along linear infrastructure. For this paper, the Monte Carlo software package GoldSim was used to represent the road or rail system.

The assessment approach requires an initial assessment of catchment dependence along the corridor. This requires knowledge of the location, catchment sizes and regional hydrology, but can also involve analysis of gauged data. Hydrological and hydraulic assessments are also required for each drainage feature along the corridor, with key information being the duration of closure for various ARI storm events.

The duration of closure for a range of Average Recurrence Intervals (ARIs) is represented in GoldSim for each drainage feature by a probability distribution. The occurrence of a storm event is sampled from distributions within the model that correspond to the ARI and can be weighted to different times of the year. For example, there is a higher probability of an event occurring during the wet season (determined from frequency analysis). Independent catchments are sampled from separate distributions.

The GoldSim model is run many times, upward of 1000 times, allowing many different sequences and combinations of storm events and crossing closures to be triggered. The resulting cumulative annual closure times from each run can be presented as a distribution from which the average annual time of closure can be determined. The distribution can also be used to assess the time of closure for any required probability; for example, the 1% annual expected closure time.

Using these results, it is possible to determine critical links and crossings allowing for prioritisation of upgrade works or focus design efforts when establishing new infrastructure. This assessment methodology provides a powerful and accessible modelling approach that uses commonly available software.

KEYWORDS

Infrastructure closure times; Flooding; GoldSim; Joint probability

REQUESTED PRESENTATION FORMAT

- Standard 15 minute Presentation and 5 minute Q&A

1 INTRODUCTION

Flooding of linear infrastructure corridors can occur as a result of multiple storm events, or a single cell that moves along the corridor. The flood immunity of long linkages of road or rail that cross catchment basins and a large number of drainage lines can be difficult to assess. In order to simplify the assessment, empirical formulas are often applied to assess flood immunity. In many cases, the infrastructure link is not assessed as a whole, with the focus being placed instead on flood prone areas.

This paper describes the use of a quantitative probabilistic approach to determine closure times and closure frequency along the whole infrastructure link. The approach uses joint probability, modelled explicitly using the Monte Carlo software package GoldSim. This assessment methodology provides a powerful modelling approach using a software platform that is in wide use across Australia.

2 FLOOD IMMUNITY CALCULATION FOR LINEAR INFRASTRUCTURE

The flood immunity of a culvert or bridge crossing is relatively straightforward to determine. The normal process followed is to develop a hydrology model of the regional catchment, develop a hydraulic model of the local area and then assess the performance of the structure under a range of design storm events (various ARIs and storm durations).

This process is repeated for all crossings along the road or rail link of interest, which may stretch hundreds of kilometres. In most cases there would be a range of flood immunities along the link. For illustrative purposes however, assume all crossings have a 50 year ARI flood immunity.

Counter to popular belief, the flood immunity of the corridor is rarely 50 year ARI. Because each crossing can experience different storm events at different times, the flood immunity of the corridor is usually less than 50 year ARI. Flood immunity along the corridor might be more like 10 to 20 year ARI, despite individual crossings having a flood immunity of 50 year ARI.

In addition to closure frequency, infrastructure managers are also concerned with closure duration. The duration of closure, often reported as “average annual time of closure” is a function of the closure frequency as well as the closure duration of individual crossings contributing to the closure. Like flood immunity, closure duration is relatively straightforward to calculate for individual crossings, but difficult to calculate for long linear infrastructure corridors.

3 ASSESSMENT METHODOLOGY

The method of assessing closure times presented in this paper is based on a Monte Carlo approach. A synthetic sample set of annual closure times is generated by running a model many times over (more than 1000 times), allowing many different combinations of closures times along the road or rail link to occur. This provides an explicit probabilistic analysis of the link, giving the user a detailed understanding of the performance of the road or rail link and identifying areas of the corridor with the greatest influence on flooding behaviour. This knowledge can allow for more informed decisions regarding prioritisation of upgrade works.

A flow diagram of the model methodology is presented in Figure 1 and discussed in the section below.

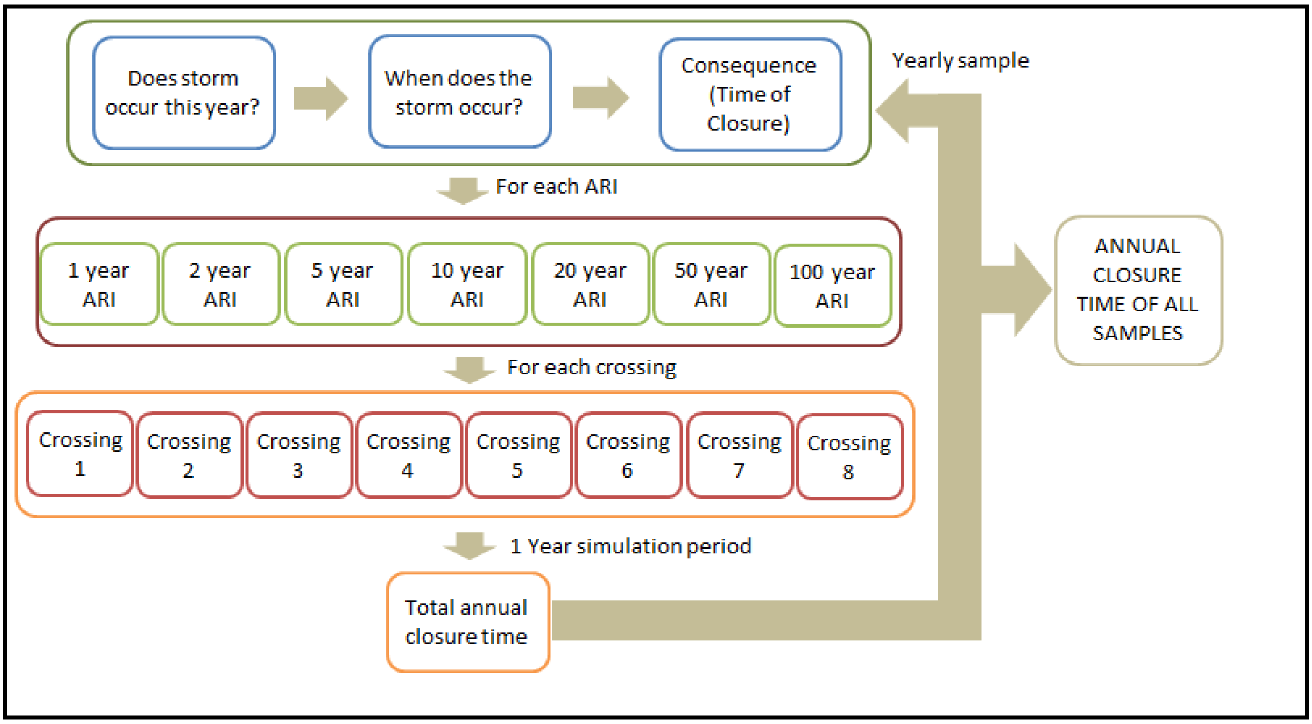

Figure 1: Conceptual model

Each crossing along the corridor is represented in the model in terms of its flooding characteristics (e.g. flood immunity and closure duration for a range of design storm events). The model is then run over a one-year simulation and each crossing is subjected to storm events based on the probability of them occurring. For example, the 100 year ARI has a 1% probability of occurring in a given year, the 50 year ARI has a 2% probability and so on. If a storm (or multiple storms) occurred in that given simulation, the model would choose when it occurred in the year using a probability distribution that could be weighted towards different parts of the year; for example, large ARIs could be weighted to more likely occur in the wet season.

The consequence of each ARI would be predetermined from hydrological and hydraulic modelling. The total annual closure time of the road or rail link would be summed up at the end of the one-year simulation period and the model would restart. The model repeats this process many times and at the completion of all model runs, the user would have a sample set of annual closure times.

The model runs on a daily time step. This enables storms at different crossings to potentially overlap or occur at the same time, possibly resulting in one of the storms not affecting the overall time.

The model relies on hydrological and hydraulic modelling of all crossings along a rail or road link to give accurate results of total link closure times. This is not always feasible on long infrastructure links due to the quantity of data and modelling required. Flood frequency analysis could be used to substitute modelling; however, gauges would not be available on all crossings (particularly minor crossings) on regional roads. A focus could be given to major crossings from large catchments as these would be expected to cause longer closure times and the resulting probability distribution could be interpreted with the goal only to reduce the frequency of long closures.

4 HYDROLOGICAL INTERDEPENDENCE

The modelling approach described above requires decisions to be made about which crossings are hydrologically dependent. That is, whether a storm event generating flooding in one catchment also causes flooding in adjacent catchments. This assessment needs to be made prior to model setup and can be made by drawing on local knowledge, analysis of hydrological historical records and/or professional judgement.

GoldSim has the capabilities to model the interdependence between catchments in a variety of detail, ranging from broad assumptions that could be used on long stretches of infrastructure corridors with hundreds of crossings, to a detailed analysis with complex dependencies that could be used on only a few crossings. This paper does not attempt to cover such assessments, and the reader is referred to discussions concerning neighbouring catchment dependencies found in papers such as Keef, C. *et al.* (2009) and Guse, B. *et al.* (2009).

5 EXAMPLE APPLICATION

An example application of the model was constructed to demonstrate the capabilities and results from the procedure. Ten crossings were examined for a number of ARI and closure time combinations at each crossing. Table 1 lists the data used for the model. For simplicity, all closure times have been rounded to the nearest day and each catchment was considered independent of one another. Average Annual Time of Closure (AATOC) has also been calculated using methods described in the Department of Transport and Main Roads (DTMR) Drainage Manual Chapter 10 (DTMR, 2010).

Table 1: Example model data used

Crossing ID	**Closure times (days)**							
	1 Year ARI	**2 Year ARI**	**5 Year ARI**	**10 Year ARI**	**20 Year ARI**	**50 Year ARI**	**100 Year ARI**	**AATOC***
1	0	0	0	1	3	5	5	0.4
2	0	0	0	0	0	10	20	0.6
3	0	0	1	1	1	1	3	0.4
4	0	0	0	1	2	2	4	0.3
5	0	0	1	1	1	1	1	0.4
6	0	0	0	0	3	5	14	0.5
7	0	0	0	1	1	3	5	0.3
8	0	0	1	1	1	1	3	0.4
9	0	0	0	0	1	2	3	0.1
10	0	0	1	3	3	6	6	0.8

*AATOC is average annual time of closure

The model was run 1000 times to generate a probability distribution of annual closure times along the whole corridor (crossings 1-10). Using a daily time step, the model run time was less than two minutes on a desktop computer. The resulting annual exceedence curve is presented in Figure 2.

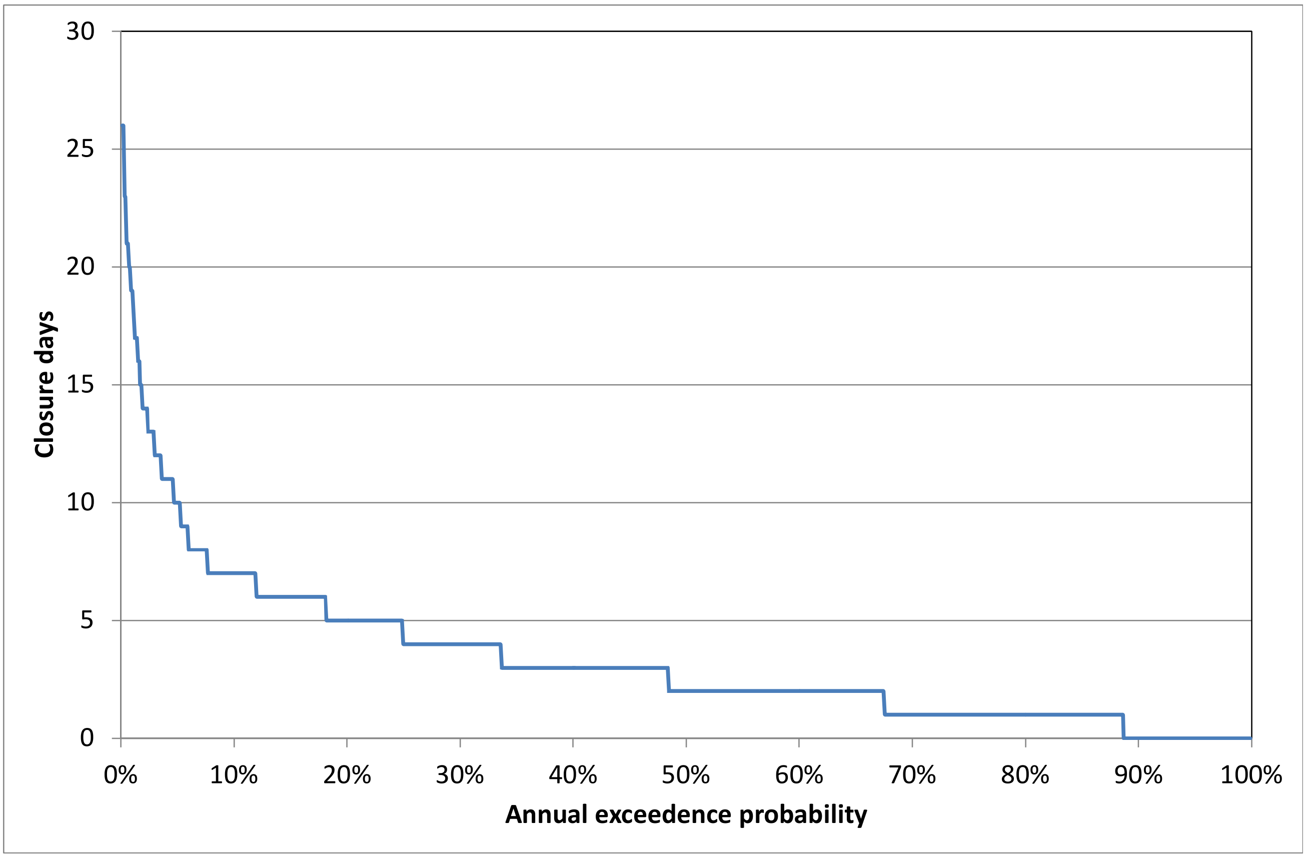

Figure 2: Model results – annual closure time for entire infrastructure corridor

The results show that 50% of the years simulated (2 year ARI) resulted in road closures of two days or less. This is an interesting result, as all road crossings have 2 year ARI immunity. The total immunity of the road is therefore considered less than that of individual crossings. This presents the case for the need to analyse whole infrastructure links as one entity.

Table 2 lists the results of the total road closures by ARI as well as the AATOC.

Table 2: Resulting model infrastructure corridor closures times

Annual exceedence probability (%)	**ARI (years)**	**Closure time (days)**
AATOC	-	3
100%	1	0
50%	2	2
20%	5	5
10%	10	7

Annual exceedence probability (%)	**ARI (years)**	**Closure time (days)**
5%	20	10
2%	50	14
1%	100	19
Maximum result	-	26

When comparing the total infrastructure corridor when compared to individual crossings, the results show a large increase in AATOC. The results also show that the larger ARIs (100 year) are controlled by the larger catchment crossings that result in long periods of closure (crossing 2). In this instance, the 100 year ARI is equal to the 1% total Annual Exceedence Probability (AEP) of crossing 2 (20 days of closure). Although they might not always be equal, it is expected that larger crossings would continue to control the lower probability events.

5.1 Upgrade works

To demonstrate how the model could be used to identify upgrade works, an example upgrade has been modelled. In this case, assume that the proponent has decided that the 1% AEP closure time for the infrastructure link can be no greater than 14 days.

Using the knowledge that the lower probability closure times are controlled by the large catchments, the best crossing to upgrade would be crossing 2. The crossing is proposed to be upgraded to provide a 50 year ARI immunity and to ensure that the 100 year ARI event closure time is improved to within a few days of the desired closure limit. In this case, the crossing is assumed to have been upgraded to the same as the closure time limit of 14 days. The new closure times for crossing 2 are presented in Table 3.

Table 3: Upgraded closure times for crossing 2

Crossing ID	**Closure times (days)**							
	1 year ARI	**2 year ARI**	**5 year ARI**	**10 year ARI**	**20 year ARI**	**50 year ARI**	**100 year ARI**	**AATOC**
2 (Pre Upgrade)	0	0	0	0	0	10	20	0.6
2 (Post Upgrade)	0	0	0	0	0	0	14	0.3

The results of the upgraded works model run are presented in Figure 3.

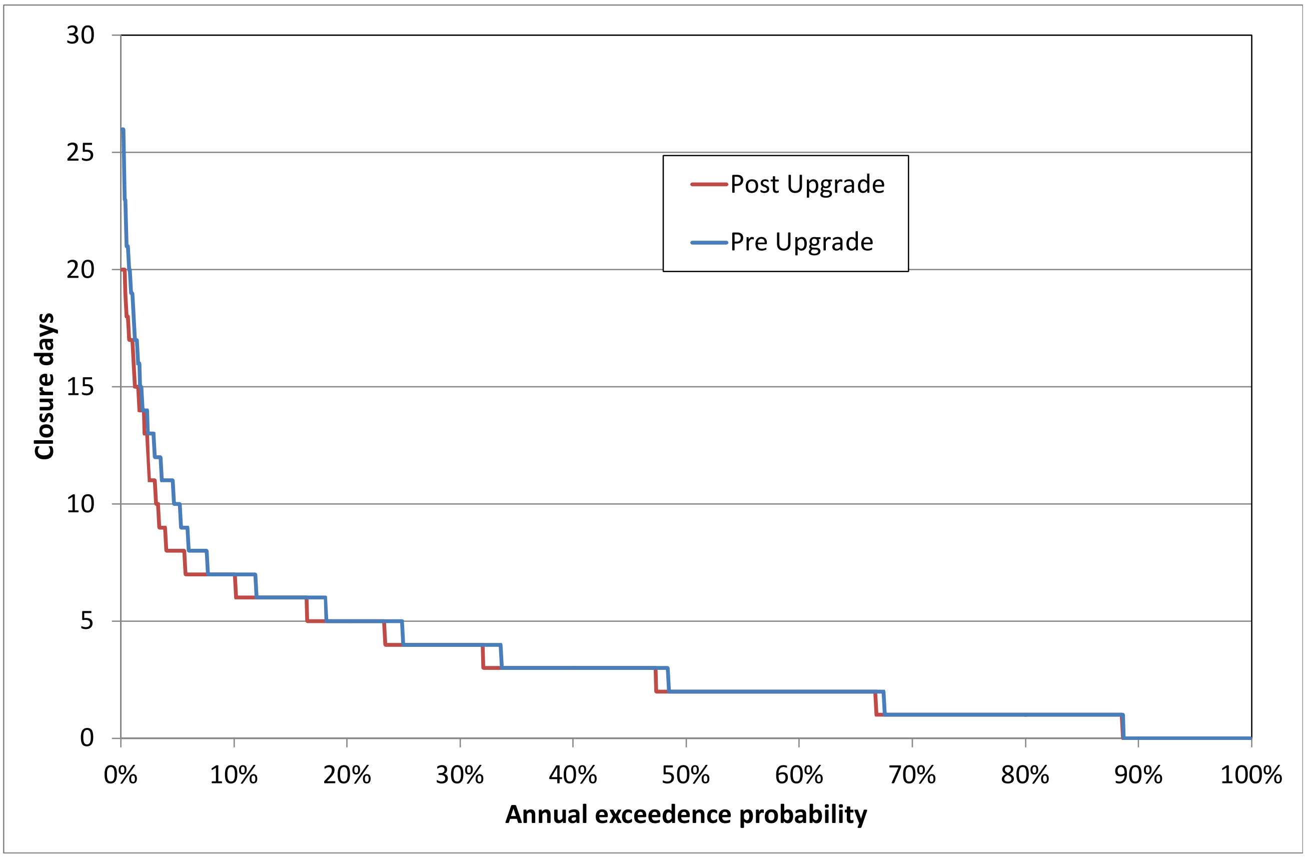

Figure 3: Upgraded works model results

The results show that the maximum result has decreased and that the 1% AEP is 16 days, larger than the desired 14 days. An iterative approach would be needed to achieve the desired outcome. However, due to the quick model run times, this is not difficult to analyse.

The results also show that the upgraded works only have a significant effect in the low AEP range (< 10% AEP). The higher AEP range (> 10% AEP) is controlled by crossings that are flooded more frequently. Although this may be an obvious statement, the aim of this assessment method is to quantify this and provide an improved understanding of the planned upgrade effectiveness and quantify the resulting flood immunity for the whole corridor.

6 CONCLUSIONS

A Monte Carlo approach using GoldSim and joint probability is proposed as a method of assessing the closure times of entire infrastructure links. The approach uses probability distributions to represent when storm events occur, from which closure times can be determined. The model runs many different scenarios to produce a synthetic dataset of annual closure times.

The methodology requires an assessment to be made about the hydrological interdependence of catchments and crossings. This could best be achieved through local knowledge, analysis of historic gauging and professional judgement. These assumptions are considered important, as they affect how well the model reflects the real world.

The example model described in this paper demonstrates the outputs and potential uses of the model approach. The proposed methodology can be modified to incorporate complexities within the system. For example, interdependencies of catchments can be modelled to reflect the level of detail needed. GoldSim has the capability to introduce elements such as storm time of concentration, culvert failures and can even take into consideration the Southern Oscillation Index and climate change.

The methodology aims to quantify the uncertainty within infrastructure links so that proponents can understand overall performance and strategically plan effective upgrades. The methodology however relies on background data and a number of studies to be effective.

7 LIST OF REFERENCES

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Keef, C.; Scensson, C.; Tawn, J.A. (2009), *Spatial dependence in extreme river flows and precipitation for Great Britain*, Journal of Hydrology, Volume 378, Issues 3 - 4, pages 240ï 252, November 2009.

8 AUTHOR BIOGRAPHIES

Ellis Symons is a civil engineer with KBR, providing technical expertise in the areas of urban and rural hydrology and hydraulics, mine water management, catchment management, floodplain management and water quality. He has worked on projects around Australia, including Queensland, New South Wales, Victoria and the Northern Territory. Ellis has worked on a variety of flood studies, including the Mitcham-Rooks rail upgrade in Melbourne, Highland Park urban stormwater flood study on the Gold Coast, Ipswich creeks flood study, Central Highlands Regional Council floodplain management and plan, Ensham mine site levee upgrade, and LNG pipeline creek crossings on APLNG.

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