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A DECISION SUPPORT FRAMEWORK FOR MULTI-HAZARD MITIGATION PLANNING

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ABSTRACT

Hazard mitigation planning is multi-facetted. First, plans should be holistic, considering a number of community goals in addition to risk management. Secondly, plans should guide development over the long term, and need to consider how the frequency, magnitude and consequences of hazards change over time. To assess future changes, a large number of environmental and anthropogenic factors that affect hazard risk need to be estimated, yet strong uncertainty exists in estimating these factors. Thirdly, implemented plans have a wide social, environmental and economic impact; impacts across these systems need to be assessed. Finally, resources for mitigation are limited; benefits of mitigation need to be clear in order to make a business case to decision makers and the public. Due to these facets, decision support systems (DSSs) that include integrated models are invaluable when planning mitigation strategies.

This paper proposes a Natural Hazard Mitigation DSS framework that is designed to support the multi-facetted nature of mitigation planning, and demonstrates how it is being applied to the Greater Adelaide region.

INTEGRATED SPATIALLY EXPLICIT SIMULATION MODEL

The proposed DSS supports mitigation planning by simulating the effects of different mitigation options across the wider social, economic and environmental systems. In order to do this, the DSS contains an integrated model, shown schematically in Figure 1. The integrated model combines flood, bushfire, earthquake, and coastal surge models with social, natural and built environment models.

With regard to risk metrics, our framework allows two different ways for describing hazard. First exogenous maps may be used that give the likelihood of hazard occurrence at a given magnitude. Secondly, endogenous models included within the DSS may be used to calculate these hazard maps. The second option provides greater flexibility in assessing the impact of mitigation options, as these can be directly calculated by the model incorporated in the system. Furthermore, feedbacks between processes impacting on hazards can be included and simulated.

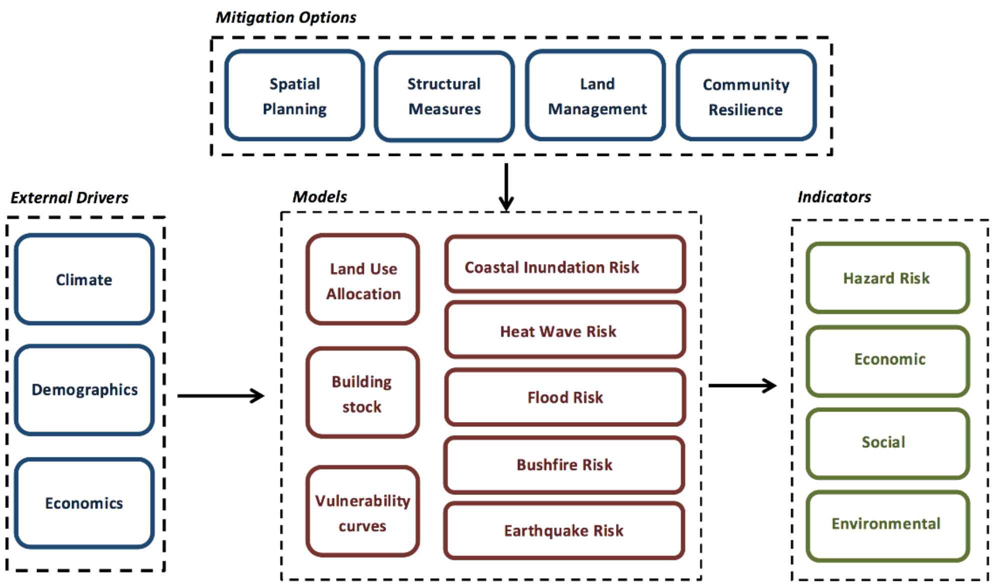


Figure 1. Modelling Components Within the Natural Hazard Mitigation DSS.

In order to assess risk, hazard — obtained by either of these two methods — is combined with dynamically calculated impact models. In our framework we define risk as the likelihood of a hazard occurring at a given magnitude multiplied by its consequence, summed across the magnitudes at which a hazard may occur at.

With regard to models of the social, natural and build environment, we have three separate, but related model components in the system:

1. A land use model that simulates changes in the social, natural and built environment as a result of socio-economic developments, spatial planning, physical characteristics of locations, accessibility and human behaviour.

2. A building stock component providing information on the mix of building types at the statistical area level 2 (SA2), as defined by the Australian Bureau of Statistics.

3. A component calculating the socio-economic impacts of hazards using the information provided by the land use model and the building stock component, together with hazard specific vulnerability curves indicating the damage based on the severity of the hazard and the building type.

The integrated model is used to estimate the values of multiple decision criteria, to enable holistic planning. In addition to risk indicators, the framework also includes indicators relating to social, environmental, and economic implications:

1. A land value component to calculate opportunity cost of mitigation options related to spatial planning based on locational characteristics;

2. Indicator models assessing the wider social implications, such as population density or accessibility to the city centre, places of employment, schools, recreational areas or (urban) green areas; and

3. Indicator models assessing the wider environmental implications, such as extent and quality of the green spaces, habitat fragmentation or (expected) urban development on natural or agricultural areas.

With regard to the temporal resolution at which these models run, most components operate at an annual resolution, in order to capture temporal dynamics well. With regard to spatial resolution, the land use model is set up using a resolution between 50 m and over 1 km square, to include sufficient spatial detail of the modelled area. Spatial indicators are calculated at the same resolution as the land use model or at the same resolution of the input data, such as the Bureau of Statistics SA1 or SA2 level.

MITIGATION ASSESSMENT CAPABILITY

The proposed DSS is designed to simulate the impact of a wide range of mitigation options. The mitigation options that the DSS is designed to simulate were identified through a participatory approach with end users, and include building code changes, land management practices, community based education, structural projects, land use planning, and legislative measures.

FORMAL OPTIMISATION TOOLS

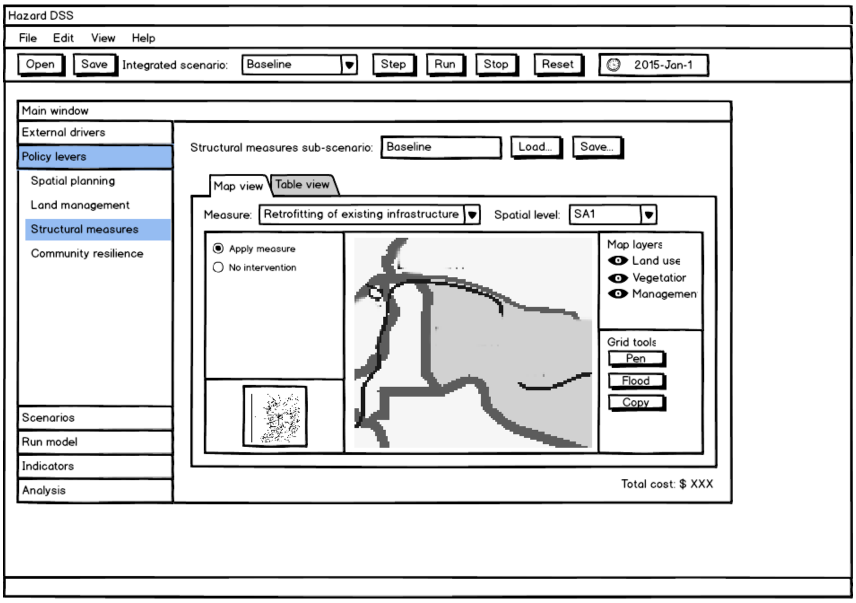
A novel component of the proposed DSS is the linkage of optimisation with the simulation model. The framework uses optimisation to screen through the available mitigation measures in order to identify near-to-optimal (Pareto efficient) mitigation portfolios, subject to budgetary constraints. In general, a large number of indicators are important for decision making, and therefore *multiobjective* optimisation methods are implemented within the software. Multiobjective methods generally find multiple (as opposed to a single) `optimal' designs that cannot be said to be better or worse than each other, but which display optimal trade-offs between the objective functions. It is important to identify these trade-offs so as to not waste scarce resources (for example, it is wasteful to implement a mitigation portfolio that has a higher cost and universally poorer indicator values than a Pareto efficient portfolio). Optimisation is used, as identifying these optimal trade-offs cannot be done manually, as there are too many possible combinations of mitigation measures to test.

Evolutionary algorithms (EAs) are used as the optimisation engine in the software, as they are robust artificial intelligence tools that can be used with any simulation model. Evolutionary algorithms work through an iterative process of constructing multiple mitigation portfolios, simulating the effect of implementing the portfolios, and using simulation outputs to evaluate their performance. This information is then used to create better portfolios, after which the process repeats until there is no further improvement in the constructed portfolios.

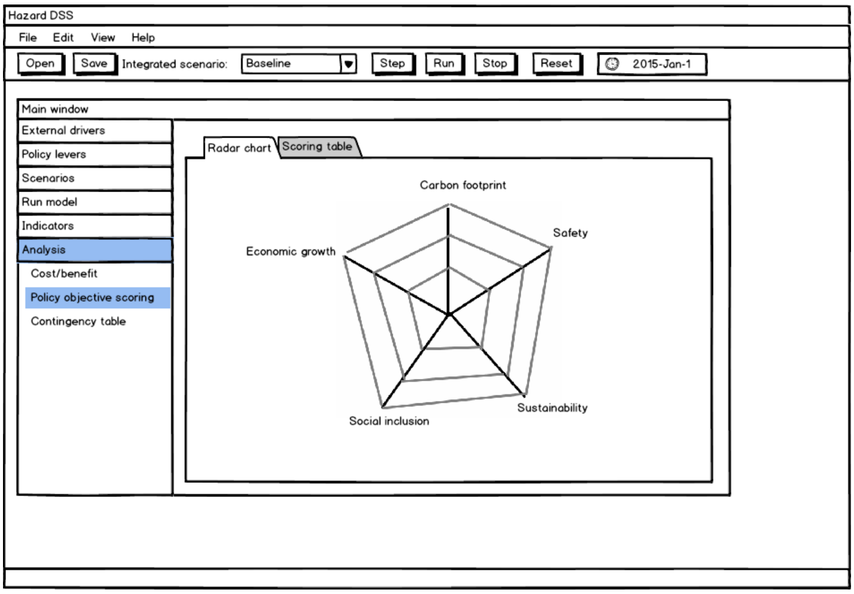
The construction of optimal mitigation portfolios is a very difficult optimisation problem, with an extremely large decision space, long simulation run times, and stochastic (probabilistic) objective functions. Consequently, parallel and cloud computing approaches are used to speed up simulation times, outputs from the landuse model are used to dynamically constrain the decision space, and multiple simulation runs are used to characterise the variability of objective values with respect to future uncertainties. This later feature also enables the optimisation of mitigation portfolios such that they are robust with respect to future pathways.

GUI DESIGN

The Natural Hazard Mitigation DSS makes use of a dual user interface to facilitate both the use of the system for scenario analysis and integrated assessment of mitigation options, and the updating of data and parameters. Only those settings relevant for the use of the model are included in the *policy interface*. The sub-models with all their adjustments are still accessible for model experts through the *modeller interface*. On a high level, access is organized by the steps that a user takes to carry out an impact assessment analysis: configure drivers, create integrated scenarios, run the simulation, review output through the indicators, and analysis.



(A)



(B)

Figure 2. Mock-up graphical user interface for the natural hazard mitigation DSS, showing (A) maps, and (B) spider diagram elements.

The DSS allows the user to visualise drivers and indicators through a combination of maps, tables and graphs. Special attention will be given on appealing and understandable ways of entering information of drivers and providing results calculated by the model. Examples are the selection of census area units to which structural mitigation options can be applied through a map (Figure 2a) and the use of spider diagrams/radar charts, such as that shown in Figure 2b.

SUMMARY

Overall the proposed natural hazard DSS framework links simulation and optimisation, combines scientific and stakeholder knowledge in supporting hazard mitigation planning, and provides the potential to identify efficient combinations of mitigation measures for multiple hazards in a complex urban or regional system.